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CONTENTS.

THE CRYSTAL FALLS IRON-BEARING DISTRICT OF MICHIGAN

BY

J. M. CLEMENTS AND H. L. SMYTH

WITH A CHAPTER ON THE STURGEON RIVER TONGUE BY W. S. BAYLEY

AND AN INTRODUCTION BY C. R. VAN HISE

CONTENTS.

ILLUSTRATIONS.

THE CRYSTAL FALLS IRON-BEARING DISTRICT OF MICHIGAN.

By J. M. Clements and H. L. Smyth.

INTRODUCTION.

By C. R. Van Hise.

This paper is an abstract of a monographic report on the Crystal Falls iron-bearing district of Michigan.[1]

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes the Lower Huronian and Upper Huronian series, and these are separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geologic province as the Huronian rocks of the north shore of Lake Huron and to be equivalent to the Lower Huronian and Upper Huronian series which there occur. The reasons for this belief are fully given in Bulletin 86.[2]

The Archean is believed to be wholly an igneous group with no known lower limit, and therefore no estimate of its thickness can be given. The Archean covers a broad area in the eastern part of the district, and from this there project west several arms. West of the main area are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 to more than 1,000 feet thick; the Randville dolomite, from 500 to 1,500 feet thick; the Mansfield slate, from 100 to 1,900 feet thick; the Hemlock volcanic formation, from 1,000 to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. We thus have a minimum thickness for the series of about 2,200 feet and a possible maximum thickness of more than 16,000 feet. However, a large part of this greater number is volcanic material. It is not

[1] Mon. U. S. Geol. Survey, Vol. XXXVI, in press.

[2] Correlation papers, Archean and Algonkian, by C. R. Van Hise: Bull. U. S. Geol. Survey No. 86, 1892, pp. 156–199.

likely that the sediments at any one place are as much as 5,000 feet thick.

The Upper Huronian is mainly a great slate and schist series, which it is not practicable to demarcate into individual formations on the maps. It is impossible to give even an approximate estimate of the thickness of this series.

Various igneous rocks intrude in an intricate manner both the Upper and the Lower Huronian series. The aim of the following paragraphs is to sketch very briefly the history of the district.

THE ARCHEAN.

The Archean consists mainly of massive and gneissoid granites. Nowhere in the Archean have rocks of sedimentary origin been discovered. The Archean granites have been cut by various igneous rocks, both basic and acid, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The ancient granites and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

THE LOWER HURONIAN SERIES.

The Sturgeon quartzite, the first deposit of the advancing sea, was mainly sandstone, but in places at its base it was a coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of a conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great conglomerate-gneiss which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies in thickness from probably more than 1,000 feet in the Sturgeon River tongue to less than 100 feet at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

For the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it can not be represented on the maps as a separate formation. In the northeastern part of the district a quartzite resting upon the Archean is overlain by an iron-bearing formation. This quartzite occupies a higher position stratigraphically than the Randville dolomite. It therefore appears that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the area the Archean was not yet submerged in the central and northeastern parts of the district. However, since the quartzite resting upon the Archean in the latter area can not be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents a transgression deposit of the same general lithological character rather than a formation all of which has exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and of the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper water over much of the district. Since the Randville dolomite has its full thickness upon the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land rose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1,500 feet, its deposition probably occupied a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation; (2) the Hemlock volcanic formation; and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material, there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate, and possibly glauconite, from which the other peculiar rocks characteristic of the iron-bearing formation were derived. The Hemlock formation is mainly a great volcanic mass, including both basic and acid lavas and tuffs, but contains subordinate interbedded sedimentary rocks. This formation occupies a larger area than any other of the Lower Huronian formations, and is perhaps the most characteristic feature of the Crystal Falls district.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreak in the western part of the district (see Pl. II).

In the southern and southeastern parts of the area the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district, and the Hemlock formation in the central part, is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near its top intercalated with the slates. The Groveland formation can not be certainly traced farther north than the north end of the western Archean oval. It is, however, apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics, of that part of the geological column taken east of the western Archean oval by the Hemlock volcanics, the Mansfield slate, and the Groveland formation, is explained by the fact that in the western part of the district the volcanoes first broke out, and there continued their activity the longest. While north of Crystal Falls the volcanic rocks were being laid down the Mansfield formation was being deposited in the southeastern part of the district. This activity there continued throughout the time during which the Groveland formation was deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent—

(1) East of the western Archean oval, to the Hemlock volcanics there found and the overlying Groveland formation;

(2) At Michigamme Mountain, to the Mansfield slates and the Groveland formation;

(3) In the Mansfield area, to the Mansfield slates and the Hemlock volcanics; and

(4) In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks of the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.[1]

Following the deposition of the Lower Huronian series, the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district, only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless where the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been comparatively little variation in the elevation of the upper surface of the series, but very great difference in its thickness.

THE UPPER HURONIAN SERIES.

After the Lower Marquette series was deposited the district was raised above the sea, may have been gently folded, and was eroded to different depths in different parts.

Following these movements and erosion the waters advanced over the district, and the Upper Huronian series was deposited. The basal horizon was a conglomerate and sandstone, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has subsequently been changed into a ferruginous quartzite. The typical occurrence of this quartzite is at the east end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartzite they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface were the great Hemlock formation, and there were formed mudstones and grits, which have been subsequently altered into mica-slates and mica-schists. After a considerable thickness of mudstone and grit was deposited there followed a belt of combined clastic and nonclastic sediments, the latter including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferru-

[1] The Penokee iron-bearing district of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, Vol. XIX, 1892, pp. 428-433.

ginous rocks there was deposited a great thickness of mudstones and grits which have been transformed into mica-slates and mica-schists similar to those composing the lower part of the series.

FOLDING OF THE ARCHEAN AND HURONIAN SERIES.

At the end of Upper Huronian time the Crystal Falls district had been an area of deposition for a very long time and a great thickness of sediments had accumulated. A profound physical revolution next occurred—the greatest since Archean time. The region was raised above the sea and was folded in a most complex manner. The more conspicuous folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds, however, have steep pitches. It therefore follows that the region was subjected to great compressive stresses in all directions tangential to the surface of the earth and that the yielding was here mainly in one direction and there in another, although on every fold there is evidence of yielding in two directions, at right angles to each other. Some of the folds are very close, as in the case of the Huronian area between the two Archean ovals in the northeastern part of the district and in the Felch Mountain tongue. In other areas—for instance, the Crystal Falls syncline—the major fold is somewhat open. However, upon the open folds are superimposed folds of a higher order, so that the detailed structure is very complicated. So far as known, the district has nowhere been faulted.

Subsequent to, or during a late stage of, this folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and the Upper Huronian rocks vast bosses and numerous dikes. The intrusives vary from those of an ultra-basic character, such as peridotites, through those of an intermediate character, such as gabbros and dolerites, to those of an acid character, such as granites. These intrusives, while altered by metasomatic changes, do not show marked evidence of dynamic metamorphism, hence the conclusion that they were introduced later than the period of intense folding already described.

METAMORPHISM.

The folding varied in its closeness in different parts of the district. Moreover, the formations are of very variable character, including a great variety of sediments and of igneous rock. The formations, therefore, vary greatly in their capacity to resist stresses. It thus follows that during the folding process certain formations yielded to a much greater degree than others. Also the amount of contained water and other conditions were variable. As a result of these many variable factors one of the most characteristic features of the district is that there are to be found nearly all varieties of metamorphism in various stages of advancement.

The Archean and other great massifs are less profoundly altered than are the softer and weaker deposits of the Huronian. In the more rigid formations, such as the granites and quartzites, all phases of alteration, both by granulation and by recrystallization, are beautifully exhibited. The Sturgeon River tongue affords one of the best-known illustrations of a conglomerate-gneiss the matrix of which has completely recrystallized and therefore can not be discriminated from a gneiss of igneous origin, but which contains very numerous pebbles and bowlders flattened in the plane of schistosity. The great Hemlock volcanic formation varies from rocks which are altered chiefly by metasomatic change to those which have become completely crystalline schists containing no vestige, either macroscopically or microscopically, of a texture or structure which may be interpreted as igneous.

The working out, by Messrs. Clements and Smyth, of the details of the transformations of the different kinds of rocks during their processes of metamorphism is one of the chief scientific results of the study of the district.

SUBSEQUENT HISTORY.

After the introduction of the intrusives the region was subjected to vast denudation, which reduced it to approximately its present configuration. This period of erosion continued until in Cambrian time, when the sea again overrode the area and deposited upon the older rocks Cambrian sediments. Long after the deposit of the Cambrian, and perhaps later Paleozoic rocks, the district was again raised above the sea, and the major part of the Paleozoic deposits have been removed, although they are found in patches throughout much of the district and occur as a continuous sheet just east of the area discussed.

The district may have again been submerged in Cretaceous time, but if so the deposits formed were removed after the area finally emerged from the sea. Since Cretaceous time the region seems to have been one of erosion. During the Pleistocene period a thick mantle of glacial deposits was spread over the entire district. Since Pleistocene time erosion has advanced far enough to uncover the rocks here and there.

CORRELATION.

In order to compare the succession in the Crystal Falls district with that in the adjacent Marquette and Menominee districts, the descending pre-Cambrian succession in each of the three districts is here given in parallel columns, the formations which are thought to be equivalent being placed opposite one another.

THE MARQUETTE DISTRICT.	THE CRYSTAL FALLS DISTRICT.	THE MENOMINEE DISTRICT.
UPPER MARQUETTE SERIES.	UPPER HURONIAN.	UPPER MENOMINEE.
(1) MICHIGAMME FORMATION, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation.	(1) MICHIGAMME FORMATION, bearing a short distance above its base an iron-bearing horizon.	(1) Great slate formation.
(2) ISHPEMING FORMATION, being composed of the Goodrich quartzites in the eastern part of the districts and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	(2) QUARTZITE in eastern part of district.	
Unconformity.	*Unconformity.*	*Unconformity.*
LOWER MARQUETTE SERIES.	LOWER HURONIAN.	LOWER MENOMINEE.
(1) Negaunee iron formation, 1,000 to 1,500 feet.	(1) The Groveland formation, about 500 feet thick.	(1) Vulcan iron formation, containing slates.
(2) Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick. (3) Ajibik quartzite, 700 to 900 feet. (4) Wewe slate, 550 to 1,050 feet.	(2) Hemlock volcanic formation, 1,000 to 10,000 feet thick. In western part of district also occupies the place of (1) and (3). (3) Mansfield formation, 100 to 1,900 feet thick.	(2) Antoine dolomite.
(5) Kona dolomite, 550 to 1,375 feet.	(4) Randville dolomite, 500 to 1,500 feet thick.	
(6) Mesnard quartzite, 100 to 670 feet.	(5) Sturgeon quartzite, 100 to 1,000 feet thick.	(3) Sturgeon quartzite.
Unconformity.	*Unconformity.*	*Unconformity.*
ARCHEAN.	ARCHEAN.	ARCHEAN.

From the three columns it appears that the general equivalence in the different districts can be made out with a considerable degree of certainty. There are, however, various differences, due to several causes.

For Upper Huronian time the great characteristic deposits were mudstone and grit, the altered equivalents of which constitute the main part of the series for the Marquette, Crystal Falls, and Menominee districts. However, there were local variations in the different districts. In the Marquette district is the Clarksburg volcanic formation, which locally largely replaces the Upper Huronian slate and schist. In the Marquette district the lower horizon is a quartzite or a peculiar schist, known as the Bijiki schist. This latter formation does not occur in either the Crystal Falls or the Menominee district. The quartzite occurs only in the eastern part of the Crystal Falls district. Finally, within the slate and schist formation in the Marquette and Crystal Falls districts is a horizon which bears ferruginous rocks and iron ores. This horizon has not been found in the Menominee district proper, although such rocks occur a short distance to the west, at Commonwealth and Florence, in Wisconsin.

The succession for the Lower Huronian in the three districts can be paralleled to a high degree of probability. The chief differences are due to the great volcanic outburst in the western part of the Crystal Falls district and to the uneven surface of the Archean land at the beginning of Lower Huronian time. As a consequence of the latter the waters did not reach the western part of the Marquette district and the northeastern part of the Crystal Falls district as early as they reached the eastern part of the Marquette district, the central part of the Crystal Falls district, and the Menominee district. The transgression of the Lower Huronian sea for the region covered for these three districts was therefore from the southeast toward the northwest.

The Negaunee iron formation of the Marquette district is equivalent to the Groveland iron formation of the Crystal Falls district and the Vulcan iron formation of the Menominee district.

The Siamo slate and the Ajibik quartzite of the Marquette district are approximately equivalent to the Hemlock volcanic formation in much of the Crystal Falls district, but in places where the latter formation displaces the Mansfield formation they are equivalent to only a part of the Hemlock volcanic formation. The Wewe slate of the Marquette district is equivalent in the western part of the Crystal Falls district to a part of the Hemlock volcanic formation, and in the southeastern part of the district is probably equivalent to a part of the Randville dolomite. It appears that the Siamo slate, Ajibik quartzite, and Wewe slate of the Marquette district and the Mansfield and Hemlock formations of the Crystal Falls district are equivalent to a part of the Antoine dolomite of the Menominee district.

The great dolomite formation occurring in all of the districts is supposed to be equivalent, except, as just explained, that the deposition of limestone continued longer in the southeastern part of the Crystal Falls district and in the Menominee district than in the remainder of the region. The absence of the limestone and lower formations in the western two-thirds of the Marquette district and the northeastern part of the Crystal Falls district is explained by the fact that during early Algonkian time this part of the region was not submerged. The Mesnard quartzite of the Marquette district and the Sturgeon quartzite of the Crystal Falls and Menominee districts stand opposite each other.

From the foregoing it is apparent that the three districts together present a most interesting and complex structural problem. While there is sufficient similarity of the formations to cause one to feel tolerably sure of their general equivalence in the different districts, one is certain that the formations of similar kind did not begin and end at the same time. Moreover, there are remarkable lateral transitions in sedimentation, as a result of the uneven surface of the Archean at the beginning of Algonkian time and because of the volcanic outbursts. As a result of the first of these conditions it is necessary to equate fragmental formations which occur in the central and western parts of the Marquette district and the northeastern part of the Crystal Falls district with nonfragmental limestones for the area to the east and south. Consequent upon the Upper Huronian volcanic outbursts in the Marquette district, the Michigamme and Ishpeming formations are largely replaced by the Clarksburg volcanics. Similar outbursts in the western part of the Crystal Falls district in Lower Huronian time placed volcanic rocks for this part of the district opposite the Mansfield slate and the Groveland iron formation.

The foregoing relations, combined with the great variety and complexity of the sediments of the district, the presence of many forms of contemporaneous volcanic deposits, the intrusion of the widest variety of igneous rocks of various ages from Archean to later Algonkian time, and the complicated folding and metamorphism to which the districts have been subjected, will readily convince one that the working out of the detailed structure of the district by Messrs. Clements, Smyth, Bayley, Merriam, and others has not been accomplished without most painstaking and laborious work, especially as the region is covered by timber or brush and is overspread by a mantle of glacial deposits.

PART I.

THE WESTERN PART OF THE CRYSTAL FALLS DISTRICT.

By J. MORGAN CLEMENTS

CHAPTER I.

INTRODUCTION.

This report is an account of a portion of the Crystal Falls district of Michigan, so called from the most important town, Crystal Falls, the county seat of Iron County. The iron-bearing district along the Paint River near the site of the town of Crystal Falls was first called in literature, by Brooks,[1] the Paint River district. As soon as the town was begun—in 1880, as near as I can learn—the name of the town was applied to the district.[2] The district is in the Upper Peninsula of Michigan, adjoining the northeast border of Wisconsin, and serves as a link connecting the two well-known iron-ore-producing districts of Michigan, the Marquette and the Menominee. The Crystal Falls district is of itself of considerable economic importance, as will be seen, though not deserving to be ranked with either of the two above-mentioned iron districts. Since the geologic relations of the rocks of the Marquette district have now been ascertained,[3] it is hoped that by means of the determination of the succession in the intermediate Crystal Falls district the Menominee rocks may be closely correlated with those of the Marquette district.

The accurate delimitation of iron-bearing, coal-bearing, or any other formations containing valuable mineral products is of inestimable value to miners and investors. In the iron districts of Michigan alone innumerable test pits have been sunk in areas of solid granite, and at great distances outside of the possible iron formations, thus wasting, of course,

[1] The iron-bearing rocks (economic), by T. B. Brooks: Geol. Survey of Michigan, Vol. I, Part I, 1873, p. 182.

[2] Rept. Com. Min. Statistics of Michigan for 1881, p. 222.

[3] The Marquette iron-bearing district of Michigan (preliminary), by C. R. Van Hise and W. S. Bayley; with a chapter on the Republic trough, by H. L. Smyth: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 477-650; Mon. U. S. Geol. Survey, Vol. XXVIII, 1897.

large sums of money. Although the investigations carried on in the Crystal Falls district, the results of which are here recorded, do not enable us to point out definitely the places where the prospector will find iron deposits, they have enabled us to delimit in a broad way the various formations, and warrant the statement that iron deposits may occur in certain areas and that the prospector will assuredly not find iron deposits in certain others.

The opportunity to study the Crystal Falls district was given me through Prof. C. R. Van Hise. In the prosecution of the field studies and in the preparation of the report, I have availed myself of his advice and suggestions, which have been generously offered, and which have been found of greatest value. To him I am most deeply indebted.

The report is based not only upon my own field work, but also upon the field work done by a number of other geologists, whose notebooks have been placed at my disposal. Among these the notes of Mr. W. N. Merriam and Dr. W. S. Bayley have been found especially valuable. Mr. Merriam, assisted by Dr. Bayley, spent a season in doing very detailed work on the area shown on the sketch map at the bottom of Pl. II, between Crystal Falls and Mansfield, and from this point northwest to some distance beyond Amasa. The geology is in general the same as Mr. Merriam outlined it on his final field map.

I wish to thank Mr. C. K. Leith, who has been of the greatest clerical assistance, and Mr. E. C. Bebb, by whom the maps were drawn; also Mr. J. L. Ridgway, by whom the natural-size colored plates of specimens were made.

Owing to its comparative unimportance economically, and also on account of its isolation, very little work of which publication has been made had been done in this district prior to that the results of which are given in this paper. As a rule the earlier observers began the season's work either in the Marquette or in the Menominee range, and, working westward, the Crystal Falls district was reached only as the season neared its close or as the appropriation was expended.

The published work upon this district is summarized in Monograph XXXVI, of which the present paper is an abstract.

MODE OF WORK.

As explanatory of the locations given in the paper, it is perhaps not out of place to give a brief description of the plan of work followed by the Lake Superior division of the United States Geological Survey in this as well as in the other Lake Superior iron-bearing districts which have been surveyed.

The Upper Peninsula of Michigan affords a good example of the excellence which can be obtained in the rectangular land survey when properly carried out by the Government. The section-corner posts originally established are in many cases still to be seen, and of course the bearing trees are even more common. Since the original survey the timber value has increased so much that in certain forested areas the section lines have been resurveyed. Not uncommonly trails follow the section lines for long distances. Moreover, the roads are frequently laid out along the section lines, thus giving permanent land boundaries. The section corners consequently offer the most reliable points from which to make locations.

Traverses are made across each section, either from east to west or from north to south, and at varying intervals, according to the discretion of the geologist and the exigencies of the case. Each geologist is accompanied by a compassman, whose duty it is to determine the course of the traverses by means of a dial compass, and the distance traveled by pacing, at the rate of 2,000 paces to the mile. Corrections are made at the corner and quarter posts. The compassmen employed are Michigan woodsmen—land-lookers or cruisers, as they are frequently called—and it is remarkable with what accuracy they will pace mile after mile through swamp and over rough hills, windfalls, etc.

The geologist explores the territory on both sides of the line followed by the compassmen. Ledges are located by the geologist pacing to the compassman as he comes opposite him in a due east-west or north-south direction. With two coordinates thus determined, the ledges are located with reference to the section corner. For uniformity and to facilitate reference and cataloguing, it is customary to give the location with reference to the southeast corner of the section. Thus, 1,000 N., 1,000 W., SE. cor. sec. 5, T. 42 N., R. 33 W., gives the location of the outcrop at the center of the section, and affords a means of finding that ledge, which could not be so accurately and concisely stated by the use of any ordinary landmarks. Moreover, easily recognized landmarks, such as houses, quarries, etc., are few, and exceedingly great changes may occur with great rapidity, such, for instance, as those caused by the widespread forest fires, so that such a method of location is practically valueless.

MAGNETIC OBSERVATIONS.

It has long been known that many rocks are possessed of decidedly magnetic properties, due to the presence in them of varying quantities of magnetic iron ore. How the property may be used as an aid to structural work and in outlining iron-bearing formations is considered by Smyth in the second part of the monograph of which this is an abstract.

By means of the dip needle and solar compass, observations were taken which enabled us to trace a curving magnetic formation for about 16 miles. The same formation was further delimited, and the direction partly checked, by the occurrence, at varying distances along this course, of outcrops of rocks of the underlying formation. The lines of maximum magnetic disturbance are represented on the accompanying general map (Pl. II) by blue lines, marked with letters D and E.

CHAPTER II.

GEOGRAPHICAL LIMITS, STRUCTURE AND STRATIGRAPHY, AND PHYSIOGRAPHY.

GEOGRAPHICAL LIMITS.

The portion of the district here described extends from the north line of T. 47 N. to the south line of T. 42 N., and from the center of R. 31 W. to the west line of R. 33 W., including approximâtely 540 square miles.

The detailed character of the formations is unknown for parts of the area under discussion. This is especially true of the northern and southwestern parts, where, owing to the readily decomposable nature of the rocks, as determined by the few ledges observed, and to the drift mantle, very few outcrops are to be found.

STRUCTURE AND STRATIGRAPHY.

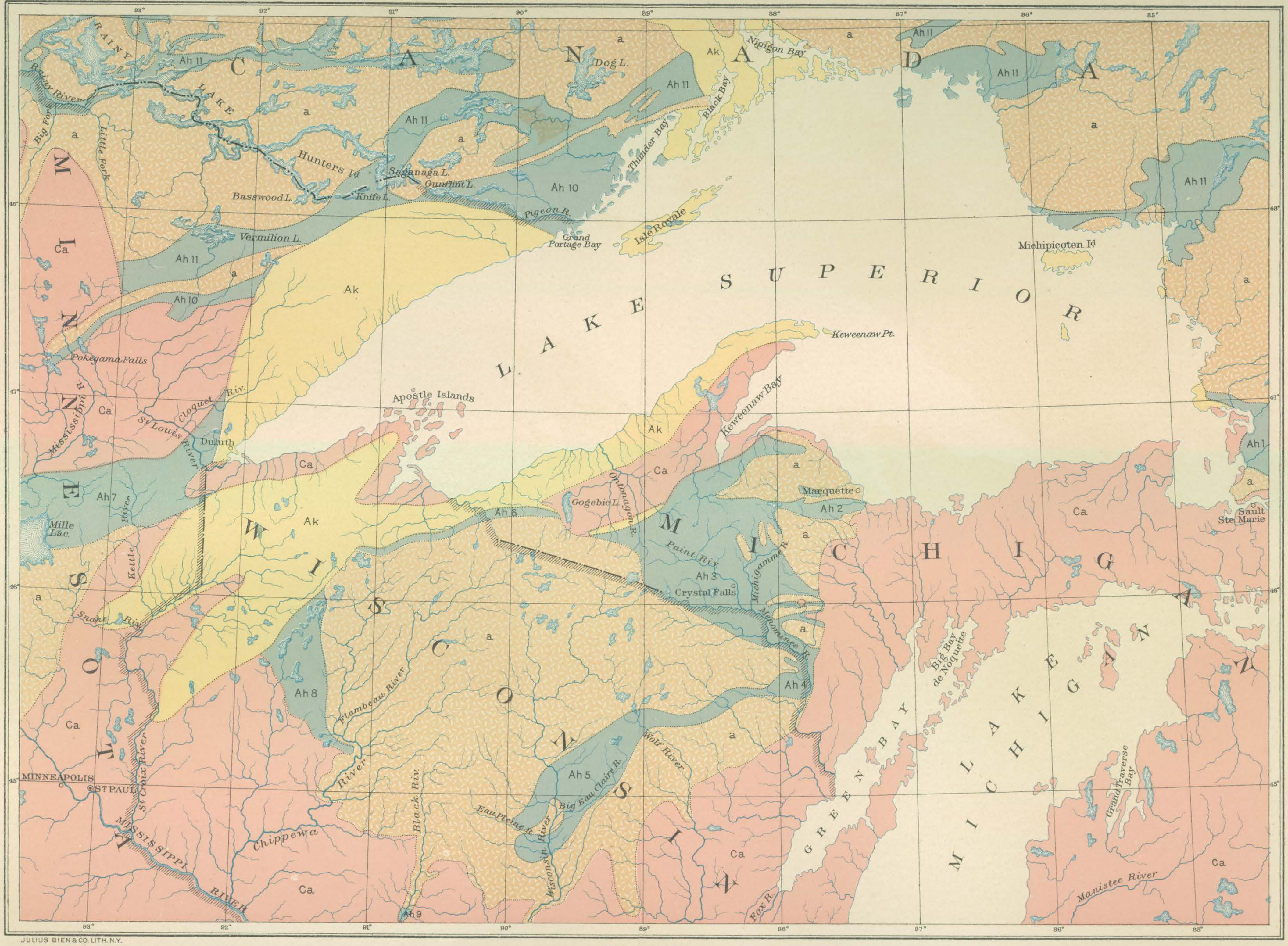
The Crystal Falls district is petrographically not sharply defined, but is continuous with the Marquette district on the northeast and the Menominee district on the southeast (Pl. I). It is, however, remarkable for the vast accumulation of volcanic rocks, which, while by no means absent from the adjoining districts, do not there play so conspicuous a rôle.

Structurally this district can hardly be better separated from the Menominee and Marquette districts than it is petrographically. The two important sedimentary troughs of the two adjacent districts are separated by an average width of 40 miles. The area between the districts on a direct course is occupied chiefly by Archean rocks, with narrow infolded troughs of Huronian rocks playing a very subordinate rôle. At the east the Archean is overlain by the sedimentaries of the Paleozoic, the Cambrian, and the Silurian. The connecting Crystal Falls pre-Cambrian series are west of this Archean dome.

In the Marquette district the essential structural feature has been shown to be a great close east-west synclinorium,[1] upon which more open north-south folds are superimposed.[2] At the western end of the district the superimposed north-south folds become close, and the Republic trough is a close fold, with an axis in an intermediate position. In the adjoining Crystal Falls district there are also two sets of folds with their axes approximately at right angles to each other. The closer

[1] Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 566 et seq.

[2] Op. cit., p. 570.



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ARCHEAN	ALGONKIAN: HURONIAN	ALGONKIAN: KEWEENAWAN	POST-ALGONKIAN
a	Ah	Ak	Ca

HURONIAN
- Ah 1 *The Original Huronian.*
- Ah 2 *The Marquette Iron-Bearing Series,*
- Ah 3 *The Crystal Falls Iron-Bearing Series.*
- Ah 4 *The Menominee Iron-Bearing Series.*
- Ah 5 *The Wisconsin Valley Slates.*
- Ah 6 *The Penokee Iron-Bearing Series.*
- Ah 7 *The St Louis Series.*
- Ah 8 *The Chippewa Valley Quartzites.*
- Ah 9 *The Black River Iron-Bearing Schists.*
- Ah 10 *The Animikie Series.*
- Ah 11 *The Folded Schists of Canada.*

GEOLOGIC MAP OF PART OF THE LAKE SUPERIOR REGION

Compiled from Official maps of U. S., Minnesota, and Canadian Surveys

Scale

0 50 100 STAT. MI.

folds are represented by the great anticline in the central part of the district. This anticline has its axial plane trending west of north and south of east, and the axis plunges down at both the north and the south end.

The more open set of folds, at right angles to the above set, is represented by the Crystal Falls syncline, with its axis striking to the south of west, and plunging west. Farther south the axes of the folds become much closer and more nearly east and west, thus nearly according in direction with the close folds of the Menominee district, where the great structural feature is a synclinorium similar to that of the Marquette, but with its axis trending north of west and south of east. Thus the structural features of the Crystal Falls district merge into those of the Menominee district, which joins the Crystal Falls district on the southeast.

A glance at Pl. II will show the presence, in the eastern part of the northern half of the district, of an oval-shaped mass of Archean, and, nearly surrounding this, a number of rock belts.

The Archean ellipse is 11 miles long and 3 miles wide on the average. The rocks are mainly granite and gneiss. They are cut by rather infrequent acid and basic dikes.

Immediately surrounding the Archean is a quartzose magnesian limestone formation, to which the name Randville dolomite has been given.[1] In the eastern half of the district, described by Smyth, where more numerous exposures are found than in the western half, the formation has an estimated thickness of from 1,500 to 1,900 feet (p. 127). Not only are the exposures more numerous, but, owing to the fact that the strata stand on edge, due to the closer folding of the rock series here, more accurate estimates of their thickness can be made.

According to Smyth (p. 128), this limestone formation, at the southeastern end of the ellipse, in its upper horizon becomes mixed with slates, and these increase in quantity until the formation passes above into a slate formation, called the Mansfield slate. This slate formation is found overlying the limestone to the west of the central ellipse likewise, but as few outcrops have been found it is not positively known to exist as a continuous zone encircling the northwestern end. In a direct line with its probable continuation to the north there was found at one place (sec. 19, T. 46, R. 32) a graywacke. This single outcrop is insufficient evidence to warrant the introduction of a graywacke formation as the northern equivalent of a part of the Mansfield slate, and it is probably only a phase of that formation. It is in the Mansfield slate that the only productive Bessemer mine of this district is found.

The close of the Mansfield slate time was marked by the extrusion of a great series of volcanics, which constitute the next formation in the succession. This volcanic formation has its best and most typical development west of the western Archean ellipse. Because the Hemlock River and its tributaries have exposed good sections in the volcanics, and because this river drains a great portion of the volcanic

[1] See Part II of this paper, by H. L. Smyth, Chapter II, pp. 110, 126.

area, the name Hemlock formation is applied to the volcanics. The dip of the flows and of the tuff beds, wherever observed, is about 75° W. The maximum breadth is about 5 miles. Deducting 15° for initial dip, this would give the enormous maximum thickness of 23,000 feet to the volcanics, upon the supposition that no minor folds occur.

These volcanic rocks have associated with them rocks of unquestionably subaqueous sedimentary origin, as is shown by their well-bedded condition and the rounding of the fragments. The subaqueous rocks are, however, composed of little altered volcanic materials, and evidently point to oscillations of the crust during the time of volcanic activity—such oscillations as have long been known to be common in volcanic regions.

Following the volcanics, and overlying them, probably unconformably, comes a series of sedimentary rocks, believed to belong to the Upper Huronian. These comprise chloritic, ferruginous, and carbonaceous slates, associated with graywackes and small amounts of carbonate beds. The general character of the series is what one would expect in rocks formed from the detritus of the Hemlock volcanics. It is in this slate series that, with the exception of the Mansfield mine, the ore deposits of the Crystal Falls district are found. The sedimentaries extend west from the Hemlock volcanics to the limits of the district, underlying thus a very broad expanse of country. Where exposed they show frequent change of character. This prevents the identification of individual beds for any considerable distance. Owing to the imperfect exposures of the beds and their close folding, it has been found impossible to subdivide this series of rocks into distinct formations.

The series has in places been highly metamorphosed, resulting in the production of gneisses and mica-schists, in places garnetiferous and staurolitic. The series corresponds in a broad way stratigraphically and lithologically to the Michigamme formation of the Marquette district.[1] Since, however, it has been found impossible to subdivide this series, and because it may possibly include more than the Michigamme formation of the Marquette district, it is considered advisable to speak of it simply as the Upper Huronian series.

Here and there in the Crystal Falls district isolated patches of Upper Cambrian or Lake Superior (Potsdam) sandstone are found. This occurs in beds which are either horizontal or inclined only a few degrees from the horizontal position. They overlie unconformably the steeply inclined Huronian strata. The great lapse of time represented by this unconformity is indicated by the deposits of Keweenawan and Lower and Middle Cambrian time found elsewhere. The Lake Superior sandstone grades from the very coarse basal conglomerate below into a moderately coarse sandstone above. The sandstone is of a reddish-brown to gray color and is not well indurated as a rule, but is loosely cemented with ferruginous and in places calcareous material. As a

[1] Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 444.

result of this imperfect induration, the sandstone is not very resistant to the agents of disintegration. Hence it is that only remnants have been found, but enough is present to indicate that the greater part, and probably the whole, of the Crystal Falls district was covered by Cambrian deposits. The thickness of the Cambrian deposits can not be determined.

Glacial drift overlies all of the other rocks.

The generalized sections through the Crystal Falls district which are given on Pls. III and IV will aid in the comprehension of the structural and stratigraphic features thus briefly outlined.

As the present report is confined to the pre-Paleozoic rocks, no detailed description will be given of the Cambrian and glacial deposits, nor will they be represented upon the map, except in those places where it has been found impossible to map the underlying rocks.

The generalized columnar section, Pl. IX (p. 84), shows in condensed form our knowledge of the formations mentioned.

PHYSIOGRAPHY.

TOPOGRAPHY.

The topography in its large features is preglacial, and in some cases this older topography, upon which the newer glacial topography is superimposed, is rather distinct. For instance, in the case of the Deer River Valley, drift has been deposited covering the gentle slopes and bottom, but is not sufficiently deep to hide completely the preglacial valley.

In the southwestern part of the district, west of Crystal Falls, or, more generally, west of the Paint River, preglacial topography is seen in places. Here we find the drift as a veneer and only partly hiding the bed-rock topography, which depends mainly upon the strikes and dips and varying characters of the rocks.

The prevailing, most noticeable topography of the west half of the Crystal Falls district is that of the drift, and is characterized by short ridges and broken chains of hills, usually oval, though at times of very irregular outline, between which are lakes and swamps. The swamps are even occasionally found on rather steep slopes, where a thick, spongy carpet of sphagnum moss retains moisture sufficient for the growth of the cedars and other trees and shrubs characteristic of the Michigan swamps. In this way the swamps follow the carpet of moss up the hills to the spring line.

The preglacial topography has been very essentially modified by the deposit of glacial drift. Especially is this true where the drift was of considerable depth, and in those portions of the district where these conditions exist we find beautifully developed glacial topography, as shown in parts of T. 45 N., Rs. 31 and 32 W., on Pl. II. Here, even though the ground is very heavily timbered, one may easily trace out the sinuous course of eskers. When traversing the country one is constantly climbing ridges, some of them 75 to 100 feet high, and often with a crest only a few—in some places not more than 4—feet wide, or is descending into potholes.

Where the drift mantle has been removed the rounded character of the rock exposures is usually shown. This holds good especially for the more resistant rocks, such as the granites and massive greenstones. Slates and tuffs, weathering more readily, have in numerous cases had time since the ice retreated to be weathered into rough, broken ledges, some of which show perpendicular cliffs.

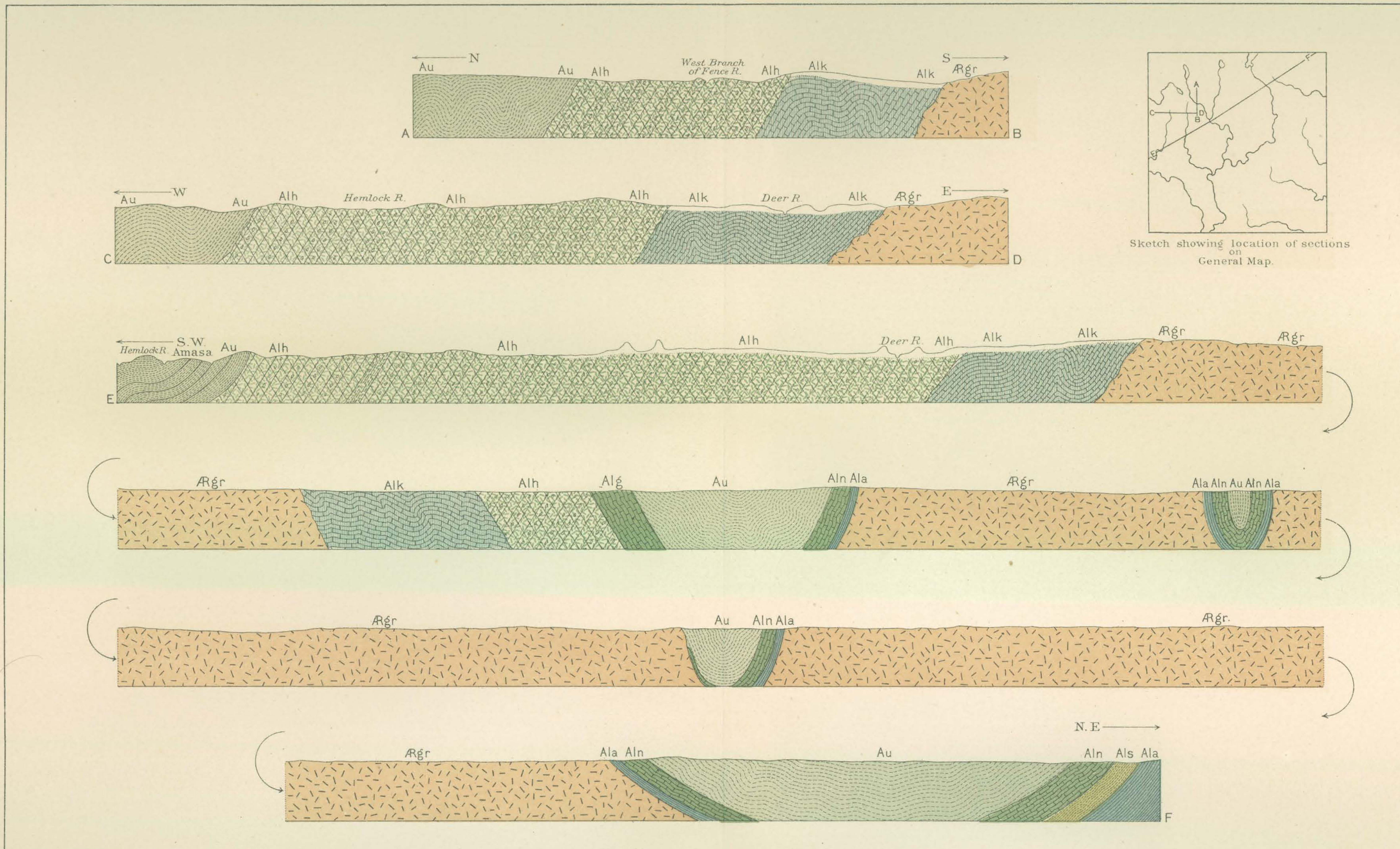
The elevations range usually from 1,400 to 1,600 feet above sea level. The hills rarely rise more than 200 feet above the low ground at their bases. The extremes of height noted in the district are from 1,250 to 1,900 feet above sea level, corresponding respectively to the valley of the Michigamme on the south and the watershed between Lake Superior and Lake Michigan on the north. Between these two extremes there is a strip of territory, 25 miles across from north to south, in which the variations in height are within the limits of 200 feet.

A consideration of the slight difference of level which prevails over the greater part of the Crystal Falls district has led Smyth to the conclusion that this portion of Michigan had, before glacial times, been reduced to the condition of an approximate peneplain. (See p. 92.) This peneplain is a continuation of the peneplain of northern Wisconsin, and lies between the northern Michigan base-level on the north and the central Wisconsin base-level on the south, to both of which attention has recently been called by Van Hise.[1]

DRAINAGE.

The greater heights in the Michigamme district are in the northern part, where some few of the hills rise to a height of 1,800 feet, and one to a maximum of 1,900 feet, above sea level, but the majority do not rise above 1,600 feet. The belt including these higher elevations extends NE.-SW. This belt represents the crest of the watershed, from which all streams on the northern side flow to Lake Superior, and on the southeastern side all flow to Green Bay of Lake Michigan. A part of this watershed is undivided, and it is not uncommon to find extensive swamps in which streams flowing to opposite sides of the watershed take their origin. That portion of the Crystal Falls district which is tributary to Lake Superior is so small that it will be totally neglected in the further discussion of the drainage. The eastern part of the district is drained by the Michigamme River, with its tributaries, the Fence (Mitchigan) and the Deer, while the Paint (Mequacumecum) River, with its main tributaries, the Hemlock and Net, drains the western and northwestern portions. The Brulé (Wesacota) flows along the southern part of the district, being for the most part just below the southern limit of the area shown on the accompanying map. It forms throughout its course the boundary line between Michigan and Wis-

[1] A central Wisconsin base-level and a northern Michigan base-level, by C. R. Van Hise: Science, new series, Vol. IV, 1896, pp. 57-59, 217-220.



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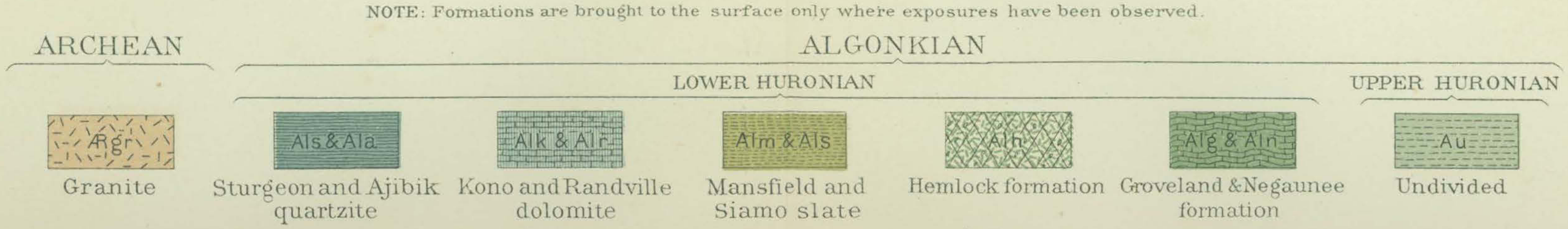
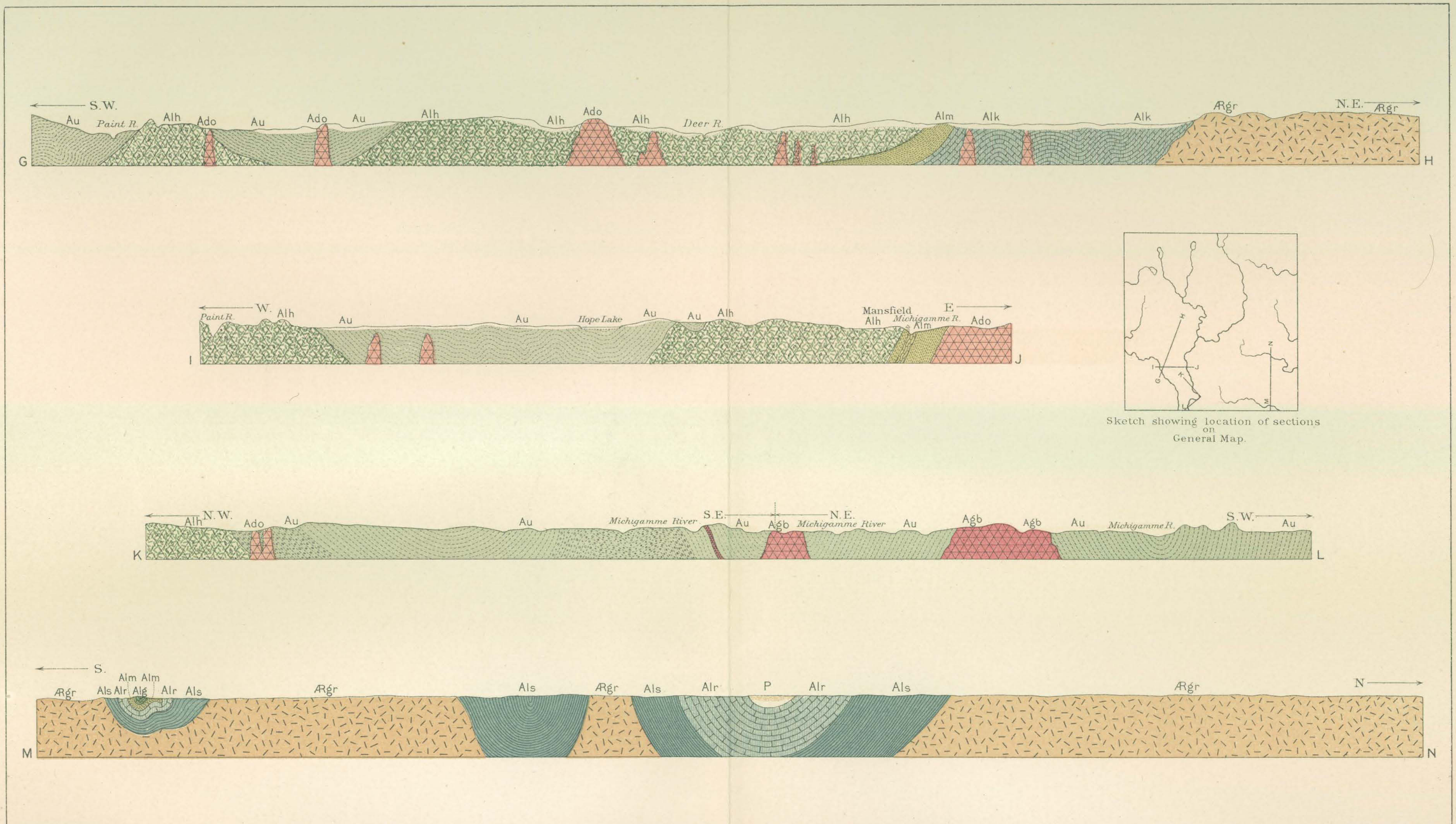
GENERALIZED SECTIONS THROUGH NORTH WESTERN PART OF CRYSTAL FALLS DISTRICT

HORIZONTAL SCALE, 1 INCH = 1 MILE. VERTICAL SCALE, 1 INCH = 1320 FEET.

ELEVATION OF BASE LINES 1000 FEET.

NOTE: Formations are brought to the surface only where exposures have been observed.





JULIUS BIEN & CO. LITH. N.Y.

GENERALIZED SECTIONS THROUGH SOUTHERN PART OF CRYSTAL FALLS DISTRICT

HORIZONTAL SCALE, 1 INCH = 1 MILE. VERTICAL SCALE, 1 INCH = 1320 FEET.

ELEVATION OF BASE LINES 1000 FEET.

NOTE: Formations are brought to the surface only where exposures have been observed.

ARCHEAN

- Ægr — Granite

ALGONKIAN

LOWER HURONIAN

- Als & Ala — Sturgeon and Ajibik quartzite
- Alk & Alr — Kono and Randville dolomite
- Alm & Als — Mansfield and Siamo slate.
- Alh — Hemlock formation
- Alg & Aln — Groveland & Negaunee formation

UPPER HURONIAN

- Au — Undivided

INTRUSIVE

- Ado — Dolerite
- Agb — Gabbro

PLEISTOCENE

UNDIVIDED

- P

consin. The Paint flows into the Brulé in sec. 12, T. 41 N., R. 31 W., to form the Menominee River. This last flows southeast through the adjoining Menominee district, and is the boundary line between Michigan and Wisconsin from its source to its mouth.

A glance at the map, Pl. II, will show the presence, especially in the northern half of the district, of a great number of lakes of varying size. These lakes are of clear water, with bottoms of gravel, or most commonly of a thick deposit of decayed vegetable matter, and are a very characteristic feature of the landscape. Many are in the midst of swamps, and are surrounded on all sides by a quaking bog, which prevents one from approaching very closely; others are surrounded by steep but low drift hills. The lakes may or may not have a visible inlet and outlet. In all cases the present water levels are considerably below the original water levels. In many cases the lakes are but remnants of much larger bodies of water. The lakes are gradually filling up with silt and vegetable growth. These lakes, covered with floating lily pads and surrounded by more or less extensive hay marshes, are favorite places for the deer, which in many parts of the district are still fairly numerous. The numerous lakes indicate the youthful character of the drainage. Many of the streams head in the lakes. In other cases they flow through them, connecting them in chains. This indicates the mode of origin of most of the streams of the area. The youthful character of the drainage is still further shown by the fact that with but few exceptions the rivers have not reached rock. They are still cutting in drift.

TIMBER AND SOIL.

The district was at one time very heavily timbered with hard wood and pine, the former on the whole predominating. Along the flood plains of the large streams one finds sandy pine barrens where once there were heavy pine forests. On the head waters the pines are found scattered through the hard wood. Individually the trees are very much larger and better than the thick and therefore smaller growth of the plains. Lumbering, which had been confined for years to the main drainage channels of the district, has of late been rapidly extended, following all the ramifications of the tributary streams, until at present there remains in this district only a few years' cut of pine, on the very head waters of the rivers. Following the lumbermen comes the forest fire, which finds most nourishing food in the dry, resinous pine tops left by them. The fires, once started, are not confined, however, to the cut pine, but spread to the adjacent standing pine, and even into the hard-wood forests, carrying destruction with them, and leaving but the gaunt, bare, and blackened trunks to mark the sites of what were formerly thick forests.

The pine-covered areas have a thin soil and are poorly adapted to agriculture. The areas covered with hard wood, on the contrary, have soil well adapted to the crops of the latitude.

CHAPTER III.

THE ARCHEAN.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The granite described in the following section belongs to the oldest formation in the district, and forms the western elliptical core designated on Pl. II as Archean. It is surrounded by sedimentary strata, which have a quaquaversal dip away from the granite as a center. The portion of the Crystal Falls district in which the granite outcrops is about 11 miles long by 3 miles in width, its longest axis extending in a NW.-SE. direction and covering parts of Ts. 44, 45, and 46 N., Rs. 31 and 32 W.

The exposures of granite are especially numerous in the southeastern part of the oval area, where, owing to the proximity of large streams, the Fence and Deer rivers, and the consequent increased erosion, the drift has been to some extent removed. In the northwestern part of the area, except in a few places, all the rocks are deeply covered with drift.

In general the topography of the area is that of the drift, but in the southern part it is seen to have been considerably influenced by the character of the underlying rocks. The granite usually outcrops in small, rounded, and isolated knobs, whose relations to one another can only be conjectured. Where an occasional knob is composed of massive granite and more or less gneissoid granite, the exposed surface is so small as to prevent the observer from determining the relations between the two. Cutting the massive and gneissoid granite are certain long, narrow masses of dark-colored rocks of rather fine grain and, with few exceptions, very schistose. From their geological occurrence it was concluded, in spite of their appearance, that they are dike rocks cutting the granite. The following paragraph, quoted from the manuscript notes of G. O. Smith, describes very clearly their field occurrence:

> The gaps in this granite ridge seem to indicate greenstone dikes, as here the granite usually has a facing of the greenstone more or less extensive, and often in the center of the gap there are several small areas of greenstone. In all cases the greenstone is markedly more affected by weathering than is the granite. A study of the relations at the few points of contact did not yield much more than negative results, but these pointed to the intrusive character of the greenstones.

RELATIONS TO OVERLYING FORMATIONS.

The relations of the granite to the sedimentary rocks might be explained in two ways—the former may serve as the base of the latter rocks, or it may penetrate them. The occurrence of the granite in an elliptical shape, with sediments surrounding it showing quaquaversal dips, might be regarded as evidence of its intrusion in the Huronian sediments, and on this theory it would follow that the granite is of Huronian or post-Huronian age. If intrusive, it should be found to penetrate and metamorphose those sediments. Against the intrusive character of the gneissoid granite and in favor of its pre-Huronian age are the following facts: (1) There is a total absence in the surrounding sedimentary strata of any dikes which are related to the granite. This is important evidence against its intrusive origin. (2) There is a total absence of any metamorphic action, so far as observed, in the sedimentaries. This is further negative evidence in the same direction. (3) On the east flank of the granite core on the west bank of the west branch of the Fence River, in the southwest corner of sec. 1, T. 45 N., R. 32 W., is a recomposed granite which passes up into a fine sericitic quartzite with false bedding. These rocks evidently derived their material from the granite, and hence mark the beginning of sedimentation in this area.

Thus the positive evidence for the pre-Huronian age of the granite confirms the negative, and since the granite underlies the oldest sedimentary rocks, whose age has been determined to be Huronian, the former is classified as Archean, that term being used here to designate those rocks of undoubted igneous character which form the foundation upon which rest the oldest determinable sedimentary rocks. It is not the province of this paper to enter into a speculative discussion of the origin of the Archean rocks of the district. For such a discussion the reader is referred to Professor Van Hise's exhaustive disquisition on the Principles of North American pre-Cambrian Geology,[1] where the conclusion is reached that "The Archean is igneous and represents a part of the original crust of the earth, or its downward crystallization."[2] The Archean has gradually reached the surface by the removal, through erosion, of the superjacent rocks.

PETROGRAPHICAL CHARACTER.

The rocks of the Archean comprise biotite-granite, gneissoid biotite-granite, and acid and basic dikes.

BIOTITE-GRANITE (GRANITITE).

The rock occupying the main and central part of the Archean area is biotite-granite. This rock is also found to some extent upon the border of the area. The rocks of this kind vary in color from light-gray rocks to those having various tints of red, depending usually

[1] Principles of North American pre-Cambrian Geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, pp. 571-874.

[2] Op. cit., p. 752.

upon the degree of alteration. They vary also from medium to coarse grained. Some varieties show a decided porphyritic texture, and in some cases also an approach to a laminated structure. The porphyritic character is due to the presence of large crystals of feldspar, which stand out from the surrounding granitic groundmass, thus producing a typical granite-porphyry. The feldspar phenocrysts lie with their longer axes parallel, and thus help to produce an imperfect laminated structure. This parallel structure in the granite-porphyry is apparently analogous to the flow structure of the volcanic rocks, and probably was produced by movements in the magma before it had reached even a viscous state, as we find that the phenocrysts give no evidence of having undergone excessive mashing or torsion. The different structural varieties grade into one another in such a way as to indicate that they are merely modifications of the same magma. In addition to these structural varieties, which are original, we find in certain places a passage from granolitic[1] to schistose rocks, in which this structure is of dynamic origin—i. e., of secondary nature.

In the thin section these rocks show the normal granolitic texture and the usual mineral constituents which characterize biotite-granites. The chief minerals are orthoclase, microcline, plagioclase, quartz, and biotite. Zircon and apatite are the accessory minerals present, and the secondary minerals include epidote-zoisite, chlorite, muscovite, rutile, and iron pyrites.

Three kinds of feldspar are present: (1) A finely striated plagioclase; (2) a feldspar unstriated, or at most showing Carlsbad twins, and presumed to be orthoclase; and (3) microcline, the last two being frequently intergrown after the manner of perthite. The plagioclase was the first feldspar to crystallize.

In most slides all the feldspars are much altered, but even in those in which the microcline is fresh the plagioclase and orthoclase always show alterations, the plagioclase altering most easily and usually being so changed that it is with difficulty that one can recognize the twinning lamellæ. Hence, some of them may have been taken for the nonstriated orthoclase. In an early stage of the alteration of the feldspars minute dark ferrite particles which impregnate them are hydrated, and this gives the feldspars a more or less distinctly red tinge. In a more advanced stage of alteration muscovite and a little epidote-zoisite are produced. Another alteration of the feldspar is always associated with marked pressure phenomena, and hence is presumed to be the result, partially at least, of dynamic action. This is the partial or complete granulation of the feldspar and the production from that mineral, with the addition from other sources of the iron and magnesia necessary, of secondary white mica and quartz and some biotite. It is quite possible that some of the small limpid grains considered to be

[1] This term has been proposed by a committee on nomenclature for the geologic folios of the United States Geological Survey, for use in place of *granitic*.

secondary quartz are really an acid feldspar. Dynamic movements are also indicated by the bending of twinning lamellæ, and were probably the partial cause of the twinning.

Biotite occurs in plates, and as a rule is better developed than are the feldspars. The biotite usually lies between the feldspar and quartz grains, almost as though it had been the last product of crystallization. In some cases the biotite is largely altered to chlorite and epidote, with the simultaneous production of bundles of needles, which are taken to be rutile.

GNEISSOID BIOTITE-GRANITE.

About the central area of biotite-granite just described, and in part forming the border of the Archean area, are rocks having a gneissic structure. With these are associated the biotite-granites. The gneissoid rocks in general are markedly darker in color than the granites, showing normally a rather dark gray. They vary little from one another in texture, and are much finer grained than the granites. The fine-grained condition of these schistose and banded rocks has, perhaps, a great deal to do with their dark color, though this is primarily owing to the amount of biotite present.

In some of the specimens the bands can be readily distinguished under the microscope, and are seen to contain a white mica and a much smaller amount of biotite. These two minerals are present in fine films between the crushed quartz and feldspar grains, giving to the rocks a very decided schistose character. These mica folia are much more numerous in certain areas than in others, producing a more or less perfect banding. The mica plates are not all parallel, although ordinarily having a tendency to this arrangement, and are usually parallel to the banding. The most perfect schistosity is thus developed parallel to the micaceous bands.

Others of the gneissoid granites, however, when examined under the microscope are decidedly granolitic, and it is only on a large scale that the banding shows distinctly.

The strike of the banding, wherever it was taken, was uniform, varying from N.–S. to nearly N. 45° W., agreeing on the whole with the trend of the Archean oval area.

The microscope shows that the constituent minerals of the gneissoid granite are the same as those which compose the granites just described. These show also the same relations to one another and the same general characters as in the granites, except where mashing has completely obliterated the original texture, and hence no further description of them is necessary.

The crushing to which the gneissoid granites have been subjected is very clearly shown in the present cataclastic condition of the quartz and feldspars.

As stated above, both the gneissoid biotite-granite and the biotite-granite proper are found in the border area of the Archean. In those rocks in which the contact shows a gradual transition from the banded rock to the unbanded the micaceous bands are clearly secondary and are the result of the crushing of the original granite, these lines representing macroscopic and microscopic shearing planes along which the feldspar and quartz have been thoroughly granulated, and sericite and some biotite produced, as was found to be the case also in some of the granites. These rocks thus agree in their dynamic origin with a similar but apparently more extensive and better developed gneissoid border facies in the Morbihan (Brittany) granites, which have been described, and whose origin has been so clearly demonstrated by Barrois.[1] Numerous other similar cases have been described recently from the Canadian granite massifs and from Sweden and other districts.

In the gneissoid granites, which are decidedly granolitic and in which the banding shows distinctly only on a large scale, the cause of the banding could not be determined, and might by some be ascribed to differentiation, though from the association of these gneissoid granites with those just described it is assumed that the banded structure is due to dynamic action. If this be the case, however, a complete recrystallization has taken place and but slight dynamic effects are now shown.

ACID DIKES IN THE ARCHEAN.

Observations upon dikes of acid rocks cutting the Archean granite are very few, and we may suppose this to be partly due to the isolated knobs, which prevented the determination of the relations of adjacent exposures of rocks of slightly different character. Some few dikes were, nevertheless, observed, and are granites varying from medium to coarse grained and from granolitic to porphyritic. The porphyritic facies is the more common. They do not show differences from the main mass of the Archean granite sufficient to warrant detailed petrographical description.

BASIC DIKES IN THE ARCHEAN.

The influence of the basic dikes upon the character of the topography has already been mentioned. They occur in long, narrow bands of varying width, and with one exception are markedly schistose. Considering the granite on a large scale as an approximately homogeneous mass, we should expect to find lines of weakness which might be indicated by the arrangement of the dikes. No such definite arrangement can be seen, however, as the dikes are found to extend in all directions.

The dikes may be classified into (1) earlier dikes, showing a schistose structure, and with no trace of igneous textures, and (2) later massive dikes, showing original igneous textures.

Schistose dikes.—The general character of those rocks occurring as dikes may be briefly mentioned. They are schistose, for the most part

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[1] Annales Soc. géol. du Nord, 1887, p. 40.

fine grained and black or dark green in color. The constituents of the schistose eruptives, arranged according to their relative importance, are biotite, hornblende, chlorite, quartz, feldspar (?), calcite, epidote, iron oxide, sphene, and muscovite.

The schistosity is always parallel to the long extension of the dikes. It does not agree in direction with the general strike of the schistosity throughout the entire district. These dikes represent belts of weakness, and it is therefore natural that the movements should occur along these belts rather than across them.

This schistosity of the dikes also gives us a slight clue as to their age. Younger than the granites they cut, they must have occupied their present position at the time the dynamic revolution took place which resulted in the development of the schistosity in the Archean, as well as in the sedimentaries. It is impossible to bring the date of their intrusion within narrow limits. It seems very probable, however, that they were formed at the time of the extrusion of the basic Hemlock volcanics, though it is impossible to prove their connection with them.

Massive dikes.—The only dike rock which retains to some extent its original texture is a very much altered, medium-grained dolerite (diabase). The alterations it has undergone are those usual for such basic types of rock, and this one exhibits nothing peculiar or of special interest. An ophitic texture, while still recognizable, is more or less obscured by the uralite which has developed out of the pyroxene. The remnants of the original plagioclase feldspar present show exceedingly slight pressure effects. The alteration processes would therefore seem to have been due to the action of percolating water, without special mechanical influence. Hence we may date the intrusion of this particular dike after the orographic movements which affected the granite core, rendering portions of it schistose, and crushing all of it to a greater or less extent. These movements are presumed to have taken place prior to or during Keweenawan time, and therefore the age of this dike is Keweenawan or post-Keweenawan.[1]

[1] For a discussion of the orogenic movements which affected the Crystal Falls district, the reader is referred to pp. 14, 66.

CHAPTER IV.

THE LOWER HURONIAN SERIES.

This series is represented in the Crystal Falls district by the following formations, given in order from the base upward: Randville dolomite, Mansfield slate, Hemlock volcanics. At the beginning of the deposition of the Lower Marquette Huronian series the entire district was covered by the pre-Cambrian sea, with the possible exception of a small island in the Archean area.

SECTION I.—THE RANDVILLE DOLOMITE.

The name Kona dolomite was given by Van Hise[1] to a dolomitic limestone formation of the Lower Huronian of the Marquette iron-bearing district of Michigan. The same formation is believed to be represented in the Crystal Falls district, but since Smyth has called this formation the Randville dolomite, for the sake of uniformity this name will be used, as it is deemed unnecessary to further complicate pre-Cambrian nomenclature by giving the formation a separate name. The best exposures of the dolomite are found east of the ellipse, in the part of the Crystal Falls district described by Smyth (p. 126 et seq.), and the reader is referred to his description for a fuller characterization of this formation.

DISTRIBUTION AND EXPOSURES.

The area in which the Randville dolomite immediately underlies the drift is a continuous zone adjacent to and surrounding the Archean core. The belt varies slightly in width along the sides of the ellipse. At the ends it is two or three times the width at the sides. This is due to the lower dip of the beds at the ends. Exposures are found in the area studied by me only on the northeast and southwest flanks of the granite core.

PETROGRAPHICAL CHARACTER.

In general the Randville dolomite consists petrographically of a fine-grained limestone with some quartz. This grades down through a calcareous quartzite, by increase of quartz, into a true quartzite. The nearer the granite the more quartzitic is the formation. At the southwest corner of sec. 1, T. 45 N., R. 32 W., upon the west bank of the west

[1] Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, p. 523; Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 240.

branch of the Fence River, is a very good exposure of the quartzite. Its derivation from the underlying granite is here shown. The rock is a very fine grained quartzite, almost novaculitic. It shows current bedding in some places, though no true bedding was observed. Immediately below this quartzite is a very schistose rock in which one can readily distinguish, microscopically, rounded to lenticular quartz areas with masses of sericite flakes between them. The contact between the quartzite and the schistose rock seems very sharp when viewed from a short distance, but is found to be indefinite when closely examined. A careful search was made along the contact for pebbles from the granite, but such were not found. However, small rounded pieces of vein quartz, probably derived from the granite, were observed. The schistose rock in its turn grades down into a grayish granite, which is also more or less schistose. We have here very evidently a transition from the granite, through the intermediate schistose recomposed granite, to the true sedimentary rock above. The meaning of this transition is considered below.

Under the microscope the cause of the schistosity of the rock intermediate between the granite and the quartzite is plain. Only quartz and sericite, with some feldspar, are present in it. The quartz is grayish and granulated, and mashed out into oval areas, representing original quartz grains. Various fragments constituting the areas are, however, angular and more or less equidimensional, and when not so never have a definite orientation of their longer axes. Between these large areas, but not between the individual small fragments constituting the areas, sericite is abundant. When the sericite is not predominant the flakes lie in a fine mass of quartz grains, each of which agrees in long direction with the mica plates and large oval quartz areas. The sericite flakes are both included in this quartz and also lie between the grains. In one instance fragments of the original feldspar are found in the midst of such an area. These quartz-sericite areas are unquestionably of secondary origin, and the minerals have developed in connection with pressure. They were probably produced from feldspar which existed in the original granite.

Whether this schistose rock was formed from a weathered but not transported granite, from an arkose or feldspathic sandstone, or from the solid granite it is impossible to say. A similar sericite-schist which developed from recomposed granites has been described by Van Hise as occurring at several localities in the Marquette district.[1] In these cases at places the fragmental characters are still sufficiently clear to admit of the statement that the rocks are sedimentary. In the Crystal Falls rock mashing has destroyed all original characters. The rock occupies an intermediate position between a metamorphosed sedimentary and a metamorphosed eruptive, and grades on the one hand into

[1] Mon. U. S. Geol. Survey Vol. XXVIII, 1897, p. 226.

a sedimentary and on the other into the eruptive. This makes it impossible to say whether it belongs exclusively to the one or to the other or in part to both. Similar relations in other parts of Michigan were explained by Rominger[1] as cases of progressive metamorphism of sediments, the granite being supposed to be the extreme stage of alteration of the sedimentary rock. Later the finding of basal conglomerates at or near these localities has shown conclusively that this explanation is incorrect and it has been abandoned by Rominger.

RELATIONS TO UNDERLYING AND OVERLYING FORMATIONS.

At only the one place cited above has a contact between the granite and the Randville dolomite been found. It is probable that unconformable relations exist even though no basal conglomerate has been discovered as evidence of wave action on the Archean coast.

Relations between the Randville dolomite and the overlying formations have not been observed in the part of the district studied by me.

THICKNESS.

Reliable data for estimating the thickness of the Randville dolomite have been obtained in the area surveyed by Smyth. According to his estimate (p. 127), the formation possesses a maximum thickness of 1,900 feet, which he presumes is too great.

SECTION II.—THE MANSFIELD FORMATION.

The formation of the Lower Huronian next above the Randville dolomite is composed of sedimentary beds in which a slate predominates. It appears to correspond both stratigraphically and lithologically with the Siamo slate formation as defined and described for the Marquette district.[2]

These slates underlie a considerable area in that part of the district described by Smyth. (See p. 131.) There their relations to the older formations are most clearly defined. I shall confine myself to the slate of the Mansfield area, the narrow valley through which the Michigamme River flows and in which the village of Mansfield and the mine of the same name are situated. The valley and these slates are well known in the Crystal Falls district on account of their economic importance. For this reason the name "Mansfield slate" is here applied to this formation.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The part of the valley occupied by the Mansfield slates begins at the north section line of secs. 17 and 18, T. 43 N., R. 31 W., and extends due south for 3 miles to the south section line of sec. 29 of the same

[1] The Marquette iron district, by Carl Rominger: Geol. of Michigan, Vol. IV, Part I, 1878-1880, pp. 15-52.

[2] Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, p. 554; Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 313.

town. The slate belt is widest at the north, being over one-fourth mile wide on the west side of sec. 17. To the south it gradually diminishes in width until it finally disappears in sec. 29. The strike of the sedimentary rocks is almost due north-south, except in a few places where the rocks have been gently flexed and the strike varies a few degrees. The dip is high to the west, ranging from 65° to 80°.

The influence of the Mansfield slate belt upon the topography is strikingly shown by the depression in which the slates are found, in which is the course of the Michigamme River. The slates are surrounded on all sides by igneous rocks which form fairly high hills, those to the west being composed of rocks of volcanic origin, those to the north, east, and south being intrusive and later than either the sedimentaries or the volcanics.

POSSIBLE CONTINUATION OF THE MANSFIELD SLATE.

In sec. 10, T. 44 N., R. 32 W., about 7 miles northwest of the extreme north end of the Mansfield area of slate, there are a couple of exposures of crumpled slates which strike slightly to the west of north. These slates, from their relations to the adjacent rocks, are presumed to be the northwestward continuation of the Mansfield slates.

PETROGRAPHICAL CHARACTER.

A petrographical description of the Mansfield slate belt must necessarily be very brief, owing to the small area and to the scarcity of the exposures.

The rocks of the Mansfield slate belt are graywackes, clay slates, phyllites, siderite-slates, cherts, ferruginous cherts, and iron ores, with the various rocks which have been derived from them by metamorphism. They vary from coarse-grained rocks to very fine-grained, slaty ones. The latter predominate, and for that reason this belt is called a slate belt. The color of the rocks varies from an olive green and purplish black to bright red for those which are very ferruginous and more or less altered.

The ordinary detrital rocks may be divided into the coarser and the finer kinds. The first are the graywackes and the second are the ordinary clay slates and phyllites. There is, however, a gradation from the one to the other.

GRAYWACKES.

The graywackes consist largely of grains of quartz and feldspar of unquestionably detrital origin. Associated with these is a large amount of mica, chlorite, and actinolite, with invariably more or less rutile. This last is in minute grains as well as in crystals. Many of the crystals show fine knee twins, triplets, and, more rarely, heart-shaped twins. Tourmaline is sometimes present. The ferromagnesian minerals develop chiefly from the alteration of the feldspar and from the finer detritus which is presumed to have existed between the grains. As a consequence, the secondary minerals lie between the original grains. Many of the quartz grains are enlarged, and here the secondary minerals are included in the new areas of the enlarged grains. In numerous cases the new quartz occupies about as much space as the original grains themselves. This shows very clearly the porous character of the original sandstone. All original grains of the rocks show signs of extensive mashing. Some specimens contain a large amount of tourmaline in long slender crystals, which penetrate both the feldspar and the quartz grains. The presence of tourmaline is especially interesting as indicating that these sedimentaries may have been subjected to a certain amount of fumarole action. According to the proportion in which the various minerals have developed, we obtain sericite-, actinolite-, or chlorite-schists produced from the graywackes.

CLAY SLATES AND PHYLLITES.

The clay slates are dull and lusterless, and are black, olive green, or red in color. They are usually impregnated with more or less iron pyrites in large macroscopical crystals. One can distinguish in them quartz, white mica, a few needles of actinolite, rutile, hematite, with a small proportion of a dark ferruginous and carbonaceous interstitial material.

The amount of iron which these clay slates contain varies very considerably. In some, hematite is present in such quantity as to cause the slates to be appropriately called hematitic slates. Such, for instance, is the one forming the footwall of the Mansfield ore body. The iron oxide gives to the slates a very bright red color where they are weathered. These weathered hematitic slates are very commonly known in the district as red slates, or as "paint rock" or "soapstone," though rocks of very different character are at times designated by these names.

The phyllites have a silky luster and a bluish-black color. They are composed essentially of white mica, quartz, some feldspar, innumerable minute crystals of rutile, and dark ferruginous specks. These seem to differ from the rocks here called clay slates only in that they are more completely crystalline, the interstitial material of the slates having disappeared.

Origin of clay slates and phyllites.—The origin of the clay slates of the Mansfield formation is probably to be looked for in the disintegration and decay of the Archean granite and the subsequent metamorphism of the resulting clay, for between the granites and the slates no other rock masses are known to have existed from which the clay could have been derived. The phyllites are presumed to have resulted from the metamorphism of the clay slates.

SIDERITE-SLATE, CHERT, FERRUGINOUS CHERT, AND IRON ORES.

The two most interesting kinds of rock from the Mansfield slate belt are those known as the siderite- or sideritic slates and cherts or ferruginous cherts, according to the quantity of iron carbonate and iron oxide present. These alternate with each other, and are found also interstratified with the fragmental slates, and thus there can be no question as to their sedimentary character. The sideritic slates are of a light to dark gray color. They are well laminated, and in some places cleave rather readily along the laminæ, though at other places they break with an almost conchoidal fracture. The weathered sideritic slates are covered by a crust of reddish-brown hydrated iron sesquioxide.

Microscopically the sideritic slates are composed of siderite, or of siderite and exceedingly fine-grained cherty silica. Roundish rhombohedra of siderite compose the purer sideritic portions. If one passes from the pure to the less pure slates the siderite gradually diminishes in quantity, the silica grains increase correspondingly, and the rock grades into the chert bands which are commonly associated with the iron carbonate in the Lake Superior region. As the carbonate alters to the oxide or hydrated oxide, ferruginous cherts are produced. The cherts are white to red, depending on the amount of iron oxide present. The manner in which the siderite alters to limonite and hematite, and the various steps of the process, have been so well described and so beautifully illustrated in Monograph XXVIII that the reader is referred to that volume for further information. None of the brilliant red jasper or jaspilite, such as that found in the Marquette district, is associated with the Mansfield slates. Associated with these slates are found iron ores of economic importance. They are described in detail farther on.

The ore-bearing rocks exist in beds in the slates or as lenticular masses which agree in dip and strike with the slates surrounding them.

None of the sideritic slates, ferruginous cherts, or ores, although interbedded with the fragmental slates, show any evidence of fragmental origin so far as the individual grains of the minerals composing them are concerned.

RELATIONS TO INTRUSIVES.

The Mansfield slates are surrounded on three sides, east, north, and south, by coarse-grained basic intrusive rocks. The fact that they are so surrounded by these rocks, which cut them off in the direction of their strike, points to the later origin of these eruptives.

RELATIONS TO VOLCANICS.

The sedimentaries are overlain by volcanics, both lava flows and tuffaceous deposits. In these tuffs, at the northeast corner of sec. 7, T. 43 N., R. 31 W., angular black slate fragments have been found similar in every respect to the slates of the Mansfield belt. From this it is clear that at least some of the volcanics are younger than a part of the slate formation. In sec. 29 similar relations obtain, the only difference being that the masses of slate and graywacke are inclosed in rather larger fragments in a volcanic conglomerate, and happen to still retain very closely their normal strike. In the conglomerates near the Mansfield mine are found chert fragments, and in some places fragments of iron oxide. These latter were evidently not included as oxide, but as fragments of cherty carbonate. Like the great mass forming the ore body, the fragments have since their deposition been altered, forming iron-oxide bodies of small size. Further discussion of the relations between the volcanics and slates will be found under the Hemlock volcanics (p. 47).

STRUCTURE OF THE MANSFIELD AREA.

It has already been seen that the Mansfield rocks strike north and south and have a high westerly dip. The two explanations of this structure which are compatible with the facts in other portions of the area are (1) that they are a western-dipping monocline and (2) that they are the west limb of an anticline.

THICKNESS.

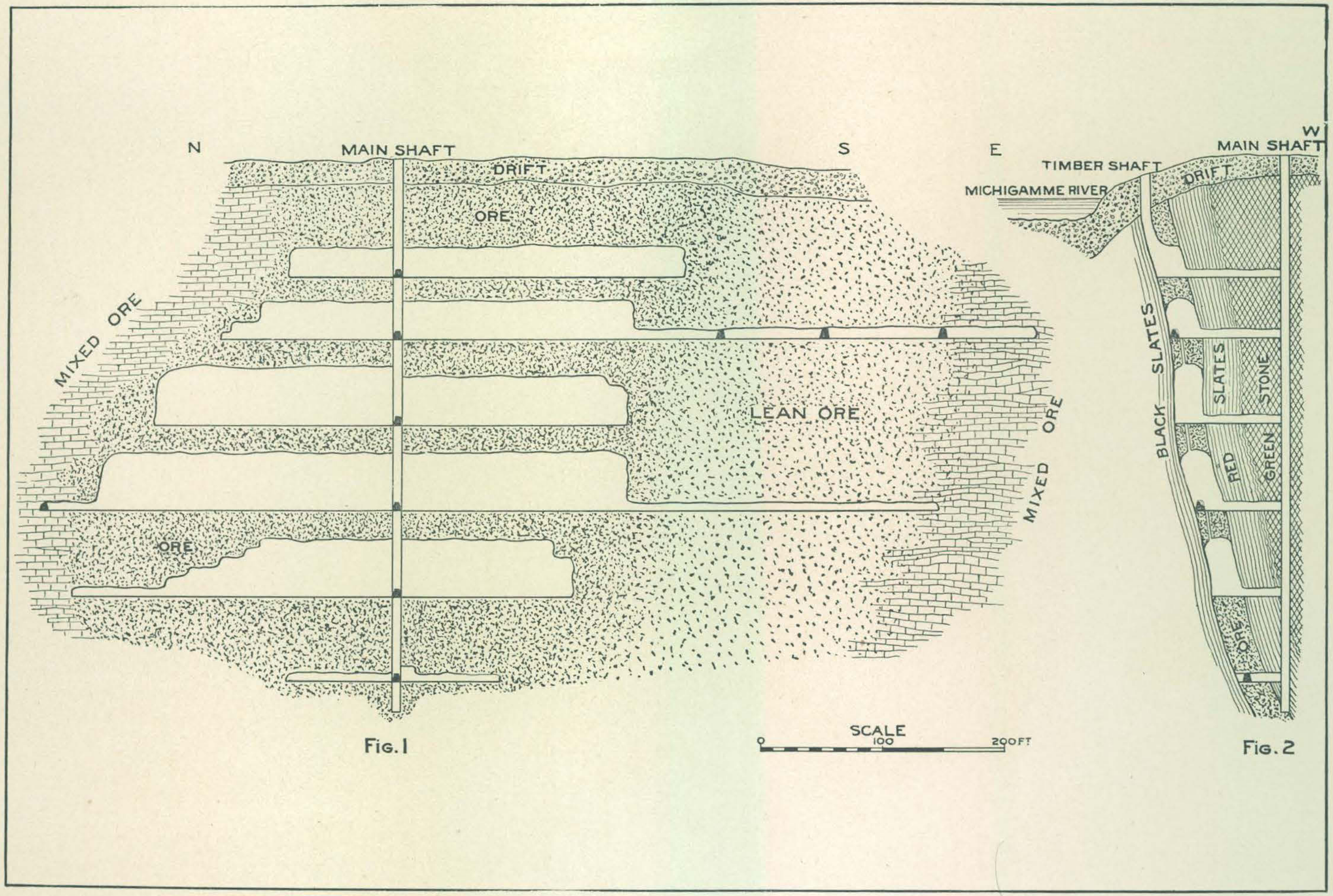
As the sedimentaries forming the Mansfield belt now dip west at a very high angle, and as there is no evidence of duplication of strata due to folding, I feel comparatively safe in giving an estimate of their thickness. The belt is widest at the north end, and there has a breadth of about 1,950 feet. The average dip of the beds is 80°, and this gives a maximum thickness of 1,900 feet. Toward the south the belt rapidly narrows, until it is cut out by the intruding dolerites. A thickness of 1,500 feet is probably not far from the average.

To the east of the Mansfield slates is a belt, varying in width up to about 1,200 feet, in which are found large masses of metamorphosed slates surrounded by intrusive dolerite. In this belt the slate masses still show a general north-south strike, with slight variations to the east or west, and a westward dip. One might, perhaps, consider this a slate area which had been completely saturated with intrusives. If it should be so considered, this thickness should be added to the estimated thickness of the slates as above given, but as intrusives predominate in it, the slate being, as it were, merely incidental, I have preferred not to include it in the belt with the slate.

ORE DEPOSITS.

Although a great deal of exploring for iron ore has been done in the Mansfield slates, only one large body of ore has thus far been discovered, in which is the Mansfield mine. This mine is situated on the west bank of the Michigamme River, in secs. 17 and 20, T. 43 N., R. 31 W. This mine was apparently prospering when on the night of September 28, 1893, a cave in occurred, letting in the waters of the Michigamme River and drowning 27 miners.[1]

[1] Report of Commissioner of Mineral Statistics of Michigan for 1896, George A. Newett, p. 84.



SKETCH OF THE MANSFIELD MINE AS IT WAS BEFORE IT CAVED IN, IN 1893.

Fig. 1. Longitudinal section. Fig 2. Cross section.

Since the cave in, until recently, the mine has remained idle. At the present writing the De Soto Mining Company has control of the mine, and, I understand, has freed it from water. Owing to the long abandonment of the mine, the direct sources of information have been closed. For a description of the ore body I am compelled to rely on such data as are available from the existing notes and plats. I am especially indebted to a manuscript description of the mine by J. Parke Channing, and to Mr. C. T. Roberts, of Crystal Falls, for plats of the mine. The sketch of the mine here introduced is compiled from an original drawing of J. Parke Channing, reproduced on Pl. V, and from data obtained from other sources.

General description of Mansfield mine deposit.—The Mansfield mine has an ore body varying from 16 to 32 feet in width. The ore body is in an almost vertical position, has well-defined foot and hanging walls of impervious rock, and has a somewhat indefinite longitudinal extent. The ore is Bessemer and occurs in an iron-bearing formation which corresponds in every particular to such formations in the other iron-bearing districts of the Lake Superior region. The ore was first found in a test pit which passed through 9 feet of drift. The main working shaft was then located about 100 feet west of this point. It was put down to a depth of 460 feet before ore was struck. From this shaft crosscuts were driven east at average intervals of 70 feet, and the ore body was met at a distance varying from 74 feet at the first level to 10 feet at the sixth level. The crosscuts, in every case, after leaving the greenstones pass through so-called red slate, at its maximum about 25 feet thick, before ore is reached, this rock constituting the hanging wall. From these data the dip of the ore body may be calculated to be about 80° W., agreeing well with the observed dip of the slates which outcrop over the area. The thickness of the ore, as shown by the cross sections, averages about 25 feet. The extreme variation in thickness ranges from two sets, or 16 feet, to four sets, or 32 feet. The strike of the slates is north and south, and the trend of the ore body agrees with this. This brings its south end under the original course of the Michigamme River, as south of the shaft the stream bends slightly to the west. An examination of the longitudinal (north-south) section through the ore body does not determine whether or not it has a pitch. The south boundary is nearly vertical from top to bottom, while the north boundary lengthens about 140 feet between the first and the fifth levels.

In the north end of the mine—that is, in line with the strike of the sedimentaries—the ore body terminates in a more or less irregular way in so-called mixed ore. This mixed ore continues to the north for over a half mile, as shown by the numerous test pits which have been bottomed in it. To the south of the mine shaft the ore body proper extends for 200 feet. It then changes its character, becoming a lean non-Bessemer ore. A long drift (335 feet) at the second level was run through this ore, and after leaving it penetrated a mixed ore, the so-called lime rock (siderite?) and quartz rock (chert?) of the miners. Three crosscuts along this drift show the ore body to vary from 20 to 30 feet in thickness, with the same foot and hanging wall as for the remainder of the mine. The same condition exists also lower down, as shown by a drift from the fourth level, 260 feet south. The figures on Pl. V, giving longitudinal and cross sections of the mine, show clearly the dimensions of the ore body.

Relations to surrounding beds.—The foot wall of the ore is a black slate, described as being rich in hematite, and bearing large crystals of iron pyrite. No crosscuts have been driven for any distance into the foot wall, so that it is impossible to say what thickness of the hematitic black slate there may be before the greenish, pyritiferous slate begins. In places a gray "soapstone" takes the place of the black slate as the foot wall.

The dump obtained by sinking the shaft in the material overlying the ore shows large masses of conglomerate, the pebbles of which are rounded and predominantly of volcanic rocks, with pebbles of chert and slate from the iron formation and slates below. These fragments are well rounded. The microscope shows grains with secondary enlargements, and there can be no doubt that the rock is a true conglomerate. Similar conglomerates, with the exception that the sedimentary fragments are wanting, have been noticed farther north along the west side of the river. There is also just west of the bridge at Mansfield, near the mine, a small exposure of conglomerate which shows an alternation of coarse and fine sediments, with a strike nearly north and south, and a dip of 80° W. To the west, above this conglomerate, and not more than 15 to 20 feet distant, are found the lavas of the Hemlock volcanics. According to the mine captain the succession west from the ore body in the hanging wall is, 20 to 25 feet of paint rock, or, as it is usually called, red slate, then conglomerate, then greenstone. It is difficult to diagnose the paint rock, as no specimens are to be had, but it is highly probable that it is a ferruginous and extremely altered lava sheet. Similar rocks are commonly found thus altered in association with the ores in the Penokee-Gogebic and Marquette districts. Lending weight to this conclusion is the fact that in some places an amygdaloidal greenstone has been exposed in test pits immediately above the iron-bearing formation.

Chemical composition and mineralogical character of the ore.—The Mansfield mine up to the present time (1896) has raised only Bessemer ore, and is the only mine in the Crystal Falls district which has supplied any considerable quantity of ore of this character. An average of a number of analyses gives the following composition: Metallic iron, 64.80; phosphorus, 0.037; silica, 3.70.[1] The ore varies from a soft

[1] An average of 62 per cent metallic iron and 0 03 phosphorus is given in the Report of the Commissioner of Mineral Statistics of Michigan for 1896, by G. A. Newett, 1897, p. 55.

limonitic hematite to a moderately hard hematite. It has ferruginous chert bands associated with it, and as the chert increases in quantity the ore grades into the lean ore.

Origin of the ore deposits.—The mode of occurrence and general characters of the ore body having been described, we are now prepared to determine the cause of the concentration of the iron at this particular point and its source. From the description it was seen that the appearance of the body of ore was that of a bedded deposit. The microscopical examination shows, however, that the ore presents no evidences of sedimentary origin. An examination of the cherts and rocks of the area which are interbedded with the ore, and also a study of the southern contact of the ore body, show that the ore is a chemical deposit, or the result of a replacement process, by which the original rock was largely removed and its place taken by the present ore. It has been shown (p. 39) that the siderite bands pass into hematitic and limonitic chert bands. It was seen that in the southern end of the mine the lean ore merges into a mass of ore bedded with chert and mixed with a rock called by the miners lime and quartz rock. I interpret this rock to be banded siderite and chert, possibly with some quartzite bands, all of which are found outcropping at the surface. The siderite evidently has been changed into iron oxide and the silica replaced by iron oxide, the banding of the original rock not being destroyed thereby. Irving[1] considered siderite to be the source of similar ore and associated chert and jasper. Van Hise[2] has fully explained the process of the concentration of the ores of the Penokee Gogebic and Marquette districts, and has applied the explanation to the other districts in the Lake Superior region. I shall not do more, therefore, than to add that the investigations in this area have shown the probable correctness of this explanation.

Much of the iron of the Mansfield ore is presumed to result directly from the alteration of the ferruginous carbonate in place, but a large amount is brought in from above by infiltrating waters. The ferruginous matter which was taken into solution during the denudation of the area has been carried down by percolating waters and deposited at places favorable for its accumulation. The beds are now upon edge, offering the most favorable condition to percolation. The conclusion is obvious that these deposits were formed after the beds were tilted and that the iron was derived from the upward extension of the rocks, which has been removed by erosion.

[1] Origin of the ferruginous schists and iron ores of the Lake Superior region, by R. D. Irving: Am. Jour. Sci., 3d series, Vol. XXXII, 1886. pp. 256-272. Iron ores of the Penokee-Gogebic series of Michigan, by R. D. Irving: idem, Vol. XXXVII, 1889, pp. 32-48.

[2] The iron ores of the Marquette district of Michigan, by C. R. Van Hise: Am. Jour. Sci., 3d series, Vol. XLIII, 1892, pp. 116-132. The Penokee iron bearing series of Michigan and Wisconsin (preliminary), by R. D. Irving and C. R. Van Hise: Tenth Ann. Rept. U. S. Geol. Survey, Part I, 1890, pp. 341-507; also Mon. U. S. Geol. Survey, Vol. XIX, 1892, pp. 245-290. Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, pp. 400-405.

Conditions favorable for ore concentration.—The conditions favorable for the accumulation of ore deposits have been ascertained by Van Hise from studies in the other iron-bearing districts of the Lake Superior region. He summarizes these results as follows:[1]

(1) The iron ore is confined to certain definite horizons, known as the iron-bearing formations. . . .

(*a*) All ore bodies have been found to be distributed very irregularly in these iron-bearing formations. This is due to the fact that they are secondary concentrations produced by downward-percolating waters, and the ore bodies therefore occur at the places where water is concentrated, in accordance with the laws of the underground circulation of waters. (*b*) These places are just above an impervious formation, at the contact of the Upper Huronian and Lower Huronian, and where the rocks are shattered. (*c*) The impervious basement formation may be a surface volcanic, a subsequent intrusive, an argillaceous stratum, or any other impermeable formation. (*d*) These impervious basements are most effective when they are in the form of pitching troughs, thus concentrating the waters from the sides along a well-defined channel. These pitching troughs may be formed by a single one of the above rocks or by a combination of two or more of them. The horizon marked by the unconformity between the Upper and Lower Huronian is a great natural zone of percolating waters. Here oftentimes the basement formation of the Upper Huronian is itself a lean ore, having derived its material from the Lower Huronian, but in this case a secondary concentration has occurred in order to produce the present ore bodies. (*e*) Finally, as a result of folding, the iron-bearing formations have been shattered, thus producing natural water courses. More frequently than not, more than one of these classes of phenomena are found together where the great ore bodies occur, and in many cases all are combined. The original source of the iron ores has been ascertained to be in many cases a lean carbonate of iron, often with a good deal of carbonate of calcium and magnesium, formed as an ocean deposit.

Van Hise adds to the above statement that all ore bodies, as a result of their methods of concentration, somewhere reach the rock surface.

The Mansfield ore body has well-defined foot and hanging walls of normally impervious rock. The iron-bearing formation is much fractured. We thus have certain of the conditions favorable to the concentration of an ore body. Whether a trough is completed by a slight cross fold in the formation, or possibly by an intersecting dolerite dike, has not been determined.

Exploration.—Exploration has developed no other deposits along the Mansfield slate belt. If other deposits exist it is highly probable that they extend to the rock surface—that is, are covered by the drift mantle alone.

The intervals between possible ore bodies along the strike of the slates are probably occupied by mixed chert and ore or a ferruginous chert. Explorations should extend from the impervious slate below the iron-bearing formation to the impervious rock above the iron-bearing formation. In order to explore the belt thoroughly, rows of pits cross sectioning the formation ought to be made at intervals not greater than 100 feet, and even with such intervals an important deposit might be missed, for it frequently happens that at the surface of the rock an ore deposit is smaller than it is at moderate depth.

[1] Fourteenth Ann. Rept. U. S. Geol. Survey, Part I, 1893, pp. 107-108.

SECTION III.—THE HEMLOCK FORMATION.

This formation, the most interesting petrographically in the Crystal Falls district, consists almost exclusively of typical volcanic rocks, both basic and acid, with crystalline schists derived from them. Sedimentary rocks play a very unimportant rôle. With one exception they have been formed directly from the volcanics, and occur interbedded with them. Cutting through the volcanics are intrusive rocks, which likewise include both basic and acid kinds. Chemically the intrusive and extrusive rocks show very close relationships.

The name Hemlock has been given to this volcanic formation because the river of that name flows through it for a number of miles and in places affords excellent exposures.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Beginning in sec. 36, T. 46 N., R. 32 W., the place where the Hemlock formation enters the part of the district studied by me, the formation has a width of one-half mile. From this place the formation has a northwest course for about 5 miles, gradually widening. It then bends to the west, and after a short distance, to the south, which course it follows for about 9 miles. In T. 45 N., Rs. 32 and 33 W., the belt has a maximum width of 5 miles. At the end of the southern course the formation bends to the southeast and continues with this general trend for about 16 miles, into T. 42 N., R. 31 W., where my field studies of it ended. At the north the belt runs into the eastern half of the district described by Smyth, and swings south, which course is followed for some 15 miles. The entire belt thus forms an oval surrounding the sedimentaries, except in the southeastern part of the district. Another area of Hemlock volcanics is found in T. 43 N., Rs. 32 and 33 W., just north of Crystal Falls. This area is about one-half mile wide just north of the city of Crystal Falls, but rapidly widens as it is followed to the west, until at the western limits of the area it is about 3½ miles wide.

A third small isolated area is found in secs. 17, 18, 19, and 20, T. 42 N., R. 32 W., and sec. 24, T. 42 N., R. 33 W., about 4 miles south of Crystal Falls.

The topography of the Hemlock formation is exceedingly rough wherever erosion has succeeded in cutting through the drift mantle. This occurs only adjacent to some of the streams. The rough topography at these places is due to differential erosion working upon rocks approximately upon edge and of differing hardness. The valleys usually indicate the location of beds of tuff, and the higher grounds are almost everywhere occupied by dense rocks forming the lava flows or by the coarse-grained massive intrusive rocks. However, in a few places the thoroughly consolidated and indurated tuffs form high hills. In traversing the Hemlock formation one makes an abrupt ascent, followed by a sharp descent into a narrow swamp, and then makes another ascent, and so on. Exposures appear for the most part in small areas along the edges of the swamps and scattered over the faces of the hills. These are fairly numerous, but so small and disconnected as to prevent the tracing out of the individual flows, although this might be possible if the traverses were made at very short intervals and the area were mapped in very great detail.

THICKNESS.

As has been seen, the belt of eruptives varies in width from three-fourths of a mile to nearly 5 miles. The dip of the rocks is about 75° W. The enormous thickness of 25,500 feet which these data would give is probably illusory.

In the case of the assumption of the thickness of a series of lava flows and tuffs, it is important to consider the initial dip which these deposits must have had. This dip varies greatly, depending upon the slope of the cone, which, in its turn, is dependent upon the viscosity of the lava and the presence of varying quantities of fragmental products. If we suppose these pre-Cambrian volcanic products to have had an initial dip of 15°, we believe we are within the limits for products consisting, as these do, of what was probably moderately viscous basalt and vast masses of fragmental material. This is based upon the assumption that the volcanics here represented were deposited for the most part upon the westward slope of a volcano or series of volcanoes. This initial dip of 15° is then to be deducted from the present dip, 75°, of the flows. Taking this into consideration, we get a thickness of 23,000 feet for the volcanics.

It is highly probable that the rocks have been subjected to close folding, and for this reason also the apparent thickness would be much greater than the true thickness. The schistose character of some of the rocks shows clearly that they have been severely mashed, and this mashing was probably produced in connection with folding. It is probable that this possible maximum thickness should be very materially reduced, possibly to one-half or one-third of the amount. However, even the possible maximum above calculated is probably paralleled by the vast masses of volcanic material accumulated around the vents of certain volcanoes, such as those of Hawaii or Iceland. Geikie writes:[1]

> The bottom of these Iceland Tertiary basalts is everywhere concealed under the sea. Yet their visible portion shows them to be probably more than 3,000 meters in thickness.
>
> An especial interest belongs to this Icelandic plateau because volcanic action is still vigorous upon it at the present day.

RELATIONS TO ADJACENT FORMATIONS.

In the northern part of the Crystal Falls district the volcanics overlie the quartzose limestone formation known as the Randville dolomite. In the central part of the district, through which the Deer River runs,

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[1] The Tertiary basalt-plateaux of northwestern Europe, by Sir A. Geikie: Quart. Jour. Geol. Soc. London, Vol. LII, 1896, p. 395.

as shown in section G–H of Pl. IV, outcrops are so scarce that it has been found impossible to trace the boundaries of these formations with any degree of accuracy. Consequently this part of the district is mapped as Pleistocene.

From the few outcrops of slate, probably equivalent to the Mansfield slate, which have been found in the Deer River area, it has been thought highly probable that this slate in an extremely plicated condition may underlie the volcanics of this area, and it is so represented in section G–H of Pl. IV. As evidence of this, in T. 43 N., R. 31 W., the volcanics overlie the Mansfield slate unconformably.

In places test pits have disclosed an amygdaloidal lava flow immediately overlying the Mansfield slates. At one place, at the northeast corner of sec. 7, T. 43 N., R. 31 W., angular fragments of the underlying black slate have been found in the tuffaceous deposits of the Hemlock volcanics. Farther south, along the contact just west of the Mansfield mine, a conglomerate is exposed which contains fragments of slate, lava, and rounded grains of quartz with secondary enlargements. The rock is evidently water deposited. There is also obtained from the workings of the mine a conglomerate, taken from just above the ore, which consists of lava fragments and pieces of chert and ore, as mentioned on p. 40. From these occurrences it is clear that some of the sedimentaries are unquestionably older than some of the volcanics, and yet the conglomerates bearing the fragments of ore and slate contain also fragments of lava, showing the existence of some of the volcanics before the deposition of this conglomerate. The only explanation of all of the facts which has occurred to me is as follows: After the ore-bearing Mansfield slate was deposited, an erosion interval occurred. Then followed a volcanic outbreak. It is highly probable that this outburst began far north of the Mansfield mine, prior to the upheaval which resulted in the erosion of the Mansfield slate. The volcanic ejectamenta were mixed with the sedimentary fragments and all together were rounded and bedded, forming in places conglomerates. In places along the shore lava flows descended, some reaching into the sea and covering the sedimentaries along the shore where no conglomerate had been formed. At other places were deposits of scoria, etc., including fragments of slate from the sedimentaries through which the volcano burst, and thus deposits of tuff (agglomerate) are found overlying the sedimentaries.

The various deposits, though really separated by a slight physical break, are practically conformable with the series below, all having a north-south strike and a high westward dip.

The formations which underlie the volcanics in the northern and southern parts of the district are of different character. This difference may be explained by supposing that the volcanoes broke out in the northern part while the Mansfield slate was still being deposited in the south. Gradually, however, the volcanic activity spread toward the south, probably following a fissure along the pre-Cambrian shore, and igneous materials buried the Mansfield slate. Hence, while on the whole these volcanics are younger than the Mansfield slates, some of the lower of them are contemporaneous with some of the upper Mansfield beds. The volcanics invariably overlie the Randville dolomite, and are unquestionably of later age than that formation.

The Hemlock volcanics are overlain throughout their extent by the Upper Huronian series of graywacke and slates. Near the contact line with the volcanics, wherever the Huronian outcrops or has been exposed by exploration, it has been found to be characterized by a line of magnetic attraction. By means of magnetic observations the line of magnetic attraction has been followed, and thus the line of contact has been traced where, owing to lack of exposures, it would otherwise have been impossible to connect the isolated outcrops.

RELATIONS TO INTRUSIVES.

High ridges composed of dolerite are found extending in a general northwest-southeast direction through the volcanics. That these masses were forced up through the Hemlock formation is indicated by the folding which they cause in certain places. Such rocks are unquestionably younger than the volcanic series. There may be seen also on the map, in T. 44 N., R. 32 W., a number of isolated knobs. These are also doleritic, and are presumed to be, like the larger ridges, intrusive in the volcanics.

The dolerites have in their turn been cut by acid dikes. These are coarse micropegmatitic granites. Similar acid dikes have been found cutting the surrounding volcanics. This set of acid dikes may be looked upon as the youngest intrusive igneous rocks occurring in the Hemlock volcanic formation.

Cutting the volcanics are also basic dikes varying from fine to moderately coarse grain. It is well known that during a volcanic epoch the outpoured lavas and clastic volcanic deposits are penetrated by dikes coming from the same magma. Whether or not these dikes are of this origin, and are hence contemporaneous with the later volcanics, or are of later age and correspond to the coarse dolerites, it is impossible to determine with certainty. They are presumed, however, to form an integral part of the Hemlock volcanics, as no connection between the dikes and the unquestioned intrusive dolerites could be traced in the field.

VOLCANIC ORIGIN.

In spite of numerous occurrences of ancient volcanoes which have recently become known, the late Professor Dana[1] makes the following statement:

> It is not yet certain that a volcano ever existed on the continent of North America before the Cretaceous period; for the published facts relating to supposed or alleged *volcanic* eruptions in the course of the Paleozoic ages are as well explained

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[1] Manual of Geology, by J. D. Dana, 4th ed., 1895, p. 938.

on the supposition of outflows from fissures and tufa ejections under submarine conditions, and none of the accounts present evidence of the former existence of a volcanic cone—that is, of an elevation pericentric in structure made of igneous ejections.

The presence in the Hemlock formation of a quantity of pyroclastics, great in proportion to the solid lavas, and the absence of any great sheets of lava, so important a product of great fissure eruptions, seem to point to the derivation of the Hemlock rocks from a volcano or volcanoes situated near the border of the contemporaneous Huronian sea rather than from a simple fissure. While some of the eruptives may have been submarine, the occurrence of large quantities of clearly subaerial deposits shows that the eruptives were largely on the land. Thus it appears that neither a fissure flow nor a submarine volcano will wholly explain the Hemlock formation. However, it is highly probable that this volcanic outburst, which piled masses of volcanic material on the land, was accompanied, as have been all or nearly all the great outbursts of recent times, by submarine lava flows and tuff ejections. No such clear evidence of the presence of a Paleozoic or pre-Paleozoic volcano on the North American continent has been adduced as that given by the English geologists for certain volcanoes in the British Isles. But while the presence of a central cone with pericentric arrangement in the Crystal Falls district is not conclusively proved, the presumption in favor of such a cone or cones having existed is certainly strong.

An attempt was made to locate the vent or vents from which the material was derived, but no evidence could be found, unless we consider the vents to have been where the accumulations were the greatest. The coarse-grained rocks which were first supposed to represent the plugs of ancient volcanoes, upon careful and detailed examination appear to be later intrusives, or else are indeterminate.

CLASSIFICATION.

The general character and distribution of the Hemlock formation having been given, we may now proceed to a petrographical consideration of the rocks comprising it. This will be given in more detail than for the other rocks of the Michigamme district because this great pre-Cambrian volcanic formation possesses peculiar interest.

The rocks of the Hemlock formation are chiefly of direct igneous origin. Some interleaved sedimentary rocks occur, which, however, with a single exception, are composed of fragments of the igneous rocks. For the sake of easy reference, the usual classification into igneous and sedimentary rocks will be used. The massive igneous rocks are subdivided, according to chemical composition, into acid and basic rocks. The acid rocks include rhyolite-porphyries,[1] aporhyolite-porphyries,

[1] According to a late ruling of the Director of the United States Geological Survey, based on the recommendation of a committee on nomenclature for geologic folios, "porphyry" is to be used only with a textural significance. Hence "quartz-porphyry," according to this ruling, should no longer be used as a rock name. The rhyolite-porphyries here described are what have been known as normal quartz-porphyries.

and acid pyroclastics. The basic rocks include the nonporphyritic basalts, porphyritic basalts and variolite, and basic pyroclastics. The sedimentary rocks are divided into the volcanic sedimentaries and the nonvolcanic sedimentaries or normal sedimentaries. The first include tuffs and ash (dust) beds (eolian deposits) and volcanic conglomerates (water deposits). The normal sedimentaries are represented by slates and limestones. Various schists are locally produced from these numerous kinds of rocks through metasomatic changes and dynamometamorphic action. Many of these schists resemble one another very closely, though, as will be seen later, they are derived from both the massive rocks and the clastics. These have been described in connection with the rocks from which they have been derived.

The following table will show the arrangement which is outlined above, and which will be followed in the descriptions:

Classification of rocks of Hemlock formation.

Igneous	Acid	Lavas	Rhyolite-porphyry. Aporhyolite-porphyry.	Schistose acid lavas.	Crystalline schists.
		Pyroclastics.			
	Basic	Lavas	Basalts	Nonporphyritic. Porphyritic. Variolitic.	
		Pyroclastics	Eruptive breccia.	Eruptive breccia. Flow breccia.	
Sedimentary	Volcanic sediments.	Eolian deposits.	Tuffs. Ash beds.		
		Water deposits.	Conglomerates.		
	Normal sediments.	Slate. Limestone.			

Each of the foregoing chief varieties will be considered separately.

ACID VOLCANICS.

The acid volcanics will be treated under the heads of the lavas and the pyroclastics.

The acid lavas occur in small quantity. They usually form isolated ridges which have a strike corresponding with that of the flows, and are believed to be interbedded with them.

The acid lavas include both massive and schistose varieties, which will be separately considered.

MASSIVE ACID LAVAS

Rhyolite-porphyry.—The massive acid lavas are all rhyolite-porphyries. Of these a portion are aporhyolite-porphyries.

Under the aporhyolites are included those acid lavas which, while now holocrystalline, are believed to have had an originally glassy base.

The acid lavas have a pronounced porphyritic texture. The quartz and feldspar phenocrysts stand out clearly from the groundmass, which is usually dense, with a somewhat resinous luster. The fresher rocks are dark grayish-blue or black, the more altered ones chocolate-brown to purplish. The weathered surfaces vary from white to reddish.

Under the microscope the rocks are found to be typical rhyolite-porphyries. The phenocrysts are chiefly corroded dihexahedral crystals of quartz. Crystals of plagioclase and orthoclase are less common. These feldspars are always somewhat altered, the secondary products being calcite, epidote, muscovite, biotite, and chlorite. The crystals lie in a fine-grained holocrystalline groundmass, composed largely of quartz and feldspar, with some zircon, and here and there magnetite. These are supposed to be the original constituents. Associated with them are considerable quantities of secondary chlorite, epidote, biotite, muscovite, calcite, and ferrite. The texture of the groundmass varies according to the mode of association of the two chief minerals, quartz and feldspar. The commonest variety is the microgranitic groundmass. A second variety is a micropoikilitic groundmass (Pls. X and XI).

The quartz phenocrysts are surrounded by zones of varying width, somewhat similar to the remainder of the groundmass. Much of the material of these zones has the same optical orientation as the phenocrysts. The quartz crystals very frequently show undulatory extinction, and oftentimes fracture planes. Along the planes of fracture are very numerous liquid inclusions, some of them with bubbles. These are clearly secondary, for, as the distance from the fracture increases, both the undulatory extinction and the number of inclusions diminish. Secondary quartz has been deposited in the crevices in orientation with the adjacent quartz. The fractures of the quartz grains extend in many cases directly across the sections. The fractures in the groundmass, as in the quartz crystals, have been cemented by secondary quartz.

In the rocks showing the micropoikilitic texture (see Pls. X and XI) the groundmass of the rocks is composed of roundish areas, the texture of which is exactly the same as that of the aureoles around the quartz phenocrysts. Many of these may be but sections through aureoles which do not chance to cut through the phenocrysts. Others of them may have no phenocryst cores. The micropoikilitic rock, therefore, appears to be very largely composed of roundish areas consisting of quartz phenocrysts with aureoles, and possibly roundish areas with micropoikilitic texture with no cores. There is no evidence that this texture, either around the quartz phenocrysts or in the groundmass, is the result of alteration since the rock consolidated, and it is therefore regarded as original.

Aporhyolite-porphyry.—The aporhyolites are intimately associated with the microgranitic rhyolite-porphyries. In every respect they are similar to them, with the exception that they show a perlitic texture, which is taken to indicate the presence of an original glass, and therefore that the rocks are aporhyolites.

SCHISTOSE ACID LAVAS.

The metasomatic alterations and some of the effects of dynamic action have already been described. Many of the porphyries have been mashed to a considerable degree. In the more extreme cases this has resulted in the obliteration of the porphyritic texture as well as the texture of the groundmass. Between these varieties in which the textures are well preserved and those in which they are destroyed there are all gradations. In proportion as the igneous textures disappear the rocks become schistose. In the more altered phases the schistose structure is marked. The phenocrysts are much shattered. The longer dimensions of the flattened crystals lie in the direction of the planes of schistosity. The quartz grains are granulated. The fractured feldspars are largely altered to quartz and biotite. The groundmass of the porphyry is made up of quartz and feldspar, between which lie leaflets of biotite and sericite. The schistose texture of this groundmass is especially indicated by the parallel mica flakes, the original texture having entirely disappeared.

ACID PYROCLASTICS.

Only a single acid pyroclastic was found. The fragments from the eruptive breccia are rounded to angular, and weather to a white color, having an exceedingly rough surface. This roughness is partly due to a perlitic parting. The matrix and the fragments alike are aporhyolite-porphyries. The phenocrysts of the fragments are larger than those of the matrix. In all other important respects both fragments and matrix are similar to the aporhyolite-porphyries already described.

BASIC VOLCANICS.

The basic volcanics include both lavas and pyroclastics.

BASIC LAVAS.

Metabasalts.[1]—The basic lavas are metabasalts. The basalts may be conveniently divided into porphyritic and nonporphyritic varieties.

The nonporphyritic basalts vary in texture from dense aphanitic kinds to medium and fine-grained varieties. The latter are usually less amygdaloidal than are the aphanitic forms. Occasionally a flowage structure is shown by the arrangement of the feldspar microlites around the amygdules. The constituents present are plagioclase, light-green fibrous hornblende, epidote-zoisite, chlorite, calcite, muscovite, apatite, sphene, quartz, magnetite, and pyrite. The feldspar, apatite, and iron oxide are the only original constituents. No measurements could be made upon the feldspar microlites, owing to their advanced alteration.

The porphyritic basalts differ from the nonporphyritic basalts only in the presence of feldspar phenocrysts. They have, therefore, a porphyritic texture. The porphyritic crystals and also the microlites determined by the Michel Lévy method appear to be labradorite, although associated with this may be some basic andesine. Associated with the feldspars there are a few phenocrysts which have been completely altered, some to uralite and others to chlorite and epidote. These possibly represent, respectively, original augite and olivine phenocrysts.

[1]The prefix *meta* is here used to indicate an altered basalt, without specifying the kind of alteration.

A single exposure of variolitic basalt was observed, and is of interest as being, so far as known, the second occurrence of variolite thus far described from North America, that by Ransome[1] being the first.

Both the porphyritic and the nonporphyritic basalts may be amygdaloidal. The minerals composing the amygdules are epidote-zoisite, biotite, chlorite, quartz, calcite, feldspar, and iron oxides. Zeolites do not occur. The amygdules are usually of lighter color than the body of the rock, and from a short distance give it the appearance of a porphyry. Where the amygdules are numerous and weather more readily than the base of the rock the exposed surface is scoriaceous, as a result of the removal of the amygdules. Where the amygdules are largely of quartz these project from the surface of the rock. In some instances hematite and quartz are so mingled as to give the amygdules the appearance of jasper, and these roundish amygdules might readily be, and indeed have been, mistaken for included jasper pebbles.

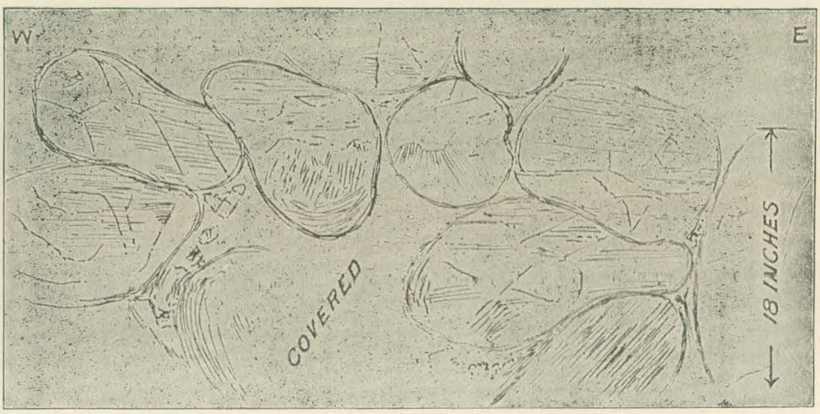

FIG. 1.—Sketch of the surface of the outcrop of an ellipsoidal basalt, showing the general character of the ellipsoids and matrix.

Both the porphyritic and the nonporphyritic basalts have undergone extensive alterations, a large part of the constituent quartz being secondary. Even in the rocks which are nearest their original condition the augite is changed to uralite, and the vitreous base, where any was present, has devitrified. Rocks in this stage of change still show the more important textural characters of igneous rocks, in many cases including those which are characteristic of glass. In a more advanced stage of change the feldspars are partly altered to a granular aggregate of various minerals. In polarized light the textures of igneous rocks are still preserved, but in ordinary light none are seen, with the exception of amygdules. In the extreme stage of alteration the rocks are green schists, showing no texture characteristic of an igneous rock. In some varieties the rocks are extensively calcified or silicified, so as to consist predominantly of calcite or quartz.

[1] The eruptive rocks of Point Bonita, California, by F. Leslie Ransome: Bull. Dept. Geol. Univ. California, Vol. I, 1893, p. 99.

Many of the lavas show an ellipsoidal parting. As a result of this, upon the flat surface of the exposures the rock resembles a conglomerate formed of round bowlders of the same kind of rock, varying from a few inches to 6 or 8 feet in diameter, lying in a sparse matrix of nearly the same color and texture as the blocks (fig. 1).

The ellipsoidal masses (Pl. VI) vary in size from a few inches to 6 or 8 feet in diameter. The ellipsoids are very fine grained, porphyritic or nonporphyritic, amygdaloidal or nonamygdaloidal. Where amygdaloidal the amygdules on the whole are more numerous near the periphery than near the center of the ellipsoids, although in some cases they are uniformly distributed. In exceptional cases the amygdules are much more numerous on the west side of the ellipsoids—that is, toward the top of the lava flows—than on the east side (fig. 2).

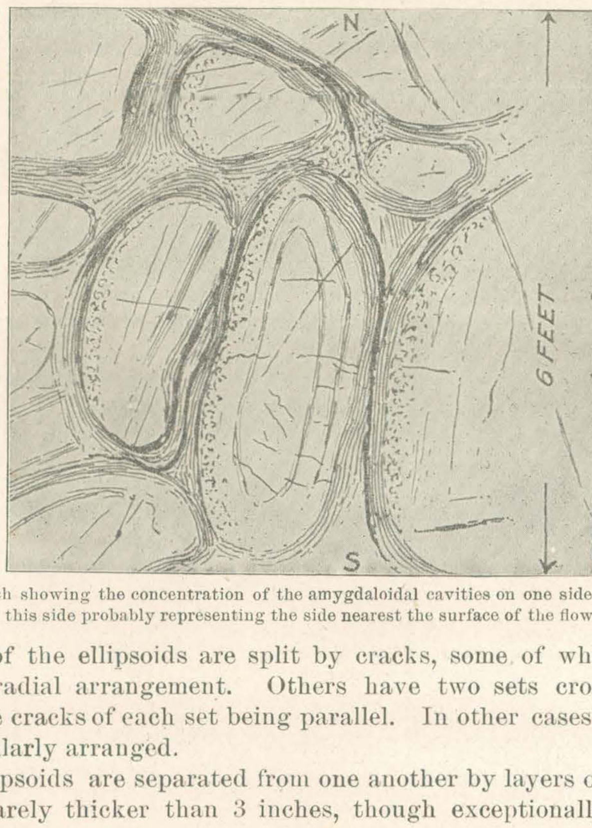

FIG. 2.—Sketch showing the concentration of the amygdaloidal cavities on one side of an ellipsoid, this side probably representing the side nearest the surface of the flow.

Many of the ellipsoids are split by cracks, some of which have a roughly radial arrangement. Others have two sets crossing each other, the cracks of each set being parallel. In other cases the cracks are irregularly arranged.

The ellipsoids are separated from one another by layers of schistose matrix, rarely thicker than 3 inches, though exceptionally nearly 6 inches thick.

In thin section the ellipsoidal blocks are similar to the ordinary basalts already described. The only point worthy of note is that the exteriors of the ellipsoids are frequently much more altered than their interiors. In cases where three blocks are in juxtaposition, one frequently finds the triangular spaces between the blocks to have within the triangle of matrix a central triangle of vein quartz. The matrix

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BASALT ELLIPSOID WITH MATRIX.

differs from the dense ellipsoids in being of a darker green color and in having a schistose structure. The schistosity is usually concentric with the ellipsoids.

In thin section the matrix of the ellipsoidal lava is entirely similar to the altered varieties of the basalts. The schistose structure is due to the parallel arrangement of the mineral constituents.

PYROCLASTICS.

The greater part of the clastic rocks has been derived from the basic volcanic rocks already described. These clastics are very characteristic of the Hemlock formation and constitute its greater part. They comprise several classes, the more important of which are the eruptive breccias, volcanic sediments, and schistose pyroclastics.

ERUPTIVE BRECCIA.

The term eruptive breccia is here used to include those clastic rocks in which angular fragments of an igneous rock are surrounded by a matrix also of igneous origin. In an eruptive breccia the fragments may be like or unlike. Likewise, the matrix may be like or unlike the fragments. Where the fragments have been rounded during the movement of the eruptive magma surrounding them the resulting rock may be called an *eruptive pseudo-conglomerate.*

Eruptive breccias are not very common in the Crystal Falls district. Where they do occur the fragments, while predominantly angular, are more or less rounded, and are similar in nature to the matrix in which they lie. Since the rocks which form them preserve the main characters of the massive lava flows which have just been described, they will not be discussed in detail. The exact method of the formation of these breccias could not be told.

VOLCANIC SEDIMENTARY ROCKS.

Under the term tuffs[1] have been very generally included all kinds of volcanic clastic rocks. This is probably due to the fact that there is frequently considerable difficulty in discriminating between eolian deposits and those which have been deposited in water. It seems desirable to make this discrimination wherever it is possible. To that end I shall in the following pages restrict the term tuff to eolian deposits. The term volcanic conglomerate, or, for the sake of brevity, simply conglomerate, will be used for those coarse deposits which have been sorted by and deposited in water and whose fragments show a roundish character. Should the fragments be angular the rocks may be called volcanic breccias.

In earlier studies[2] on Tertiary volcanics it has been found practicable to maintain this distinction, and it is also maintained in the present study of pre-Cambrian volcanics. I am confident that the same distinction

[1]Text book of Geology, by Sir Archibald Geikie, 3d ed., p. 135.

[2]Die Gesteine des Duppauer Gebirges in Nord-Böhmen, by J. Morgan Clements: Jahrbuch K.-k. geol. Reichsanstalt, Vol. XL, 1890, p. 324.

could be made more generally than it is, and that if more generally employed it would tend to greater precision in the separation of rocks of different characters. However, it is rather difficult to separate true eolian deposits of volcanic fragmentary materials from those in which the fragments have been deposited rapidly through water without having embedded organic remains and without having undergone sufficient attrition to be much rounded. More or less rounding, it is well understood, results from the attrition of the volcanic ejectamenta during their ascent and descent through the air, so that they may in this respect resemble many of the sedimentaries. The exact mode of origin of many of the volcanic fragmental deposits of the Crystal Falls district is not clear. The greater portion appear to be of true eolian origin, and where the origin of any is in doubt it has been put with those of eolian origin.

Coarse tuffs.—The coarse tuffs include rocks composed of fragments of all sizes, from the large volcanic blocks to the fine-grained particles of sand and ashes (dust) which fill the interstices (Pl. VII). The ejectamenta may be more or less rounded by attrition during their progress through the air, so that if a refinement of the nomenclature should be needed one might very properly be justified in speaking of tuff breccias and tuff conglomerates.

Tuffs are very common, and characteristic for the district. The character of the beds is best shown on the weathered surfaces. Here the scoriaceous and dense light-green fragments stand out well from the brownish-red matrix of more altered, finer fragments and cement. On a fresh surface the interstitial material usually has a darker green color than the fragments. The fragments have a prevailing green color, but many, especially in sections, are brown, much darker than any of the rocks forming the lava flows. The larger fragments are usually sharply angular, but in many cases are more or less rounded, because of attrition during their progress through the air. They are for the most part not scoriaceous, though rather commonly amygdaloidal. The macroscopically dense fragments seem to predominate, though the amygdaloidal ones do occur in some specimens in nearly equal quantity.

The fragments of the tuffs are derived from the various kinds of basalt already described as forming the lava flows.

Among the fragments some of the most typical of these rocks have been found, and, remarkable as it may seem, some of the thin sections from them show the least altered basalts.

In addition to the kinds mentioned under the basalts, there are a number which differ slightly from them, and apparently represent more glassy modifications of the basalt magma.

Owing to the fragmental nature of the exposures, it is impossible to get a correct idea of the maximum thickness of any of the tuff deposits. Exposures were seen which gave a thickness of over 500 feet for some of these deposits, but as their farther continuation had been cut off by valleys, most probably eroded in the tuffs, no means was afforded of determining their total thickness.

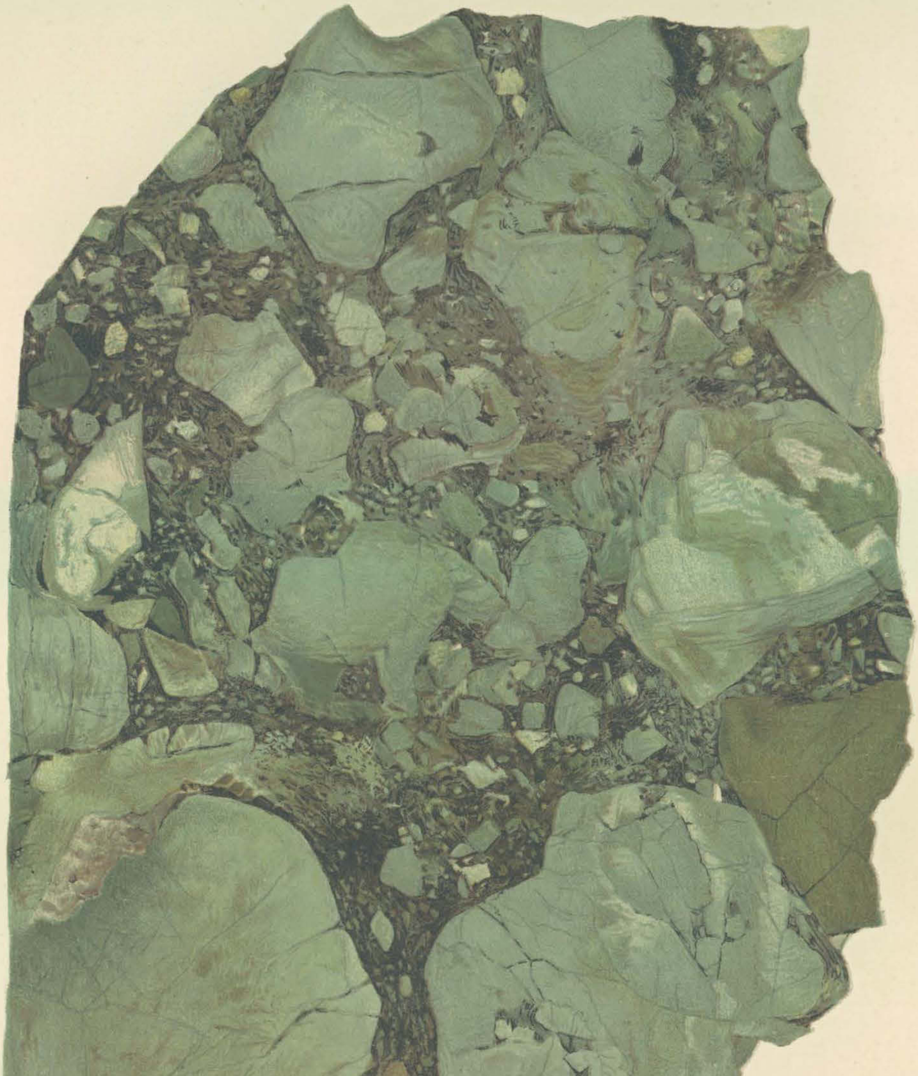
PLATE VII.

PLATE VII.

REPRODUCTION IN COLORS OF A BASALT TUFF.

This illustration is a faithful representation of the appearance of the polished surface of a pyroclastic from the Hemlock formation. It is somewhat doubtful whether or not the fragments composing the rock have been deposited through the mediation of water or of air alone. The larger fragments are rather dense. Vesicular fragments are more common among the smaller particles. Pyroclastics similar in appearance to this are of very common occurrence in the Crystal Falls district, and huge cliffs of it are readily accessible from the railroad.

Specimen No. 23644. Natural size.



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BASALT TUFF.

It is almost needless to state that most of the tuffs have undergone a great amount of alteration. The alterations were apparently due to an interchange of the various elements without essential variation in the chemical nature of the rock as a whole. Since water is the chief agent through which alterations occur, they always begin along the interstices. In the case of the fragments, the alteration accordingly proceeds from the outside inward, and ordinarily at an equal rate all around the fragment, following its contours. In this way zones of somewhat different mineralogical composition are formed, surrounding the less altered part of the fragment. This secondary zonal structure may be observed more or less imperfectly in almost any of the sections made from the breccias, but is much better shown in the field, where the concentric zones are brought out on the large weathered surfaces of the bowlders.

Fine tuffs or ash (dust) beds.—These are composed of the fine dust ejected during the volcanic disturbances. In many cases they possess well-developed cleavage, and are very puzzling in the field on account of their striking resemblance to normal subaqueous sedimentary slates. The fragments are angular, vesicular, and completely altered. The glass fragments are likewise angular, and have the characteristic sickle-shaped forms. The few mineral fragments (feldspar) are angular and rather fresh.

Relations of tuffs and ash (dust) beds.—These pyroclastics seem to predominate in the northwestern part of the district, in the neighborhood of the small town of Amasa. Especial opportunities for observing the relations between the tuff and the ash beds are offered by the third cut of the Chicago, Milwaukee and St. Paul Railway west of Balsam, Michigan. Gradation can be traced from the coarse tuffs to those delicately banded. The average thickness of a single ash bed probably does not exceed 5 feet. In the same exposures the tuff beds are from 50 to 100 feet thick, and even more.

Volcanic conglomerates (tuffogene sediments, Reyer).—That certain of the pyroclastics have been brought together and rearranged by the agency of water is made clear by their characteristic structure. Such rocks are the volcanic conglomerates. In very many respects they are strikingly like the various eolian deposits, tuffs, etc., described above. They agree with them in color. The same varieties of volcanic rocks are represented that are found in the tuffs. They are true basalt conglomerates.

In size the fragments differ from one another just as they do in the case of the eolian deposits. Many of the largest are several feet in diameter, but more commonly they vary from masses two feet in diameter to small pebbles. Associated with the larger fragments, and forming the material partly filling the interspaces and aiding in cementing them, are very fine-grained fragments derived from the trituration of the waterworn lapilli and blocks. The coarse bowlder conglomerates grade through finer conglomerates into very fine material. This fine material shows beautifully marked false bedding. The banding in the rocks is caused mainly by variations in the size of the fragments.

SCHISTOSE PYROCLASTICS.

At various places in the Hemlock formation there occur clastic rocks which have become schistose. Two isolated exposures of pyroclastics are known whose characteristics have been so changed that, while recognizable as clastics, it is impossible to say whether they belong to the eolian or the water-deposited class. Upon the weathered surface the rock is covered with brownish ocher, and on fresh fracture it is dark green and very schistose. Neither in exposures nor in hand specimens does it give any indication of its origin.

In thin section, however, one may see macroscopically the fragmental characters. The fragments are elongated and rounded. The amygdaloidal texture is also seen, showing the volcanic nature of the fragments, though the majority are dense.

THE BONE LAKE CRYSTALLINE SCHISTS.

Under this name are included certain crystalline schists which are best developed in the northern part of the Crystal Falls district, in the vicinity of Bone Lake. If one examined isolated specimens of certain of these rocks it would be impossible to determine their origin, but through studies in connection with the alteration of the altered and schistose lavas and pyroclastics already described, the problem has been very greatly simplified. These schists, as will be shown in the following pages, are but extremely metamorphosed members of the Hemlock volcanic formation. Since in the limited area in which the rocks occur the secondary characters are dominant, while the primary volcanic characters have nearly all disappeared, a brief separate description of these rocks seems warranted, but they are not represented by a separate symbol on the map.

Distribution.—The crystalline schists predominate in T. 46 N., R. 32 W. Near the western limit of this township the belt occupied by these rocks is about 2 miles wide. As it is followed to the east past Bone Lake, and then to the southeast, it gradually narrows, until, in sec. 36, T. 46 N., R. 32 W., the eastern limit of the area studied by me, it is only about half a mile wide. Except in the vicinity of Bone Lake, where erosion has uncovered some of the knobs, outcrops are very scarce, since the drift is very heavy and the drainage is poorly developed.

Field evidence of connection with the volcanics.—If we examine attentively the Hemlock formation in its typical development, beginning, say, in sec. 27, T. 45 N., R. 32 W., and following its northward extension through secs. 22, 16, and 15 of the same township, we shall observe instances of banding in the tuffs and of schistosity in the amygdaloidal lavas and pyroclastics. The strikes and dips of the primary and secondary structures approximately coincide, both having a general north-south strike, and dipping high to the west. Throughout this area, however, the unmistakable massive volcanics are the predominant rocks. Continuing our examination farther north, into sec. 34, T. 46 N., R. 33 W., we find rocks which possess almost invariably a strongly marked schistosity, but with their volcanic origin clearly shown by the flattened amygdules. This is also true for the exposures east of this place on the under side of the Hemlock belt, in sec. 31, T. 46 N., R. 32 W. The strike of the schistosity of the amygdaloids varies from N. 30° E. to N. 70° E., and the dip is high to the northwest. Farther along this belt to the northeast, in sec. 24, T. 46 N., R. 33 W., schistose pyroclastics were observed striking N. 80° E. The original characters of these pyroclastics have been almost entirely obliterated. The exposures next to the east, in sec. 16, T. 46 N., R. 32 W., possess all the characters of crystalline schists. Somewhat farther east, however, associated with these schists, are isolated outcrops in which traces of flow structure and remnants of amygdules were observed, and in some, traces of igneous textures were seen under the microscope. The schistosity of these rocks strikes for the most part to the south of east, varying from N. 65° W. to N. 80° W., and dipping to the northeast. Following the belt as it now turns to the southeast, the crystalline-schist characters prevail, the volcanic characters being obliterated. The schistosity at the same time bends farther around to the southeast, pointing toward the continuation of this area of volcanics to the southeast, outside of the area studied by me.

The field observations force on one the conclusion that these schists are metamorphosed volcanic rocks, and this conclusion is strengthened by the detailed petrographical examination.

Petrographical characters.—The crystalline schists are fine to medium grained schistose rocks, which vary in color from a moderately light green for the more chloritic phases to a very dark green or purplish black for those in which the hornblende, mica, and iron ores are prominent. The minerals of which the rocks are composed, arranged in order of importance, are hornblende, biotite, feldspar, chlorite, epidote, muscovite, quartz, magnetite, hematite, ilmenite, and rutile. Under the microscope the schistose structure is seen to be produced by the general parallelism of the bisilicate constituents. The porphyritic texture is seen in a few specimens, and hornblende forms the phenocrysts.

According to the quantity and association of the minerals above described as occurring in the schists, the following rocks have resulted from the complete metamorphism of the basic volcanics: Amphibolites, chlorite-schists, epidote-schists, mica-schists, and mica-gneisses, and possibly siliceous hematite and magnetite ore. The complete metamorphism of dense basic lava flows into crystalline schists has been described by Williams[1] for the Menominee and Marquette districts, and

[1] The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890.

for the Marquette district also by Van Hise and Bayley.[1] Williams has also described the production of schists from the igneous clastics in the Menominee district,[2] and similar products have been described from the Marquette district both by Williams[3] and by Bayley,[4] and to these the Bone Lake crystalline schists are comparable.

THE NORMAL SEDIMENTARIES OF THE HEMLOCK FORMATION.

The normal sedimentaries are in small quantity. It has been seen (p. 39) that the Mansfield slate is overlain by a conglomerate in which volcanic material predominates, but which contains partly rounded fragments of chert and slate and round quartz grains derived from the underlying sedimentaries. But for the intermingling of this normal clastic débris with the pyroclastics, the conglomerate shows nothing different from the volcanic conglomerate already described. It is a transition rock between the tuffs and the normal sedimentaries.

Similarly, in sec. 34, T. 45 N., R. 33 W., a gradation from the volcanic conglomerates to the true normal sediments occurs in the upper horizon of the Hemlock formation. These normal sediments are slates about 175 feet thick, containing lenticular masses of limestone. These beds dip 80° to the west, generally strike north, but vary in places a few degrees to the west. They are underlain by conglomerates containing well-rounded volcanic pebbles. This volcanic conglomerate grades from the coarse conglomerate up into what might be termed a water-deposited volcanic sand. The pebbles are all of volcanic material. Between the conglomerates and slates is a small area without outcrop. Overlying the slates is a succession of tuffs and lava flows.

The slates range in color from light gray and green to purplish red, and the lenses of limestone vary from cream color to purplish red. In thin section the slates are seen to be composed of a felt of sericite, chlorite, and quartz, with associated innumerable minute rutile crystals, and here and there a large spot of limpid quartz. A ferruginous carbonate is present in all of them in porphyritic rhombs. Where chlorite is abundant, the slates are a light green. Where iron oxide is abundant and the chlorite less plentiful, the slates are purplish. The character of the rock or rocks from which they were derived, whether volcanic or not, can not be determined definitely.

The lenses of limestone are rather pure, consisting mainly of calcite, with some few scattered areas of cherty silica. On the edges of the lenses some of the slate material is found forming bands in the carbonate. There intermediate phases grade on the one hand into the pure carbonate and on the other hand into the slate beds. The crust of limonite which may be seen on the weathered surface of the rock indi-

[1] Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, pp. 152-159.
[2] Bull. U. S. Geol. Survey No. 62, p. 133.
[3] Op. cit., p. 158.
[4] Mon. U. S. Geol. Survey, Vol. XXVIII, pp. 160-169.

cates that the calcite is rather ferruginous. The process of alteration is clearly seen under the microscope, where many of the grains are surrounded by rims of hydrated oxide of iron and hematite.

ECONOMIC PRODUCTS.

Building and ornamental stones.—The rocks of the Hemlock formation are not likely to be much used for building purposes. The compact basalts possess in a high degree the two essential features of strength and durability. For trimming in contrast with lighter stones they might be found desirable, and it may be suggested that they are especially suitable for mosaics in which rich greens are desired. They are of too somber a color to be used in large quantity for anything else than foundations. Moreover, the difficulty and consequent expense of quarrying them, and their remoteness from cities of large size, will operate strongly against their use.

The pyroclastics are natural mosaics, and some of them have a very pleasing appearance (Pl. VII) and are suitable for table tops, wainscoting, etc.

Road materials.—The importance of good roads in aiding in the material development of a region can hardly be overestimated, and in the building of good roads, especially in thinly inhabited regions, the proximity of good road material is of prime importance. Thus far the 15 miles of good road between Crystal Falls and the adjacent mining villages have been covered with the ferruginous chert and slates from the dumps of the mines, and unroll themselves to the traveler like red ribbons laid through the green woods.

No rock is better adapted for use in building macadamized roads than the basalt, and the Hemlock formation offers an inexhaustible supply of this. The fine-grained, compact basalts are by far the best rocks obtainable, and, other things being equal, should of course be chosen rather than the scoriaceous, and consequently weaker, facies; but these weaker kinds, and also the pyroclastics, are preferable to the cherts and slates which have been used. The cherts have been preferred on account of their hardness, but, while they are very hard and durable, the dust and sand from them possess but slight capacity for cementation. Consequently the roadways upon which quartzite and chert have been used are more likely to wash than are the roads macadamized with basalt, since the dust in this latter case serves as a cement which binds the larger fragments more firmly together. The road commissioners have thus far used very little basalt, chiefly for the reasons that no crusher was at their disposal, and the chert and slates were at hand and ready for use.

CHAPTER V.

THE UPPER HURONIAN SERIES.

The upper series of this district is connected in the northeastern part of the area with the Upper Marquette series of the Marquette district, already described in the Fifteenth Annual Report and in Monograph XXVIII. In these reports the Upper Marquette series is regarded as a part of the Upper Huronian. As has been stated, the Crystal Falls district is the southwestern extension of the Marquette district, and consequently we should expect the chief formations of the two districts to be continuous, and so they are. Because of the drift and because of a change in the character of the rocks, in mapping the western part of the Crystal Falls district it has not been practicable to divide the Upper Huronian into several formations, corresponding to those in the Marquette district. No independent name will be given to it, but it will be called simply the Upper Huronian, with the understanding that it corresponds stratigraphically to the Upper Marquette series.

DISTRIBUTION AND EXPOSURES.

Beginning in the northeast part of the area discussed by me (see Pl. II), this series covers parts of T. 46 N., Rs. 31 and 32 W., where it is only 4 to 5 miles in width. It is here a northwest-southeast syncline. From this place it stretches beyond the northern limit of the map. With slight interruptions where intrusives occur, it extends in a broad area to the west and south about the Hemlock volcanics to a point lying beyond the limit of the map. On the east side of the district it abuts against and is folded in synclines in the Archean granite.

Exposures are scanty for the greater part of the area in the Crystal Falls district underlain by the Upper Huronian series. This is due to two conditions: First, the soft character of the rocks constituting the series, and, second, the deep covering of glacial drift which is found spread over the entire district. The Upper Huronian is composed in great measure of slates, which are interbedded with much smaller quantities of graywackes and chert. The slates are eroded much more readily than the associated harder beds, and therefore we rarely find the soft slates exposed except along valleys.

THICKNESS.

Since the Upper Huronian sediments cover a broad area their thickness must be very considerable. Owing, however, to the scarcity of the exposures, it is impossible to give even an approximate estimate of it.

FOLDING.

The extreme northwestern part of the area has not been studied in such detail as to enable the minor folds to be determined. In general, the series may be said to fold around the Lower Huronian, following the general outline indicated by its color, as shown on Pl. II, and having a steep dip away from it. In sec. 20, T. 45 N., R. 35 W., large outcrops of chert are folded in a most complicated fashion and are locally brecciated. South from this point the evidence of subordinate cross folds is marked. As a result the line between the Lower Huronian and Upper Huronian is undulatory. The indentations in the Lower Huronian represent minor cross synclines and the protuberances represent minor cross anticlines.

CRYSTAL FALLS SYNCLINE.

Near Crystal Falls is the most important of these synclines. This town and a number of small outlying mining villages are situated on a syncline. The character of this syncline is shown better by the distribution of the Hemlock volcanics than by the sedimentaries, owing to the scarcity of the outcrops of the latter. The broad belt of northwest-southeast trending volcanics, situated 3 miles northeast of Crystal Falls, bends to the south in secs. 11, 12, and 13, T. 43 N., R. 32 W., and gradually changes to a slight southwest trend. In the reentrant angle of this volcanic formation is the Crystal Falls syncline, its course being that of a southwestward-opening U. The axial line of this U probably has a westward pitch, corresponding with the general folding of this part of the district.

Near the center of the U, and just a little northwest of Crystal Falls, in secs. 17 and 20, T. 43 N., R. 32 W., is an area underlain by volcanics, which trends east and west and can be followed westward into sec. 1, T. 43 N., R. 35 W., beyond the map limits. It varies in width from one-fourth mile to 4 miles, averaging about 2 miles. The contacts of these volcanics with the Upper Huronian sediments are not exposed. Hence definite proofs of their relations can not be given. Underlying the sediments the volcanics have been folded with them, and subsequent erosion has exposed the volcanics along the axis of an anticline.

The southern arm of the curved syncline bends around the extreme southern projection of the Hemlock volcanics in secs. 1 and 2, T. 42 N., R. 31 W, and north of Lake Mary swings east into sec. 32, T. 43 N., R. 31 W. Here ferruginous slates are exposed, bordering the Michigamme River at the so-called Glidden exploration. The extension east from this point of these lowermost Upper Huronian beds soon passes under the sand plains and drift hills and is lost. The higher beds of the series are, however, exposed in the lower course of the Michigamme, Paint, and Brulé rivers, which give good sections across them. In this portion of the area discussed the extension of even these higher parts of the formation can not, however, be followed farther east than the Michigamme River.

That the Crystal Falls synclinal basin is not simple, but has minor rolls, is shown by the way in which the Upper Huronian series indents the Lower Huronian at the eastern end. Also the close and complicated folding is shown by mining work, and can be nicely seen in the open pits of the Columbia and Crystal Falls mines, in the exposures in the railroad cut near the Crystal Falls mine, and also along both banks of the Paint River near the town of Crystal Falls. Pl. VIII shows the general character of this syncline. The folding has produced extensive reibungsbreccia. Near Crystal Falls, along the river bank, about one-fourth mile south of the railroad bridge, may be seen such a breccia, which has been formed at the junction of a chert with the slates.

TIME OF FOLDING OF THE UPPER HURONIAN.

The latest folding to which the rocks of the Crystal Falls district have been subjected is that which affected the Upper Huronian and likewise involved the underlying Archean and Lower Huronian rocks. Therefore the determination of this period of folding is of especial interest as marking the close of orogenic movements in this district.

Overlying the Upper Huronian is the Cambrian or Lake Superior (Potsdam) sandstone. The beds of this formation are horizontal, or else show a very slight tilting, following the general inclination of the district, which perhaps to a great extent may be explained by the initial dips of the beds. They overlie with strong unconformity the upturned and strongly plicated beds of the Upper Huronian. This unconformity marks a lapse of time represented in other districts by the following events: (1) A period of upheaval and denudation of the Upper Huronian; (2) The subsidence and deposition upon the truncated Upper Huronian sediments of the heterogeneous volcanic and sedimentary Keweenawan series; (3) The upheaval and truncation of the Keweenawan, in which movement, of course, the Upper Huronian was likewise involved in the Keweenawan areas. Subsidence of the land areas and transgression of the Cambrian sea followed, with deposition of the horizontal Lake Superior sandstone upon the inclined Keweenawan and Upper Huronian rocks. The Upper Huronian of the Crystal Falls district may have been involved in one or both of the foldings which took place prior and subsequent to the Keweenawan; or, second, since no Keweenawan deposits are known in the Crystal Falls district, it may be that it suffered an early period of powerful orogenic movement, which raised the rocks above the sea, and was synchronous with the pre-Keweenawan upheaval. A long period of erosion, accompanied perhaps by other less important orogenic movements, may have followed, contemporaneous with the activity of the Keweenawan volcanoes and the oscillatory movements of the Keweenawan region. The latter I conceive to be the most probable view. If this is correct the intense folding of the Upper Huronian sediments in the Crystal Falls district took place immediately preceding the deposition of the Keweenawan series in other parts of the Lake Superior region.

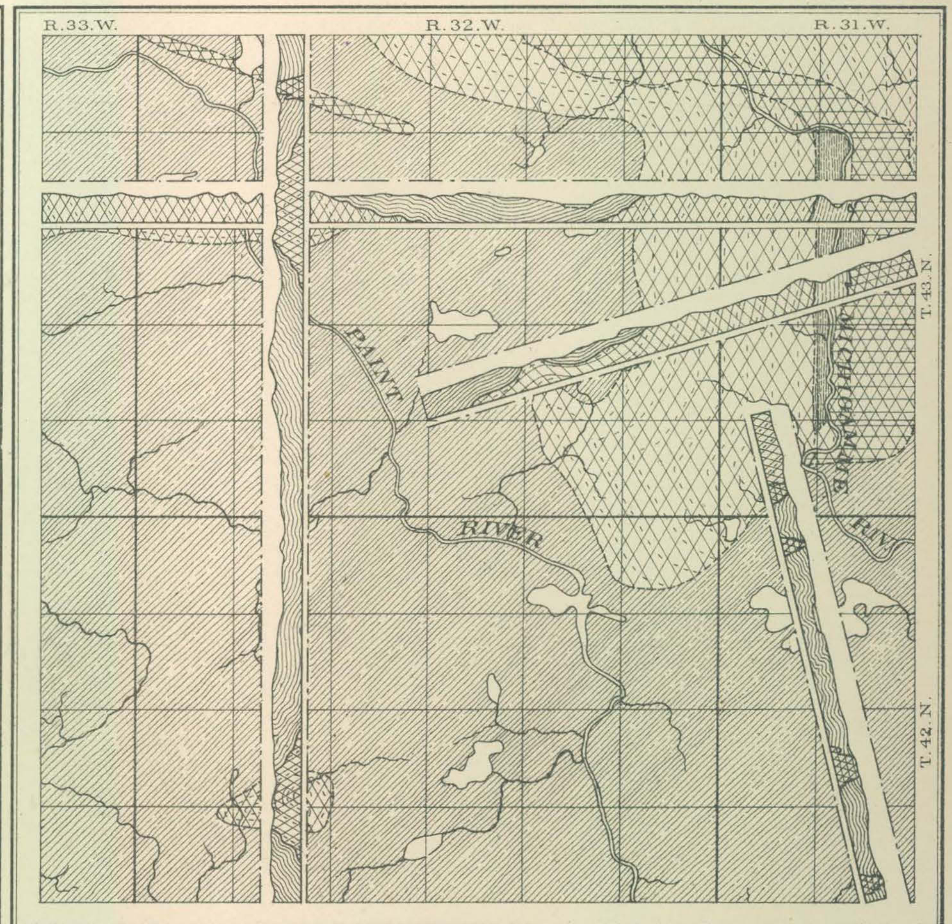
PLATE VIII.

PLATE VIII.

IDEALIZED STRUCTURAL MAP AND DETAILED GEOLOGIC MAP, WITH SECTIONS, TO SHOW THE DISTRIBUTION AND STRUCTURE OF THE HURONIAN ROCKS IN THE VICINITY OF CRYSTAL FALLS, MICHIGAN.

Idealized structural map of the vicinity of Crystal Falls. An attempt has been made to illustrate upon this map the distribution of the Huronian rocks, and at the same time our conception of the general features of the structure of this area. The drainage is merely introduced for the purpose of orientation. The topography as here represented does not agree with the true topography of the area. The bottom of the geologic basin now occupies, as the result of erosion, the highest places topographically.

Detailed geologic map, with sections, to show the distribution and structure of the Huronian rocks in the immediate vicinity of Crystal Falls. This serves as a key to the accompanying idealized structural map.



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IDEAL STRUCTURAL MAP AND DETAILED GEOLOGICAL MAP WITH SECTIONS TO SHOW THE DISTRIBUTION AND STRUCTURE OF THE HURONIAN ROCKS IN THE VICINITY OF CRYSTAL FALLS, MICHIGAN

VERTICAL SCALE OF SECTIONS - 1 INCH - 1200 FEET. ELEVATIONS OF BASE LINES - 1000 FEET ABOVE MEAN SEA LEVEL

SCALE 0 1 2 MILES

ALGONKIAN

LOWER HURONIAN — MANSFIELD SLATE, HEMLOCK FORMATION

UPPER HURONIAN — UNDIVIDED

INTRUSIVE — DOLERITE

RELATIONS TO OTHER SERIES.

It has been seen that in the western part of the district the Hemlock volcanics are the highest member of the Lower Huronian. At the end of the volcanic activity there must have taken place a very general transgression of the sea, as is evidenced by the continuous belt of sedimentary rocks which encircle the volcanics. The very marked change in the character of the rocks from subaerial volcanics to true sedimentaries partly marks the division of the Upper Huronian and Lower Huronian series. The determining points in favor of this subdivision are found in the eastern part of the district described by Smyth and in the Marquette district still farther northeast. In only one place in the eastern part of the Crystal Falls district, in sec. 26, T. 44 N., R. 32 W., has a contact between the two series been obtained. A drill hole here passed through a mottled slate just before entering the Lower Huronian volcanics. A similar slate was obtained at Amasa, overlying conglomeratic volcanic material which outcrops at the surface, but no direct contact has been found. With most careful examination I have been unable to determine whether the conglomeratic rock is a true volcanic tuff deposited upon the land or is water-deposited volcanic material, and thus possibly a basal conglomerate of the Upper Huronian.

RELATIONS TO INTRUSIVES.

The Upper Huronian, as well as the Lower Huronian, has been penetrated by intrusive rocks. The difference in the character of the intrusives of the two series is, however, interesting. As has been seen (p. 48), the Lower Huronian is cut by vast masses of basic rocks and by rare dikes of acid rocks. In the Upper Huronian intrusives of the southern part of the district the acid rocks are more abundant, but are still subordinate to the basic.

Recent work in the district has shown the Upper Huronian rocks to be unquestionably the western continuation of the Michigamme formation, to which the rocks correspond petrographically. The Michigamme formation has recently been carefully studied by Van Hise, and described by him in detail in Monograph XXVIII. A more general description is given in the Fifteenth Annual Report.[1]

Since such great petrographical similarity between the Upper Huronian deposits in the western half of the Crystal Falls district and the above formation in the adjoining district exists, and since nothing of exceptional interest has been observed in their study, the reader is referred to the papers mentioned for details. The following general description, while based upon the study of many exposures, specimens, and 75 sections of these Crystal Falls rocks, may still be considered to

[1] Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 598-604.

some extent as an abstract of the above-mentioned papers, in which the few changes made necessary by the slightly different characters have been incorporated.

PETROGRAPHICAL CHARACTERS.

The rocks of the Upper Huronian may be divided into those of sedimentary and those of igneous origin.

The preponderant deposits of the western half of the Crystal Falls district were muds and grits. With these were subordinate quantities of carbonates. In a few places sheets of basic rocks were intruded between the sedimentary beds and are now found alternating with them. Widely distributed basal conglomerates, coarse quartzitic conglomerates, and quartzites, such as characterize the lowest horizon of the Upper Huronian Ishpeming formation of the Marquette district, are absent. Work already completed outside of the immediate area covered by this report shows the presence of a small area of surface volcanics associated with the modified Upper Huronian sediments. This evidence of contemporaneous volcanic activity is closely paralleled by the Clarksburg[1] volcanics of the Upper Marquette of the adjoining district.

SEDIMENTARY ROCKS.

The sedimentary rocks of the Upper Huronian series in the western part of the Crystal Falls district are graywackes, ferruginous graywackes; micaceous, carbonaceous, and ferruginous clay slates and their crystalline derivatives; and thinly laminated cherty siderite-slate, ferruginous chert, and iron ores. With these we find in only two places rocks of a well-developed conglomeratic nature.

Some of the rocks have undergone great metamorphism, and we find the graywackes and slates passing into chlorite-schists, mica-schists, and mica-gneisses. The ore deposits of the district are associated with the least-altered sedimentaries.

The graywackes and slates are found chiefly in the northern and western parts of the district, while the single conglomerate, the metamorphosed or micaceous graywackes and slates, the mica-schists, and the mica-gneisses are confined to the extreme southern portion. The graywackes and slates of the district in general differ from each other chiefly in coarseness of grain. They are commonly interbedded in the same exposures. The rocks vary in coarseness from medium-grained graywacke to aphanitic slates, and in color from gray to green and black, the aphanitic slates being usually the darkest. These fine-grained rocks always show well-developed slaty cleavage. Throughout the area the rocks are very thoroughly consolidated, and in places where they have been most altered they are completely crystalline schists.

[1] Fifteenth Ann. Rept., pp. 604-607; Mon. XXVIII, pp. 460-486.

The iron-bearing rocks of the Upper Huronian comprise cherts, siderite-slates, ferruginous cherts, iron ores, and subordinate quantities of ferruginous graywackes and clay slates.

The least altered of these is a siderite-slate. This is a fine-grained gray rock composed almost entirely of siderite, usually in rhombohedral crystals, with very little minutely crystallized silica between them in places. Wherever they have been exposed to the weather any length of time these rocks have a deep reddish-brown oxidation crust. Alteration, also, follows along crevices, and thus the siderite is rapidly oxidized. The main products derived from these siderites are like those of the more important ore-producing parts of the Penokee and Marquette districts, namely, hematite and limonite. Little magnetite has been found. These siderites are interbanded with the black carbonaceous clay slates. In some cases the dividing line is sharp. In others, as the siderite lessens in quantity, fragmental material increases until only a few crystals of siderite are found scattered through the clastics. Their association with the carbonaceous fragmentals would seem to indicate, as pointed out by Van Hise,[1] that the siderite owes its formation to the presence of organic material.

The ferruginous cherts (the term is here used as defined by Van Hise[2]) are banded chert and hematite, with some magnetite, in which the iron oxide is derived from a previously existing siderite, and in which the cherty bands are not of fragmental origin. This alteration from the siderite to hematite may be easily followed from the fresh siderite, through that which is slightly discolored, to the reddish-brown earthy mass, and then to the crystalline hematite. Such alteration processes have been illustrated and clearly described a number of times by Van Hise, so that no further mention will be made of them.

The ferruginous graywackes may be described as rocks which are of partly fragmental and partly chemical origin. For instance, the transition may be traced from a rather micaceous magnetitic graywacke in which ordinary and false bedding may be seen, to a rather schistose rock in which magnetite is predominant, but in which there is considerable fragmental quartz and secondary muscovite and chlorite. This rock represents an original grit containing more or less siderite. Dynamic action may have changed the siderite to magnetite and produced from the fine fragmental mud the muscovite and chlorite.

Microscopical description of certain of the sedimentaries.—In the following pages I shall describe in a brief way only the graywackes and slates, which are the most common rocks of the district, and those rocks which have been produced from them by metamorphism.

The graywackes and slates consist chiefly of readily distinguishable fragmental quartz and feldspar grains, which are embedded in a matrix consisting of fine-grained quartz, feldspar (?), biotite, muscovite, chlorite, some siderite, epidote, small quantities of magnetite, hematite, and

[1] Fifteenth Ann. Rept., p. 601; Mon. XXVIII, p. 447. [2] Mon. XIX, p. 203.

iron pyrites, and a dark clayey mass. This mass appears to contain a considerable amount of black carbonaceous material and reddish-brown ferruginous matter in finely disseminated specks. The greater the quantity and the finer the character of this matrix the more difficult it becomes to determine its constituents with any degree of certainty. In the slates the matrix plays the chief rôle, while in the graywackes the large fragmental grains form the predominant material. By a diminution in quantity of the matrix and fragmental feldspar grains the coarser-grained clastics approach very closely to true quartzites, but in no case was a pure quartzite found.

The constituents which can be recognized without difficulty as original ones are the larger grains of feldspar and quartz. These show pressure phenomena of all grades, from slight wavy extinction to complete granulation. Many of the large fragmental quartzes are mashed into oval-shaped areas or are broken into numbers of fragments. The large feldspars are broken and are altering to quartz and secondary clear feldspar with a simultaneous production of epidote and mica. In their least-altered condition the original feldspars are cloudy, and hence may be readily distinguished from the limpid secondary grains.

The small mineral particles of the matrix which include the mica do not show undulatory extinction, like the large fragmental quartzes and feldspars. These micaceous minerals are in automorphic plates and wrap around the quartz grains, and in some cases likewise project into them. These constituents of the matrix are all believed to be secondary minerals derived from the original clayey matrix and from the alteration of the feldspar fragments, with the possible addition of infiltrated material. At places all of these minerals occur together, but more commonly one finds various combinations of certain of them. When muscovite is present in large quantity it is usually not accompanied by biotite or chlorite, the iron and magnesium necessary for the production of biotite and chlorite evidently not being present. These last two, however, are always associated. As the mica increases the schistosity of the rock increases in a corresponding manner, and the rocks become what may be spoken of as micaceous graywackes.

These micaceous graywackes represent a somewhat more advanced stage of metamorphism of the rocks than the graywackes just described, and the extremely altered varieties of them are very close to the mica-schists and mica-gneisses, according to the respective amounts of secondary feldspar present. No distinction, however, can be made in the field between some of the less metamorphosed graywackes and these micaceous ones. The chief difference appears to be in the fact that in the micaceous graywackes the larger feldspars are almost completely altered and the finer matrix is completely recrystallized into readily distinguishable mineral particles. In these more metamorphosed rocks the parallel intergrowth of secondary muscovite and biotite is nicely shown, a thin leaf of biotite being included between two lamellæ of muscovite. A considerable quantity of epidote is scattered in large grains through the micaceous graywackes, besides occurring in aggregates of small grains. Some crystals of apatite and tourmaline were observed. Rutile is found in some quantity, and with it is also sphene, both of them possibly resulting from the alteration of titanium-bearing iron ores in the original graywackes. The iron present in the original graywackes as siderite and the minute specks of oxide have been collected into large crystals of magnetite and also into aggregates of smaller, well-defined magnetite crystals.

The highly metamorphosed micaceous rocks included under the general term micaceous graywackes have the interlocking groundmass texture of the schists, but some of the larger grains show clastic forms. No sharp line can be drawn between these metamorphosed sediments on the one hand and the mica-schists and mica-gneisses on the other.

In the mica-schists and mica-gneisses all of the original mineral grains have been completely crushed and recrystallized, and we can find no microscopical criteria which enable us to class them with the sedimentary rocks. Dynamic action in the district had sufficient power and duration locally to complete the metamorphism of the original sedimentaries and produce perfectly crystalline schists, as described by Van Hise in the Penokee and Marquette districts.[1] These crystalline schists are throughout moderately fine grained, and consist of quartz, feldspar, and mica, with associated epidote, rutile, tourmaline, and iron oxides, and in a few exceptional cases crystals of staurolite and garnet. In some of the rocks quartz and mica are preponderant and feldspar is practically wanting, and we have mica-schists. In others all three are essential minerals, and we have mica-gneisses. The presence of the feldspar, and to some extent the proportion of the mica and other minerals, depend upon the character of the original sediments. Conclusive evidence of the sedimentary origin of these schists is furnished by their occurrence in the field, where are found all gradations between them and rocks of unquestionably sedimentary character.

IGNEOUS ROCKS.

The igneous rocks which are found to have penetrated the Upper Huronian after the important folding of the rocks took place are not included here, but may be found described under the heading of intrusives (pp. 82–84). In this place I wish to call attention to certain hornblende-gneisses which occur near Norway portage, on the Michigamme River, and also extend in large outcrops west of the river for about 2 miles and east for about a mile. These are interlaminated in thick masses with the mica-schists. They are perfectly crystalline hornblende-gneisses, consisting of common hornblende, quartz, feldspar, and some iron oxide. The hornblende is present in large quantity, the parallel plates of that mineral giving the rock its schistosity. None of the minerals are automorphic, but all occur in interlocking grains.

[1] Mon. U. S. Geol. Survey, Vol. XIX, 1892, pp. 332-342; also Mon. XXVIII, 1897, pp. 449-450.

Without going into a detailed description of these schists it will suffice, perhaps, to state that they are similar in all respects to schistose hornblendic rocks, which in other parts of the Lake Superior region have been traced into igneous rocks.[1] These schists are believed to be basic igneous rocks, either intrusives which were injected parallel to the bedding of the Upper Huronian sediments prior to the folding or else contemporaneous volcanics. They have been metamorphosed and rendered schistose by the same forces which metamorphosed the sediments. This explains the perfect agreement of their schistosity with that of the adjacent sediments.

ORE DEPOSITS.

HISTORY OF OPENING OF THE DISTRICT.

For a number of years after the opening of the mines of the Menominee range prospectors worked in various places northwest of that range, seeking to follow the iron range west of the Menominee River. As a result of this endeavor, the deposits at Florence, and then those farther north and west at Crystal Falls, were in turn located. It was not until 1881 that sufficient exploratory work had been done at Crystal Falls to warrant a belief in the future of this iron-bearing area. In April, 1882, the Chicago and Northwestern Railway completed its branch to Crystal Falls and the shipment of ore began. The Amasa deposits were not exploited to any great extent until the year 1888, when the Chicago and Northwestern Railway built a branch from Crystal Falls to Amasa. The Chicago, Milwaukee and St. Paul Railway in 1895 completed a line from Channing to Sidnaw, which runs through Amasa.

DISTRIBUTION.

The iron-bearing rocks trend northwest-southeast from Crystal Falls. East of Crystal Falls some of the ore deposits are found in proximity to the Hemlock volcanics, and extend along a line located a short distance from them. Other deposits are those at Amasa, about 12 miles northwest of Crystal Falls. These are near the contact between the Upper Huronian and the Lower Huronian, and above the Hemlock volcanics, like the deposits east of Crystal Falls. Four miles north of Amasa are the explorations in sec. 20, T. 45 N., R. 33 W., in which the iron-bearing beds are exposed. Another exposure of the iron-bearing formation is in sec. 34, T. 46 N., R. 33 W., about 4 miles farther north. These are the northernmost known exposures of the iron-bearing rocks of the Upper Huronian in the Crystal Falls district. However, dial-compass and dip-needle work has located a line of magnetic attraction for about 12 miles to the north and east. By means of this line of magnetic attraction, and with the assistance afforded by occasional outcrops of Lower Huronian Hemlock volcanics, the possible continuation of the iron-bearing belt was approximately located.

[1] Bull U. S. Geol. Survey No. 62, by G. H. Williams, 1890; Mon XXVIII, 1897, pp. 152–159, 203, 208.

I shall take up the four localities mentioned in which iron ore has been found and discuss them in some detail, beginning at the north and least important and passing to the south and most important parts of the district.

Western half of sec. 34, T. 46 N., R. 33 W.—In the western half of sec. 34, T. 46 N., R. 33 W., there are outcrops of a magnetitic graywacke that grades into a rock which might properly be called a magnetite-schist but for the fact that its partial fragmental nature is still very apparent. The rock contains a varying quantity of magnetite, always enough to exercise a very great influence upon the magnetic needle. However, in no case have true ore deposits been found in it, although the rock has been extensively test-pitted. The strike is in general north-south, with a high dip to the west, thus agreeing with the trend of the Hemlock volcanics. The highest outcrop of the volcanics is a schistose amygdaloid. After an interval of no exposure of about 30 feet graywacke appears, and this grades up into the magnetitic beds.

Sec. 20, T. 45 N., R. 33 W.—To the south, in sec. 20, T. 45 N., R. 33 W., are outcrops of ferruginous cherts, which in places contain "bands and shots" of ore, the thicker bands being 1½ inches across. These outcrops have tempted prospectors to do considerable exploring by means of both test pits and diamond-drill holes. The results have been negative. The general map, Pl. II, shows that the Upper Huronian at this place indents the Lower Huronian series, indicating, as has already been said, the presence of a westward-pitching syncline. The presence of this syncline is further shown by the strike obtained on the outcrops of chert found at this locality. The greater part of the northern ledges give an east-west strike, with a variation of but a few degrees to the north of east. The southernmost outcrops show a strike which varies from N. 27° E. to N. 34° W., for the most part a nearly north-south strike prevailing. The dip is in all cases high, ranging from 80° to 87°. The severe deformation is clearly shown by the plication of the beds and by faults whose extent can not be determined, but which are accompanied by rather extensive reibungsbreccias. The breccias are cemented by iron oxide and quartz.

The Amasa area.—The Amasa deposits must of necessity be very briefly described, as I have been unable to obtain much information concerning the relations of the rocks as shown in the closed mines. The section (see fig. 3) from west to east—i. e., from the higher to the lower beds—obtained in two drill holes, is as follows:

Section of the Amasa area.

	Feet.
Gray sericitic slate, discolored by iron	115
Chert and jasper	59
Pyritiferous black slate and quartzite	180
Ore formation	30½
Magnetitic slate	42
Mottled slates, red and green, containing iron. Drilling ceased after passing through	70

The beds protruding at the surface are found to be immediately underlain by greenstone, in places massive, in others tuffaceous.

The foot and hanging slates are very much alike, the hanging, however, being very pyritiferous, and the foot containing much more iron than the hanging. This iron is in the form of hematite and magnetite. Below the black magnetic slate is the ferruginous mottled slate, which apparently lies next to the Lower Huronian Hemlock volcanics. The so-called ore formation consists of banded chert and jasper, with which the hematite bodies are associated.

The Crystal Falls area.—The most of the observations upon the ore bodies and their relations to surrounding beds have naturally been made in the vicinity of the town of Crystal Falls, where, owing to the extensive development of the mines, the underground conditions could best be studied. The conclusions reached, however, are confidently believed to hold good for the entire Upper Huronian of the district.

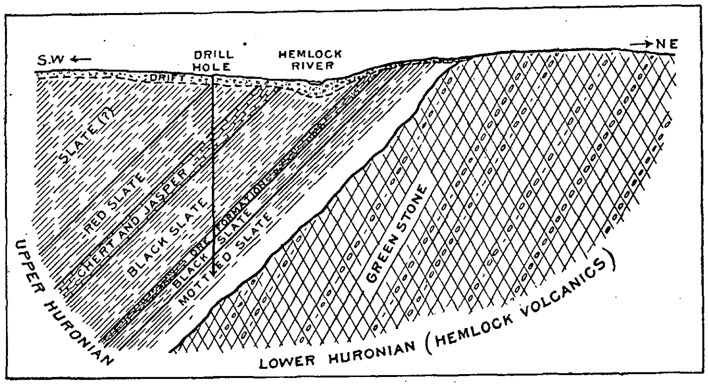


FIG. 3.—Profile section illustrating results of diamond-drill work.

In the description of the folding of the Upper Huronian it was stated that the Crystal Falls area is in a synclinorium, forking, as the result of a subordinate central anticline, so as to produce a U opening to the south of west. It is in this basin that the important mines of the Crystal Falls district are situated. One row of mines lies to the west and northwest of the main mass of Hemlock volcanics. A second and more important set of mines follows an east-west line south of the subordinate area of volcanics, which lie just north of Crystal Falls, in the midst of the Upper Huronian sediments.

The second set of mines, including the Crystal Falls, Great Western, Lincoln, Paint River, Lamont, Youngstown, and Claire, lies near the axis of the syncline—that is, along the line of major folding, and consequently greater mashing. The Columbia, Dunn, Mastodon, and others to the west are probably the western continuation of this line of mines, and follow the trend of the main synclinal axis of the district. The position of these mines with reference to the main structural features of the district may be seen on the structural map and the detailed map which serves as a key to it, Pl. VIII.

The section made through the closely folded Upper Huronian beds by the Paint River affords the best opportunity in the district for studying the rocks, but the rocks are so crumpled that even here the succession was not made out with certainty.

The sketch, fig. 4, by W. N. Merriam, shows the folding of the slate and chert strata as seen in the railroad cut between Paint River and the Lincoln mine. The strike of the rocks is about N. 80° E. The sketch is taken looking almost along the strike of the beds. In fig. 5 a

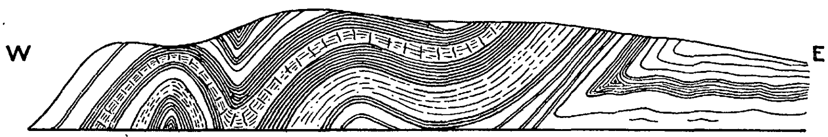


FIG. 4.—Sketch illustrating contortion of Upper Huronian strata.

second sketch is given, also by W. N. Merriam, which illustrates the rapid change in strike in these beds, due to the contortion of the strata.

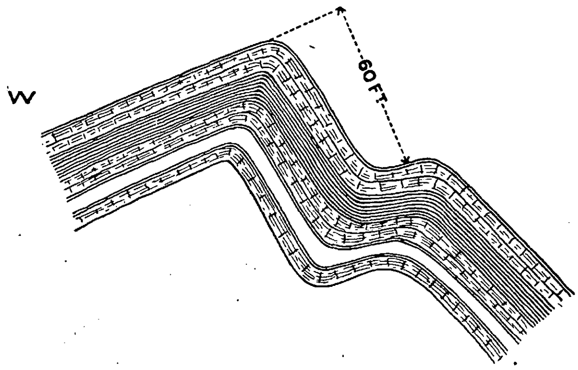


FIG. 5.—Sketch showing change of strike of Upper Huronian beds, due to the folds.

This change is seen near the east end of the wagon bridge, just across the Paint River from Crystal Falls.

CHARACTER OF THE ORE.

The ore obtained from the Crystal Falls district is chiefly soft red hematite, though in places it is hydrated and graded as brown hematite (limonite). The ore is very porous and shows many crystal-lined cavities. At places a hard steel hematite ore is found, which runs as high as 70 per cent metallic iron and is almost hard enough to scratch quartz. This ore occurs in very small quantity, associated with the soft ores, and appears for the most part to have formed in geodal cavities. When the cavities are still partly open the ore has botryoidal and stalactitic forms.

The ores are very similar to those of the Michigamme slates of the Upper Marquette series, but differ very considerably from those of the Lower Marquette series, in which the hard hematites and magnetites are important ores, and from the ores of the Menominee district, which produces large quantities of soft blue hematite, some martite, and also some specular ore.

With one exception the ores are too high in phosphorus for Bessemer ore, and the one exception is just within the limit.

The following figures show the average composition of the ores for the district. They were taken from analyses furnished by the management of the various mines and from the reports of the State commissioner of mineral statistics of Michigan.

The metallic iron of the ores ranges from 54 to 63 per cent, averaging about 59 per cent. Phosphorus in exceptional cases is as low as 0.05 per cent, though usually ranging from 0.1 to 0.7 per cent, most commonly approaching the higher figure. Silica averages about 3 per cent. These analyses show the ore to be rather low grade. It is due to this that this district has been so sensitive to the prices of iron ores. A low market price makes the cost of production exceed the selling value, and under these conditions work necessarily stops.

RELATIONS TO ADJACENT ROCKS.

The ore is associated with white or reddish chert, which in places is jaspery. The cherty iron formation passes into ore by a decrease of the silica. An intermediate phase is chert with "bands and shots" of ore. In places the chert is more or less brecciated, and the ore often has a similar character. Commonly the ore is completely surrounded by the chert beds, or chert and ore, forming the so-called mixed and lean ore. In such cases they form both the foot and the hanging walls of the ore body, but the ore-bearing chert formation is always associated with black carbonaceous slates, which constitute the base on which the ore-bearing formation rests. In the Youngstown mine 3 feet of so-called "graphite" was passed through before the usual carbonaceous slates were reached.[1] The hanging wall is also carbonaceous slate. At places thin quartzitic beds which approach a true quartzite are associated with the slate.

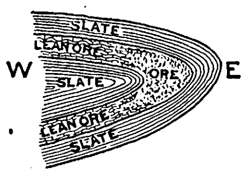


FIG. 6.—Sketch to illustrate the occurrence of ore bodies.

The ores occur in the cherts in pockets and lenticular masses, which always agree in greater dimensions with the strike of the beds with which they are associated. The lenticular character is well shown in the Dunn, Columbia, and Great Western mines. In the Dunn mine the bodies overlap. In the Great Western mine in 1887 seven different ore bodies in an east-west line, separated by areas of barren rocks, mostly slate, were being mined. In following these isolated ore bodies to the east, at various places they are found to turn around a horse of rock. Their occurrence is illustrated by fig. 6, a horizontal section.

[1] This information was furnished by Mr. C. T. Roberts, of Crystal Falls. It was not possible to obtain a specimen of the graphite for examination.

Evidently the ore bodies accumulated in westward-pitching synclinal troughs, in which the hanging wall appears to the miners as a horse of rock.

The ore bodies in general pitch to the west at varying angles, corresponding to the pitches of the axes of the synclines in which they occur. The pitches of these folds in turn correspond to the western pitch of the Crystal Falls synclinorium, of which the secondary synclines containing the ore bodies are a part. A typical example of the occurrence is shown in the Armenia mine ore body, which is found, according to Van Hise,[1] "at the bottom and on the sides of a synclinal trough, pitching at an angle of about 45°." The trend of the axis is to the south and west.

The dip of the ore bodies is always steep, and generally to the south, but varies in places to a few degrees north.

ORIGIN.

The fact that the important mines in the district are located in a synclinal basin and that they all possess an impervious footwall of black slate gives very clearly the reason for their existence and indicates their mode of origin. They are concentrates in synclinal troughs.

In the Marquette and Penokee-Gogebic districts the ore bodies are very frequently found associated with dikes of dolerite (diabase) which have been altered to "diorite"-schists and so-called soapstone or paint rock. Only one such association is known for the Crystal Falls district. Wadsworth mentions[2] having seen a dike in the Paint River mine.

In the field notes of the Lake Superior Survey for 1891 I find the statement that "the strata of the ore formation, which here strike nearly east and west, are cut by an eruptive dike which runs about northwest and southeast. This dike hades to the west and forms with the hanging slates of the ore formation a trough pitching to the west at a very steep angle. In this trough is situated the ore body upon which the Paint River and the Monitor[3] mines are working." This ore body is stated to be about 100 feet wide, 300 feet long, and of unknown depth. When I was in the district the mines were closed, or were shipping only from stock piles, so that I had no opportunity of verifying this observation. From the above statement it appears that in this particular case the ore is due to the presence of this dike, as it occurs in a pitching trough formed by its junction with the impervious slate. These same relations are well known to be the cause of similar occurrences in the Lake Superior districts above mentioned.

The original rock from which the ores were formed was cherty iron carbonate, which in many places is found associated with the iron-bearing formation. The cherty carbonate shows the various stages of alteration from the compact cherty siderite to the banded ore and chert

[1] Iron ores of the Marquette district of Michigan, by C. R. Van Hise: Am. Jour. Sci., 3d series, Vol. XLIII, 1892. p. 130.

[2] Sketch of the geology of the iron, gold, and copper districts of Michigan, by M. E. Wadsworth: Rept. State Board of Geol. Surv. for 1891-1892, 1893, p. 108.

[3] Now known as Lamont mine.

rocks which form the nuclei for the addition of the iron obtained from the higher extensions of the beds. Percolating waters have been the agents in this process of replacement and concentration. Consequently, where the rocks have been most shattered we find the water is especially active. Hence it is, also, that we find the deposits in this closely folded part of the Upper Huronian.

As to the origin of the cherty carbonate itself we know nothing definitely. Its association with the carbonaceous slates would indicate the agency of organic matter in its production, possibly in some such manner as is rather generally accepted for the formation of the Carboniferous carbonate ores. The Upper Huronian ores, as well as the Lower Huronian, are supposed to have been formed in this way and from the same kind of rock. Under the consideration of the Lower Huronian ores (p. 43) these points were discussed and references were given to the literature, and the reader is referred to that discussion for further details.

SIZE OF THE ORE BODIES.

No definite general statement can be made as to the size of the ore bodies, as this varies considerably. None of the bodies which are being worked, so far as I can learn, are less than 30 feet wide. In one of the old mines crosscuts disclosed a width of nearly 200 feet. This same ore body is known to be at least one-fourth mile long.

METHODS OF MINING.

The first development of the iron ores of the district was by the stripping and open-cut methods, very few resorting at once to underground work. At present all work in the district is underground. Thus far the work has not been carried to very great depth, the two deepest mines, the Great Western and Dunn, having reached a depth respectively of 700 and 720 feet.

In the early days of the district an extensive system of timbering was resorted to; but as this item became increasingly burdensome, owing to the increase in the value of timber, the system of filling was resorted to where practicable (Mastodon) or the system of caving was employed. At the present time most if not all of the important producers are mined with open stopes, pillars being left where necessary.

PROSPECTING.

Owing to the impossibility, with our present knowledge, of mapping the individual beds of the Upper Huronian, it is not possible to give directions with reference to the exact lines which should be followed in prospecting for ore. However, since those areas which are underlain by eruptives have been delimited, there is no longer any excuse for wasting time and money in prospecting in these unpromising portions of the district. Where indications point to considerable rock movements and where the sideritic rocks are found associated with impervious slates explorations are warranted.

CHAPTER VI.

THE INTRUSIVES.

Under this general head there is here included a very varied assortment of rocks exhibiting in common intrusive relations to sedimentary and igneous rocks. This division is used merely because it simplifies the classification of the rocks of the district, and the term intrusives is not to be interpreted as synonymous with the "dike rocks" (ganggesteine) of some authors, a petrographical division which, in the opinion of the writer, is not warranted.

These intrusive rocks differ very materially, in field occurrence, petrographically, and in point of age, from the igneous rocks thus far described. In age much younger than the volcanics, they still bear a close resemblance to some of them; indeed, some forms are identical in character. Massive granular rocks are the common forms. Porphyritic varieties are very subordinate.

The rocks are all considered as intrusives into either the Lower or the Upper Huronian. In most cases the intrusive relations may be said to be rather inferred than demonstrated, for the direct contacts have been observed in very few cases. However, where isolated sets of knobs of eruptive rocks are found in areas the greater portion of which are underlain by sedimentaries, the natural inference is that they penetrate these sedimentaries. Where isolated sets of knobs are composed of the same kind of rock or show variations of the same type, they may be presumed to be connected. For the most part the dikes and bosses are too small to admit of being indicated on the accompanying map. Wherever their size has warranted it they have been represented, as in the case of the acid intrusives between the Paint and Michigamme rivers and of the basic intrusives north of Crystal Falls.

AGE OF THE INTRUSIVES.

The intrusives have forced their way through the Lower and the Upper Huronian sedimentaries, but have never been found to penetrate the horizontal Lake Superior Cambrian sandstone. These facts alone are conclusive proof that their period of intrusion falls in the lapse of time between the deposition of the Upper Huronian and that of the Upper Cambrian.

In the discussion of the time of the folding of the Upper Huronian the conclusion was reached (p. 66) that this folding took place preceding the deposition of the Keweenawan series. If the intrusives to be described had existed at that time of folding, they must certainly have suffered from the orogenic movements. Examination of the exposures of the intrusives has not shown schistose masses, nor has detailed microscopical study disclosed the cataclastic textures which accompany powerful dynamic movements, except in one case. Such being the facts, the conclusion follows that the intrusives were introduced subsequent to the folding of the Upper Huronian or are of Keweenawan or of post-Keweenawan age.

A closer approximation to the age of the intrusives is not possible, unless we rely upon lithological similarity. The dolerites of the Crystal Falls district are similar to those forming the flows and dikes of the Keweenawan on Keweenaw Point. They are also similar to the basic intrusives of the Marquette district, with which this district is practically a geological unit; and likewise they agree petrographically with the dolerite dikes of the Penokee-Gogebic district. In both districts the late intrusives have been considered to be of Keweenawan age.[1] While correlation by means of petrographical similarity would not be held for widely separated areas, it seems to be well worth considering for areas which are so closely connected as are the iron districts of the Upper Peninsula of Michigan.

Judging from the evidence thus presented, the dolerites of the Crystal Falls area are probably contemporaneous with the intrusives of the Penokee-Gogebic and Marquette districts and the volcanics of the Keweenawan.

RELATIONS OF FOLDING AND DISTRIBUTION OF THE INTRUSIVES.

In the preceding chapter, in the sections on folding of the Upper Huronian (p. 65), it was shown that the main folds of the district follow an approximately northwest-southeast course, and that upon these are superimposed minor folds approximately at right angles to these. The lines of weakness parallel to the axes of the main folds have been taken advantage of by certain of the intrusives, especially the dolerites.

A glance at the map (Pl. II) shows that the dolerite dikes which have been traced for considerable distances—that is, those that are more than great knobs uncovered by erosion—have a northwest-southeast trend, in agreement with the general direction of the major folding of the district. The only apparent exception is that part of the great mass in sec. 43, T. 31 N., R. 32 W., which extends north and south along the Michigamme River, but this is really not an exception, since the folds of the Mansfield slates here run in the same direction.

As this abstract has already become long, no description of the various intrusives will be attempted. In the monograph a full and careful description of the rock facies and a discussion of their relations and gradations are made.

[1] Mon. U. S. Geol. Survey, Vol. XIX, 1892, p. 349; Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p, 218.

The intrusives comprise rocks of acid, basic, and ultrabasic composition, represented respectively by the granites, the dolerites and basalts, and the picrite-porphyries.

The acid intrusive rocks may be divided into ordinary biotite-granite (granitite) with a micropegmatitic variety, and muscovite-biotite-granite.

The basic intrusives are represented by the dolerites and basalts. The dolerites are the most important.

Basalt has been described at length under the volcanics, where it plays an exceedingly important rôle. Basalt as a dike has been found in only two places.

The picrite-porphyries occur in isolated outcrops of comparatively small size.

Beginning near the town of Crystal Falls in isolated knobs, and extending southeast toward the Michigamme River, where the exposures are larger and better connected, is found a series of rocks whose characters are of much interest.[1]

These rocks are all intrusive in character, and, with few exceptions, are medium to coarse grained; and while the granitic texture is predominant, there are certain facies in which the texture is parallel and even porphyritic. They have been only slightly affected by dynamic action, and in purely local cases. Analyses show them to vary in chemical composition from those of intermediate acidity to those of ultrabasic character.

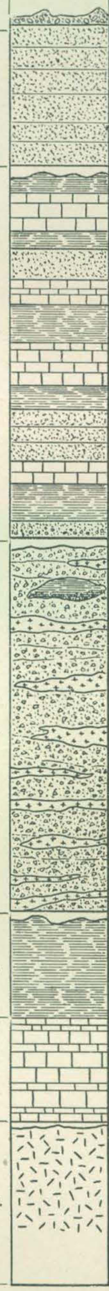
The prevailing rock types are, on the one hand, diorites of intermediate acidity, ranging to more acid rocks, tonalites, quartz-mica-diorites, and granite (plagioclastic); and, on the other, hornblende-gabbro, gabbro, norite, and lastly, peridotite of varying mineralogical character. The rapid changes in mineralogical composition and texture in a single rock and the changes from one facies into another, show very clearly the intimate relationship of these rocks to one another, and warrant the assumption that they all make up a geological unit.

Granite is present as a local facies of the diorite. However, it is very subordinate in quantity and not altogether typical, and as no analysis has been obtained, its position is still more or less doubtful.

In the full paper the thesis is maintained that a magma has separated into the various products mentioned. This is indicated by the relations in the field, by the microscopical study, and by chemical analyses.

[1] A study of some examples of rock variation, by J. Morgan Clements: Jour. Geol., Vol. VI, 1898, pp. 372–392.

Period.		Formation name.	Formation symbol.	Columnar section.	Thickness, in feet.	Character of rocks.
Pleistocene.		Glacial drift.				Usual characters.
Cambrian.		Potsdam sandstone.	€p.		?	Thickness unknown. Yellowish to reddish brown sandstone, not thoroughly cemented, therefore disintegrates readily. Found in patches in many places, and always lying either in beds which are horizontal or else possess slight dip to the south. This may represent the initial dip with which the beds were deposited.
Algonkian.	Upper Huronian.	Undivided.	Au.		?	A series of very great but unknown thickness. It consists of alternating beds of slates, graywackes, siderite, and chert. With these, especially associated with the last two, are found hematite and limonite ore bodies of variable size and of great economic importance. From this series is derived nearly all the ore supplied by the Crystal Falls district. In the southern part of the district, especially well exposed in the vicinity of the Paint and Michigamme rivers, the slates and graywackes have been metamorphosed into schists and gneisses. This series is cut by dikes of rock ranging from acid to ultrabasic, which have, in places, metamorphosed the sediments.
Algonkian.	Lower Huronian.	Hemlock.	Alh.		?	The thickness of this vast pile of volcanic ejectamenta can not be estimated with any degree of accuracy. It consists chiefly of interbedded acid and basic lavas and associated tuff deposits, and the water-deposited materials derived from them. Near the top of the volcanics a lenticular area of normal sediments, slates with lenses of limestone, is found. This formation is cut by acid and basic dikes.
Algonkian.	Lower Huronian.	Mansfield slate.	Alm.		1500	Estimated to be about 1,500 feet thick. It consists of interbedded fragmentals, slates, and graywackes and, associated with these, ferruginous chert and carbonate. From these last has been derived the ore found associated with them. The Mansfield mine, by which is exploited the only ore body in the Mansfield formation, supplies the only Bessemer ore of the Crystal Falls district. These slates are cut and metamorphosed by basic dikes.
Algonkian.	Lower Huronian.	Randville dolomite.	Alr.		1500	The thickness is that estimated for this formation in the eastern part of the district by Smyth. The prevailing rock is quartzose dolomite, of a very friable character.
Archean.		Granite.	Ægr.			It shows the usual characters of granite. It is schistose on flanks of massif, and is cut by acid and basic dikes, which are massive and schistose.



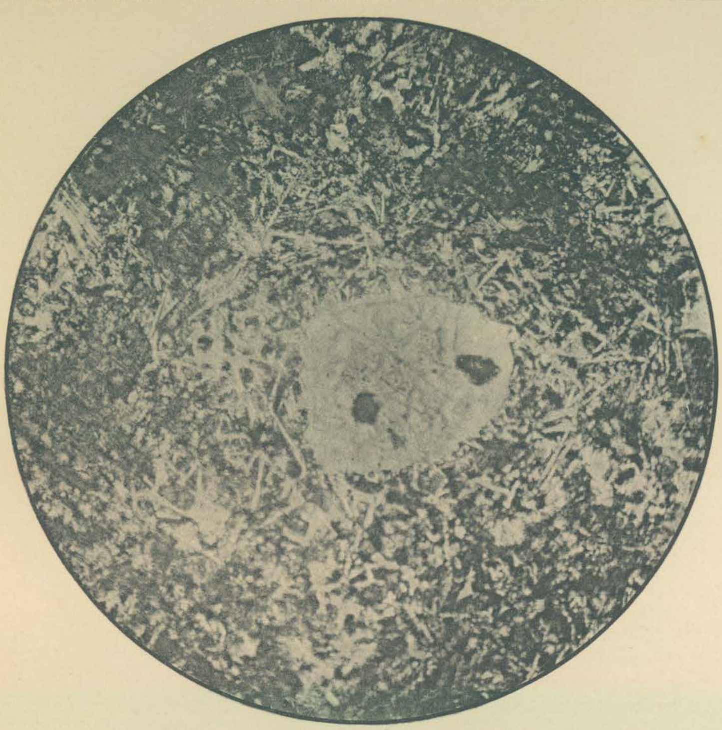
GENERALIZED COLUMNAR SECTION.

PLATE X.

PLATE X.

A. Micropoikilitic rhyolite-porphyry, showing the peculiar texture of the zones which invariably surround the quartz phenocrysts in sections in which the texture occurs. The same texture prevails in the groundmass. The irregular white areas which are continuous with the quartz phenocrysts and are connected with one another represent quartz. Disconnected dark and light areas between the quartz stringers are feldspar grains. These do not possess uniform orientation, hence the texture is not micropegmatitic. Specimen No. 32119. With analyzer, × 90.

B. Photomicrograph of micropoikilitic rhyolite-porphyry. In this rhyolite-porphyry the micropoikilitic texture is much finer than that represented in fig. 1, and the quartz in the zones shows a tendency towards spherulitic development. Owing to the extreme fineness of grain, it is difficult to distinguish the quartz and feldspar in many cases. The greater part of the light areas shown in the photomicrograph are quartz. The dark areas between the quartz, and also some of the lighter areas, represent irregular pieces of feldspar. Specimen No. 32137. With analyzer, × 90.



(*A*)

(*B*)

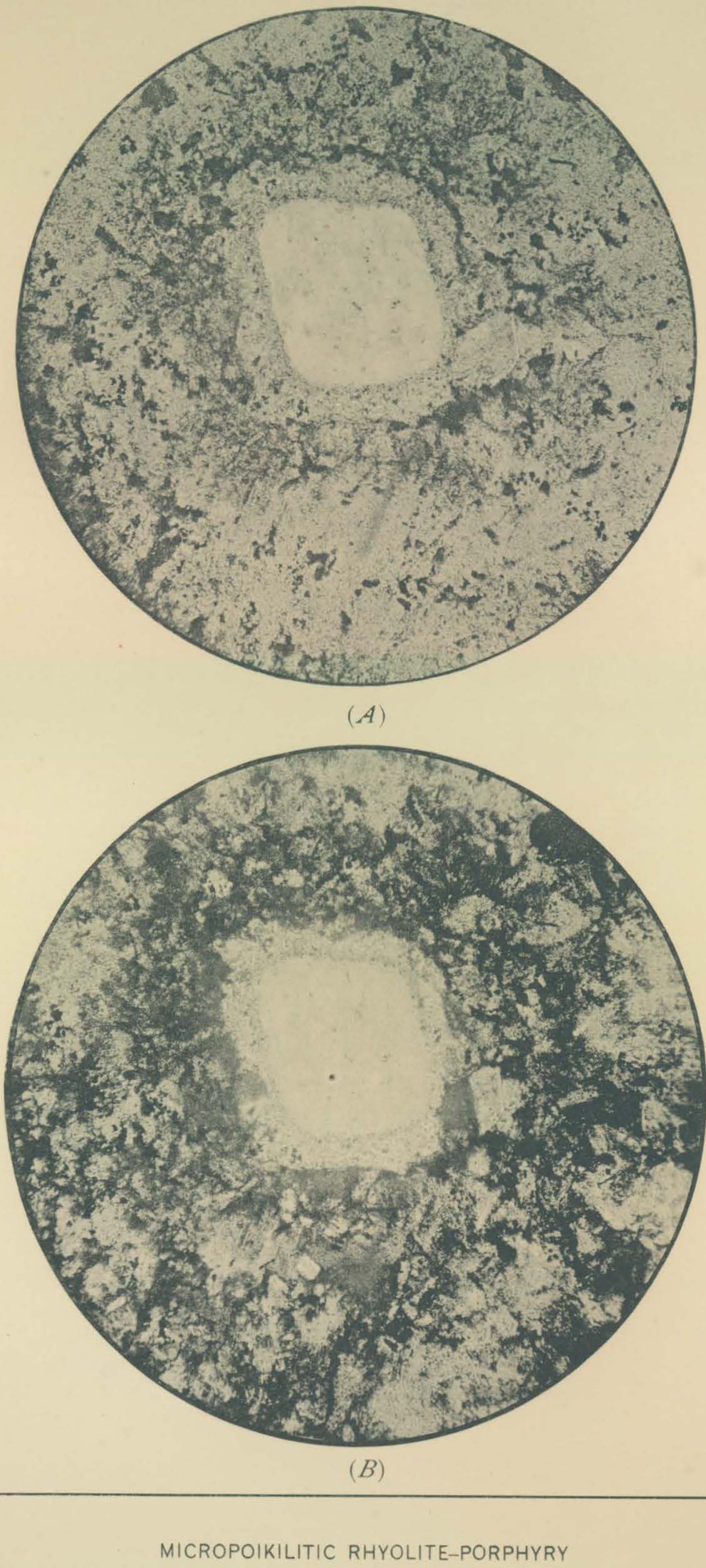
MICROPOIKILITIC RHYOLITE-PORPHYRY

PLATE XI.

PLATE XI.

A. Rhyolite-porphyry with aureoled phenocrysts. The finest-grained type of micropoikilitic texture is here represented. The groundmass of this porphyry consists of rounded areas of material (quartz-épongeuse) corresponding to that forming the zones around the phenocrysts. Between these areas there may be found in places small feldspars. These sections of photomicrographs represented in figs. 1 and 2, Pl. X, and this figure, show every gradation in the micropoikilitic texture, from that which is with difficulty distinguishable as such to the coarser-grained unmistakable variety. Specimen No. 32136. Without analyzer, $\times$ 90.

B. Rhyolite-porphyry with aureoled phenocrysts. This is the same section as represented above, when viewed between crossed nicols. The texture of the groundmass is brought out somewhat better, the feldspars especially become more noticeable; for instance, one Carlsbad twin may be seen at the lower right-hand corner of the phenocryst partly indenting the aureole. Other feldspars may be noticed through the groundmass. In other portions of the section from which this photomicrograph is taken the quartz phenocrysts have no aureoles, and the groundmass possesses an imperfect micrograniti c texture. This figure brings out clearly the gradation toward that texture. Specimen No. 32136. With analyzer, $\times$ 90.



MICROPOIKILITIC RHYOLITE-PORPHYRY

PART II.

THE EASTERN PART OF THE CRYSTAL FALLS DISTRICT, INCLUDING THE FELCH MOUNTAIN RANGE.

By Henry Lloyd Smyth.

WITH A CHAPTER ON THE STURGEON RIVER TONGUE, BY WILLIAM SHIRLEY BAYLEY.

CHAPTER I.

GENERAL OBSERVATIONS.

INTRODUCTION.

The territory to be described in this and the four chapters following is situated in the upper peninsula of Michigan, between the Marquette and Menominee iron ranges, and is all embraced within T. 42 N., Rs. 28–30 W., and Ts. 42–47 N., Rs. 30–31 W. Much of the area of about 300 square miles included within these townships had been covered hastily by previous reconnaissances of the Lake Superior division of the United States Geological Survey, the results of which were placed at my disposal. Our task was to go over with especial care those portions in which outcrops had been found by our predecessors or which seemed likely to contain the iron-bearing formations. At the same time much of the rest was examined more hurriedly.

The tract surveyed in detail comprises a continuous belt about 30 miles in length, and of irregular width, varying from 2 to 5 miles, lying wholly within the drainage basin of the Michigamme River and its principal upper tributary, the Fence River, and extending from the northern end of the Republic tongue, where rocks of well-determined Marquette types occur, south as far as the south line of T. 43 N., R. 31 W. From this line we passed southeast (leaving a gap of 5 miles) across the low divide between the Michigamme and the head waters of the Sturgeon, to the Felch Mountain trough, which was then carefully studied for a distance extending 13 miles to the east.

Until within the last few years the larger part of this area had been very difficult of access, and much of it is difficult still. The rock surface is almost wholly concealed by a cover of glacial deposits of various kinds; dense forests and great swamps also obscure the rocks and make traveling difficult and slow. It is therefore not a field to invite geological study. While exploration for iron ore has here and there passed the frontiers of the productive ranges on either side, the general ill success which attended the early enterprises has discouraged the active search that would at least have resulted in important additions to geological knowledge. For these reasons the area as a whole, with the exception of the Felch Mountain trough, has remained almost unknown, geologically, until our work in 1892. The references to it in geological literature are consequently but few in number, and are for the most part merely the records of the unrelated observations of casual visitors. These will be fully treated in the monograph of which this paper is an abstract.

The district, nevertheless, deserves attention, from both an economic and a geological standpoint. The iron-bearing formations of the Marquette range extend into it from the north, those of the Menominee range from the south. On the west the ore deposits of the Crystal Falls area are connected, geographically at least, with the western extension of the Menominee range. Between these boundaries the area stands as the largest one remaining in Michigan in which iron-bearing formations are known to occur, but as yet not known to contain important bodies of ore. Here, too, if anywhere, the questions of the equivalence or nonequivalence of the individual formations of the Marquette and Menominee iron-bearing series are to be answered.

It is proper to state that the field study, in consequence of the conditions under which this work was done, was almost wholly directed to the economic questions, and that it was not originally anticipated that the results were to be published as a monograph on the district. Field work was begun and ended in 1892. Since that time there has been no opportunity to revisit localities, and the conclusions now stand essentially as they were reached in the field. Considering both the obscurity and the complexity of the area, it is very probable that further study of the important localities would result in clearing away many of the difficulties as well as in the modification of certain of the opinions now held.

Efficient aid in the field work was rendered by Messrs. Samuel Sanford and Charles N. Fairchild for nearly the whole period, and by Messrs. E. B. Mathews and H. F. Phillips for part of it, as assistant geologists, and by Messrs. Lewis and Forbes as skilled woodsmen.

PRELIMINARY SKETCH OF THE GEOLOGY.

The rocks of the Crystal Falls and Felch Mountain areas range in age from the Archean to the early Paleozoic. North and west of the Michigamme River, where geological boundaries are most susceptible of determination, the granites and gneisses of the Archean come to the surface in three oval areas of great regularity of outline, from 10 to 12 miles long, by 2 to 6 miles wide, while the intervals between the Archean ovals are occupied by highly tilted sedimentary and igneous rocks of Algonkian age. The lower member of the Algonkian has derived its materials from the wasting of rocks lithologically similar to the underlying granites and gneisses. In the southern and eastern portions of the district the edges of the tilted older rocks are partially covered by a blanket of gently dipping sandstones of Cambrian age, very soft and easily disintegrated. These rocks first appear near the Michigamme River as detached outliers. Southward and eastward from that river the separated patches become larger and more abundant, until finally, a few miles beyond the eastern limit of our work in the Felch Mountain trough, they unite and entirely cover the pre-Cambrian formations.

CHARACTER OF THE SURFACE.

In its most general aspect the surface throughout this area is a plain—somewhat rolling, indeed—which slopes gently upward from the southeast toward the northwest. The surface is formed partly by the soft and gently inclined Upper Cambrian sandstones and partly by the much harder and highly tilted pre-Cambrian rocks, of diverse physical and mineralogical characters, and yet over all it maintains a very uniform slope. On the southeast, in the Felch Mountain trough, the plain has an average elevation above the sea of 1,200 to 1,300 feet. In the northwest, in the southern sections of T. 47 N., R. 31 W., the average elevation is 1,800 to 1,900 feet. Since the intervening distance is somewhat more than 30 miles, the general slope is therefore less than 20 feet to the mile.

The minor topographical features based upon this plain are multitudinous in variety and detail, but generally insignificant in relief. The maximum difference of elevation between the top of the highest hill and the bottom of the neighboring valley is generally less than 300 feet, this height being reached in but two cases. The country possesses no commanding eminences, and in the widest panoramas now and then obtainable from the summits of glaciated knobs the background is restricted to a radius of a few miles. In these the general evenness of the sky line is usually broken only by the remnants of the old forest which have not yet succumbed to fire and the lumberman.

These lesser features have been shaped by the work of the continental ice sheet both through the materials which it brought in and through those which it carried away. In the areas underlain by relatively massive rocks, particularly the Archean crystallines, the surface has been left mammillated with rocky knobs, which doubtless were the unattacked cores rising into the pre-Glacial zone of disintegration. These are separated by the similar inverse forms, now for the most part occupied by swamps. In the Archean borders of the Felch Mountain area, where the glacial cover was originally thin, the periodical fires that have followed lumbering operations have burned out the organic matter from the soil and so loosened it that on the steeper slopes it has been entirely washed away and the rock surface laid bare. The hummocks and bowls are generally elongated east and west, which is the direction both of the gneissic foliation and of the ice movement. The elevations rise, often with steep smooth walls, for 5, 10, 20, or even in some cases 60 feet above the intervening depressions. The latter hold muskeg to the rims. In the wet season they fill with water, which overflows to the next bowl below; but permanent lines of minor drainage, here as well as elsewhere in the Archean areas, are very infrequent.

Over most of the area, however, the ice has spread a sheet of till and here and there deposited the materials swept along in the subglacial streams in characteristic complexity of form and grouping. The more prominent elevations are, in fact, deposits of modified drift, although occasionally small rock masses like Michigamme Mountain, which is composed of material that offers a most stubborn resistance to all degrading agents, reach an elevation of 100 to 200 feet above the general level of the surrounding country. The fact that the name "mountain" has been applied to hillocks of this order by the surveyors and woodsmen who have the widest knowledge of the Upper Peninsula conveys perhaps the clearest idea of the generally level character of the surface.

While the details of the topography are thus mainly glacial in origin, the broader features of the next order of importance have often clearly been determined by the presence of the more resistant rocks. The large structural domes of the Archean, which are such characteristic geological features, are also indicated by a general upward swell of the surface of the areas which they occupy. The topographical transitions at the margins of these swells are frequently abrupt, and sometimes for considerable distances are marked by scarp-like slopes in the granites, caused by the almost vertical contacts with the softer Algonkian formations. Considerable portions of all three of the Archean ovals in the northern part of the district display this slight topographical prominence. Marginal scarps are particularly well shown in the oval west of Republic, in secs. 19 and 30, T. 47 N., R. 30 W., and along the south side of the oval which lies between the Fence and Deer rivers, near their junctions with the Michigamme. The more important bodies of greenstone also are generally marked by a noticeable degree of elevation. Thus the great intruded sheets folded in with the Lower Marquette series in secs. 24, 25, and 36, T. 47 N., R. 31 W., give rise to long, broad ridges that closely follow the changes in the strike. But in all these cases the topographical emphasis is very slight, and the plain as a whole may truly be said to maintain its general slope with practical indifference to the weather-resisting differences in the underlying rocks.

These broader swells of the harder rocks are separated by broad, slightly lower-lying plains, in many of which a valley character is still distinctly recognizable in spite of the fact that they especially have been covered with deposits of modified drift. The present drainage, in its main lines, largely follows these older valleys, although much confusion, especially noticeable in the details, has of course resulted from their partial choking by the drift.

DRAINAGE.

Nearly all the surface water of this district finds its way to Lake Michigan through the Michigamme and the Sturgeon rivers, which are independent branches of the Menominee—the largest river flowing into Lake Michigan from the west. A few square miles along the eastern boundary, however, are tributary to the Ford, which flows into Green Bay north of the Menominee. Of these, the Michigamme drains by far the largest part of the district. This river heads in Lake Michigamme, which it leaves in sec. 9, T. 47 N., R. 30 W. (near the northern border of the area shown on Pl. II), at an elevation above the sea of 1,580 feet. Thence it flows for 8 miles southeast to Republic, in a synclinal valley cut out of the soft schists of the Michigamme formation. This valley, which is nearly a mile wide at the northern end and less than half as wide at the southern, is bordered on both sides by the harder Archean granites, which rise with rather steep slopes to the general level of the plain. Throughout the length of the valley the river flows over glacial drift, but at Republic, where the soft rocks come to an end, it breaks across rocky barriers in a succession of rapids, and continues, first nearly due south and then southwest, over glacial deposits which completely mask the bed rock for 10 miles. South of the Archean oval which occupies the western part of T. 44 N., R. 31 W., and the eastern part of T. 44 N., R. 32 W., the limestones and slates of the pre-Cambrian are again exposed, and over these the Michigamme flows in close conformity to the general strike as far as the range line.

In the southern sections of T. 44 N., R. 31 W., the Michigamme receives two tributaries from the north, the Fence River, which comes from the eastern side, and the Deer River, which comes from the western side of the Archean mass just mentioned. The head waters of the Deer and of the western branch of the Fence flow through the same section (21) in T. 46 N., R. 32 W., north of the Archean oval, but farther south they diverge to an extreme distance of 10 miles, and afterwards converge, so that their points of junction with the Michigamme are but 4 miles apart. The area thus inclosed is broadly concentric with the Archean oval. In the case of the Fence, at least, the river is placed within a wide depression coincident with the softer stratified rocks of the Algonkian, and following very faithfully their general strike. Within this valley deposits of glacial sand and gravel are very abundant, and because of these the river often swings aside across the strike for a mile or more. In secs. 21 and 29, T. 45 N., R. 31 W., and in sec. 10, T. 44 N., R. 31 W., excellent rock sections are afforded by such digressions.

The old valley between the two Archean ovals west of the Republic tongue (see Pl. II) is, on the south, entirely filled with glacial gravels to the level of the old divides, and the large brook known as the east branch of the Fence is diverted to the western of the two ovals. The valley is clearly indicated, however, by an interesting series of lakes, of which Squaw, Trout, and Sundog, each about 1 mile in length, are the largest.

The area drained by the Sturgeon lies in the extreme southeastern part of the district, wholly within the marginal fringe of sandstone. The relation of its course to the geology is known in detail only within portions of the Felch Mountain trough. This it first enters in the northern portions of secs. 35 and 36, T. 42 N., R. 30 W., in a loop into the Algonkian, from the northern Archean margin, to which it again returns. Five miles farther east it crosses the trough from north to south, transverse to the strike of the Algonkian formations, to the contact with the southern Archean mass. It follows this contact eastward for 2 miles, and then strikes southward across the Archean to the Menominee River, not again returning to the Felch Mountain trough. The river valley in the Felch Mountain trough is very distinct, and where bordered by Potsdam outliers, it is rather deep, with precipitous banks. It is but slightly affected by drift deposits. Its course shows an almost complete disregard of the structure of the Algonkian and Archean rocks, and so has the usual characters of a superimposed stream.

The Michigamme River, as was early noted by Pumpelly, has practically no eastern branches within this district. The Escanaba and Ford rivers, which reach Lake Michigan directly, and the Sturgeon, which joins the Menominee below the mouth of the Michigamme, all head within 2 or 3 miles of the latter, the course of which is transverse to their general direction. The Michigamme thus flows along the eastern edge of its drainage basin. This fact—the most striking in the general distribution of the streams of the district—is the result of causes which in part, at least, go back to very remote geological periods.

CHAPTER II.

MAGNETIC OBSERVATIONS IN GEOLOGICAL MAPPING.

As has been said already, the area in which our work was done is largely drift covered, to somewhat varying but usually considerable depths; the mantle, on the whole, is so evenly spread that in many sections outcrops of any rocks except those belonging to the Archean are few and scattered, and sometimes are almost entirely lacking over whole townships.

Under these circumstances, and since also the pre-Cambrian rock structure is complex, even a general outlining of the old formations would be impossible by the usual geological methods, and if we were restricted to these there would be no alternative but to map most of the territory as Pleistocene. It happens, however, that the Algonkian rocks of Michigan contain a large amount of magnetite, which is known from observation in the developed ranges to be characteristic of certain geological formations. It undoubtedly occurs in greater or less amount in all the sedimentary rocks, and is also present, sometimes in considerable quantities, in rocks that are not sedimentary, as around the margins of the old intrusive diorite bosses. But generally speaking, its occurrence in large quantities is confined so closely to definite geological formations, in which it is found in characteristic association with certain other minerals, or to horizons within those formations, that it can be guardedly used in identifying them and in tracing them from localities where they outcrop through areas in which they are buried. This use is not only justified, from an empirical standpoint, by the presumption in favor of analogies to which no exceptions are known, but it has a rational basis in the view of the late Professor Irving,[1] which is steadily gaining ground, that at least much of the iron of this magnetite was originally buried in the same formations in which it now occurs, through the agency of organic life. From this point of view the magnetite is in a certain sense a fossil, but with the important practical advantage over other organic remains that it need not be dug up in order to prove its existence.

These magnetite-bearing rocks always produce disturbances in the compass needle held in their neighborhood. By a systematic location and comparison of these disturbances the position of the rocks which produce them can be determined with a considerable degree of precision, even when they are deeply buried. Besides showing their position,

[1] Classification of early Cambrian and pre-Cambrian formations, by R. D. Irving: Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 451-452.

the magnetic observations may, and often do, indicate certain other geologically important facts, such as whether the rocks are flat lying or highly tilted, the direction of strike and dip, and in some cases the depth to which they are buried. The methods employed in the field work were based on those described by Maj. T. B. Brooks,[1] who perfected the dial compass and predicted the importance of magnetic methods in geological mapping, but the results reached in interpretation were gradually developed in the progress of this work, as we were daily brought face to face with phenomena which called for explanation.

It must be clearly understood that in the iron ranges of the south shore of Lake Superior magnetite is rarely concentrated in large bodies, and that, in fact, its known occurrence as such is restricted to a small part of the western Marquette district, where in one producing mine it now forms practically the whole product, and in another a variable but usually important part of the whole. It is, therefore, well understood in the Upper Peninsula that disturbances of the magnetic needle, however great, do not mean workable deposits of magnetite. Whatever significance such disturbances possess is stratigraphical, and, properly interpreted, may lead to discoveries of rich ore, other than magnetite, in formations to the position and attitude of which the attractions may furnish a clue. But it may be asserted as a general proposition, the essential truth of which has been established by the experience of many years, that in the region referred to magnetic disturbances usually mean that magnetic iron ore in a workable deposit does not exist in the area of disturbance.

In the monograph of which the present paper is an abstract will be found a full description of the character of the magnetic rocks, the distribution of magnetism in these rocks, the instruments and methods of work employed in following magnetic belts, and the facts which are obtained by such instruments. The general principles which follow from the foregoing are considered, and these principles are applied to a number of special cases. In the present paper it is not practicable even to summarize the results of this part of the monograph.

[1] Geol. Survey of Michigan, Vol. I, Part I, 1873, Chapter VII.

CHAPTER III.

THE FELCH MOUNTAIN RANGE.

SECTION I.—POSITION, EXTENT, AND PREVIOUS WORK.

The Felch Mountain range includes 12 sections in the southern tier of T. 42 N., Rs. 28, 29, and 30 W., beginning with sec. 33, T. 42 N., R. 28 W., on the east, and ending with sec. 34, T. 42 N., R. 30 W., on the west. The range is known to extend beyond these limits both to the east and to the west. Rominger states[1] that it has been traced 1 mile east of the eastern boundary of the area shown on the map (Pl. II), and also west of its western boundary to the Menominee River north of Badwater village. From a hasty reconnaissance of the country to the east it seemed probable that but few additional facts could be determined because of the swamps and the extensive cover of the Paleozoic sandstone, and these sections were therefore not studied in detail. We were not able to continue the work to the west on account of the lateness of the season, but it is desirable that it should be continued in this direction at some future time. The sections surveyed include, however, that portion of the range in which outcrops are most abundant, and which has been the principal seat of exploration for iron ore.

The strong magnetic attractions in several of these sections, and the prominent outcrops of ferruginous jaspers at Felch Mountain in sec. 32, T. 42 N., R. 28 W., and in sec. 31, T. 42 N., R. 29 W., were early noticed by the United States land surveyors and indicated on the township plats. With the rapid development of the Marquette range after the close of the civil war the attention of miners was quickly drawn to these as to other outlying prospects, with the result that vigorous exploration was begun on this range even earlier than on the Menominee range proper.

The geology was first studied by Maj. T. B. Brooks, 1869–1873, for the geological survey of Michigan, and the general conclusions reached by him[2] will be stated and discussed in Monograph XXXVI. The main points of these conclusions may briefly be summarized:

(1) The iron-bearing rocks of the Menominee region occur in two approximately parallel east-west belts (the northern belt being the Felch Mountain range and the southern belt the Menominee range), separated by a broad granite area which narrows toward the west by

[1] Geological report on the upper peninsula of Michigan, by C. Rominger: Geol. Survey of Michigan, Vol. V, 1895, p. 35.

[2] See Geol. Survey of Michigan, Vol. I, Chap. V.

the convergence of the iron belts. The northern and southern belts were not traced into each other, but their probable connection was inferred from their bending toward each other, and from the occurrence of rocks of the iron-bearing series west of the granite area. The equivalence in age of the two belts was inferred from the lithological and stratigraphical similarity exhibited by the great quartzite and marble formations, from the probable continuity above referred to, and from the similar relations of these formations to the basement granites.

(2) The iron-bearing formations of the Felch Mountain range were believed to occur at two horizons. That of Felch Mountain itself, in sec. 32, T. 42 N., R. 28 W., was held to be a ferruginous phase of the lower quartzite. On the other hand, the exposures of sec. 31, T. 42 N., R. 29 W., were regarded as belonging to a horizon above the lower marble, and as the close equivalent of unimportant lean ores of the Menominee range.

(3) In geological structure the Felch Mountain area was held to be a northward-dipping monocline.

(4) As a consequence of this conception of the structure, Major Brooks supposed that there were two marble formations.

Dr. Rominger investigated the Felch Mountain range from 1879 to 1884, and the large body of facts brought to light by the progress of exploration subsequent to Major Brooks's visit are reported by him in Vols. IV and V of the same survey. Rominger's work resulted in a recognition of the general synclinal character of the range and in a more accurate determination of the geological succession.

SECTION II.—GENERAL SKETCH OF THE GEOLOGY.

The rocks of the Felch Mountain range extend from the Archean to the early Paleozoic. The Paleozoic is represented by the Lake Superior sandstone, of supposed Upper Cambrian age, and the overlying Calciferous limestone. These formations were originally laid down upon the upturned edges of the older rocks, and have not since suffered relative displacement to any notable degree. As has already been stated, subsequent erosion has to a great extent removed this overlying blanket and laid bare the older rocks, except for the covering of recent glacial deposits. However, the Cambrian sandstone, and, to a less extent, the Calciferous limestone, still occupy considerable outlying detached areas throughout most of the district, but gradually coalesce beyond the eastern end, where they completely cover the older rocks and limit all further geological study of them in that direction. The Paleozoic rocks will not be considered further at present.

The Archean, which is here made up of granites, granitic gneisses, and various kinds of crystalline schists, is the basement group of the region. The areas in which these rocks are now exposed at the surface represent the cores of the larger arches which were constructed over the whole region by the early manifestations of mountain-building energy. Our studies have dealt with the Archean only in narrow marginal zones, and have included little more than the location of its outer boundaries, except when it was necessary to go deeper in order to complete the work over a full section. Consequently no attempt at classification can be made upon the map.

The rocks, chiefly of sedimentary origin, which are intermediate in age between the Archean below and the Paleozoic above, and therefore fall within the system to which the name Algonkian has been given by the U. S. Geological Survey, occupy a narrow strip, nowhere more than 1½ miles wide, and usually less than a mile, which, as a whole, runs almost exactly east and west for a distance of over 13 miles. This strip constitutes the Felch Mountain range. On the north and south it is bordered by the Archean. The lowest member of the Algonkian occupies parallel zones next the Archean, both on the north and on the south, and is succeeded toward the interior of the strip by the younger members. While the general structure therefore is synclinal, a single fold of simple type has nowhere been found to occupy the whole cross section of the Algonkian formations; but usually two or more synclines occur, separated by anticlines, which may have different degrees and directions of pitch, different strikes, or may be sunk to different depths, and are besides often complicated both by subordinate folds and by faults.

Among the Algonkian rocks we distinguish two main divisions or series, which are probably separated from each other by an unconformity. Owing mainly to the peculiar lithological and weak physical character of the younger of these two series, actual contacts between them have not been found, and the evidence for unconformity consequently consists not so much in observed discordance of structure as in an inferred discordance based upon their relative surface distribution.

In the lower of these two series are included four formations, which clearly appear to be identical in lithological character and order of superposition with the four formations that, so far as is known, make up the lower iron-bearing series along the Menominee River. These are, from the base upward, (1) the Sturgeon quartzite, (2) the Randville dolomite, (3) the Mansfield schists, and (4) the Groveland iron formation.

Above this series follows the younger series, which lithologically and in its areal relations is very incompletely known. It includes mica-schists, ferruginous schists, and thin interbedded ferruginous quartzites. These rocks, which must for the present be grouped as a single formation, are believed to have been deposited contemporaneously with the somewhat similar rocks that occur in the Menominee area, at Iron Mountain, but are most extensively exposed west of the Menominee River, and especially in the Commonwealth and Florence district in Wisconsin.

SECTION III.—THE ARCHEAN.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The Archean occurs in the Felch Mountain district in two belts, which limit the Algonkian rocks on the north and on the south. The northern belt occupies a triangular corner in secs. 34 and 35, T. 42 N., R. 30 W., at the extreme western end of the area surveyed in detail, and even in these it has not been directly observed; but its presence is inferred from outcrops in the adjoining sections west and north, and from the observed strikes in the overlying Algonkian formations. For the next 11 miles east its southern boundary lies in the tier of sections next north of those mapped in detail, and always less than a mile away. Our work first touches the southern area of the Archean on the west, in secs. 3 and 2, T. 41 N., R. 30 W., a short distance south of the township line. Thence, for 3 miles eastward, the boundary follows the township line, and in sec. 31, T. 42 N., R. 29 W., crosses it with a trend somewhat north of east. From the west line of sec. 31 to the east line of sec. 36, T. 42 N., R. 29 W., the Archean occupies the southern third of the south tier of sections. Thence, for 1½ miles, it bends northeast, and in sec. 32, T. 42 N., R. 28 W., reaches farthest north in the center of the sections. From this point the boundary runs southeast, with a sinuous embayment to the south, and passes outside the limits of the map a little north of the southeast corner of sec. 33.

Throughout the Felch Mountain range the southern Archean is much better exposed than any of the other terranes. In the western portion of the range, where hardly more than the contact zone falls within our limits, outcrops are not especially numerous; but in the six eastern sections, which include a belt from a quarter to a half mile wide, a very considerable portion of the surface is bare rock. This exceptional degree of exposure has been brought about by forest fires, which, by loosening the thin soil and destroying the protecting cover of vegetation, have facilitated its removal from the steep-sided knobs that are such characteristic features of the Archean topography.

Along the contacts between the Archean and Algonkian there is usually, but not always, a topographical depression, occupied by swamp or stream. North of the southern Archean mass this depression is a well-marked linear valley, extending, with some interruption, from sec. 33, T. 42 N., R. 28 W., on the east, for 6 miles west, to sec. 33, T. 42 N., R. 29 W. For 2 miles in the middle of this stretch the valley is occupied by the Sturgeon River, thence west for 2 miles by a small feeder of the Sturgeon, while the eastern third holds swamp, with ill-defined drainage. On the south the Archean boundary of this valley generally rises with steep slopes, which are frequently escarpment-like in character, and for short distances present smooth faces to the valley. In sec. 33, T. 42 N., R. 28 W., the mural face, which runs southeast across the eastern half of the section with the regularity of a ruled line, is a true fault scarp. Toward the western end of this valley, in sec. 32, T. 42 N., R. 29 W., the floor gradually rises and the swamp area broadens, penetrating the Archean in a network of thicker and thicker mesh about the higher hummocks, until these are finally overtopped.

PETROGRAPHICAL CHARACTERS.

The rocks of the Archean areas may be divided into four distinct types, namely: (1) Granites or granitic gneisses; (2) gneisses, with banding or distinct lamination; (3) mica-schists, and (4) hornblende-gneisses or amphibolites. Between the first two divisions there is an extremely close mineralogical and chemical likeness, while in these respects the fourth division stands against all the others in strong contrast.

(1) The granites of the first division are, as seen in the field or in the hand specimen, holocrystalline rocks of fine to medium grain, in which the eye can readily distinguish the presence of quartz, pink feldspar, muscovite, and biotite. In color they are prevailingly of pink or reddish tints of light shades. Structurally they frequently appear in small areas to be entirely massive; but the hammer, even in the most massive occurrences, can usually part them along roughly parallel surfaces, which glisten with spangles of mica, indicating a certain degree of alignment in these constituents. Generally, however, a rude foliation is more or less distinctly visible, and is sometimes exceedingly well developed, even to the point of fissility. It is always apparently due to the parallel arrangement of the micas, which are more abundant as the foliation becomes more distinct.

The field relations show that the massive and more or less foliated varieties of this division are closely bound together by indistinguishable gradations, and indeed often constitute a visibly integral mass. The usual arrangement of the micas is not parallel to a surface, but parallel to a line which is generally inclined to the horizon at angles varying between 10° and 35°. A hand specimen, when turned about the direction of foliation as an axis, shows a parallel arrangement of the micas on all sides, and a continuous glistening follows the revolution, while on a surface at right angles to this direction the micas are not parallel, and wind about the other constituents indifferently.

In the more fissile varieties the outcrops often have a rough, channeled surface, suggestive of the surfaces familiar in closely crenulated mica-schists or the corrugated walls of a fault. Similar corrugated surfaces frequently separate more massive from more fissile parts of the same outcrop.

Under the microscope the essential constituents of the granites and granitic gneiss are seen to be quartz, orthoclase, microcline, plagioclase, biotite, and muscovite, with the iron ores, titanite, and occasionally apatite and zircon, as accessories. In the massive phases the general relations of these minerals to one another and their order of crystallization in no respect differ from those of igneous granite. The quartz, which is the last mineral to form, contains numerous fluid and gas inclusions, the former often with a moving bubble. Of the feldspars, microcline is much the most common, then plagioclase, while orthoclase is generally comparatively rare, although sometimes it is more abundant than the microcline. The plagioclase, from its relief and extinction angles, is probably not lower in the scale than oligoclase. The orthoclase is usually crowded with alteration products, and sometimes the dull interior is surrounded with a narrow unattacked rim. Both micas are always present as original minerals, and, on the whole, biotite is the more abundant. The micas occur in small, stout crystals, often as inclusions in the quartz and feldspars. Magnetite is rare, but occurs in idiomorphic forms in the later constituents, as do also minute crystals of zircon and apatite. Thin sections, even of most massive looking specimens, invariably show the effects of pressure in the undulatory extinction of the quartz and the bending and occasional fracture of the feldspar.

In the foliated varieties, with which these massive varieties are closely associated, the effects of mechanical stresses are the striking microscopic phenomena. The constituent minerals are essentially the same as in the massive phases, but the micas are relatively more abundant. The quartz and feldspar individuals are fractured and strained, and occur in irregular cores, separated by anastomosing zones of a fine quartz-feldspar mosaic. In these last, new micas in long curving individuals and clusters have been developed in great numbers.

The rocks of this division, therefore, have the chemical composition and all the physical and petrographical characters of igneous granites. The positive proof of igneous origin, however—actual injection into older rocks—has not been found. Irruptive contacts may possibly exist and may have escaped notice, since neither the Archean as a whole nor its internal relations were the objects of especially rigid scrutiny. Igneous granites of Algonkian or later age ought to be found within the Archean areas, for several granite dikes are known to penetrate various members of the Algonkian series. Whether the known granites within the Archean are really lower-lying and larger masses with which such dikes are genetically connected is not known, but the possibility must be admitted. The banded gneisses are often so faintly foliated and resemble the granites so closely in color and grain that the distinction can be made only with the microscope, and igneous contacts between them might easily be overlooked.

The gneissic members of this division are merely crushed granites, and owe their foliation to the crushing and to the growth of fresh mica in the fractured zones. They differ from the banded gneisses in furnishing both field and microscopic proof of the way in which the foliation was formed and of the rocks from which they were derived.

(2) The banded gneisses have essentially the same mineral composition as the granitic gneisses of the first division. They are distinguished by the eye mainly by the fact that the component minerals

occur in more or less distinct layers, from a fraction of an inch upward in thickness. The lamination, which only rarely is very regular, seems to be caused in most, if not in all, cases by the alternation of darker layers which are relatively rich in biotite with lighter layers which are comparatively and sometimes wholly free from it. The white layers are almost always coarser in texture than the darker, and frequently are coarsely pegmatitic. The individual bands are not indefinitely persistent, but wedge out to knife edges. The banding is sometimes so indefinite as to be lost in the hand specimen, the large surface of an outcrop being necessary to bring out the slight differences in shade. In color these rocks are light gray, dull white, or pink. The banding shows great variations in angle of dip, but the strike is generally fairly constant within a few degrees of east and west. In a few localities distinct contortion and pitching folds were observed in the gneissic banding. The lamination of these gneisses is, so far as has been observed, of the plane-parallel type. The bands are thoroughly welded together, and as a rule the rock breaks indifferently across them.

Under the microscope the composition of these rocks does not differ from that of the granitic rocks of the first division. The structural characters, however, are in strong contrast. Even in those specimens which possess the most indistinct foliation, all the minerals are elongated in a common direction. While the individual grains in most cases show more or less strain and are frequently fractured, their mutual boundaries are usually sharp and clear, and it is evident that the forms are not the direct result of the pressure that has affected their optical properties. The evidence is quite clear that the minerals now present have crystallized in parallel elongated forms, and it is to this they owe their prevalent lamination, even when the color banding is indistinct or wanting.

Subsequent to the time of crystallization they have been exposed to the action of great stresses, which not only have left a record in the strains now frequently perceptible in the minerals of the early crystallization, but also in many cases have produced roughly parallel fractures and fracture zones, sometimes coinciding with and sometimes oblique to the early lamination. In these zones coarse micas have grown, reenforcing the old lamination when parallel to it, and when oblique producing a less regular secondary foliation, which is entirely analogous and probably contemporaneous with the foliation of the crushed granites.

(3) The mica-schists are not widely distributed in the portion of the Archean areas included in the Felch Mountain map. They are well represented in the northern Archean area beyond the limit of our work, but within this limit they are known only in secs. 34 and 35, T. 42 N., R. 29 W., where an overthrust fault brings them into successive contact with the Randville dolomite and Sturgeon quartzite for a distance of three-fourths of a mile. An excellent section, which includes the faulted contact with the dolomite, is exposed along the Sturgeon River below the dam in the northern portion of sec. 35. Though so poorly

represented, the mica-schists possess an unusual interest, both in their field relations and in their microscopic characters.

The mica-schists, when fresh, are dark gray, rather soft rocks, of fine to medium grain, with a generally well-developed schistose structure. The most noticeable constituent, in spite of the dark color, is muscovite, which occurs in pearly flakes of large size plentifully sprinkled along the cleavage surfaces, and is especially characteristic of thin seams which are much more fissile than the rest of the rock, and part it into parallel bands with much regularity. Biotite, however, is the more abundant mica, although in smaller and less conspicuous plates, and to it the dark color of the rock is due. Quartz, and sometimes feldspar, may also be recognized.

These rocks offer little resistance to the weather. The biotite gives up its iron with great ease, staining the outcrop a dull red. The final product is a slightly coherent ferruginous mixture in which the large muscovite plates alone are recognizable. At a less advanced stage of weathering the alteration of layers more rich in biotite produces color banding in reds and grays.

The mica-schists contain many intruded dikes and sheets of flesh-colored pegmatite and also of amphibolite, both of which are generally parallel to the foliation. The pegmatites are typical "schriftgranits," the feldspar being microcline. Both pegmatites and amphibolites show ragged and intrusive contacts with the schists when these are examined in detail.

Under the microscope the mica-schists are thoroughly crystalline aggregates of quartz, biotite, and muscovite, always with more or less microline. Magnetite is always present as a primary mineral, and hematite or some hydrous oxide of iron between hematite and limonite is very abundant in the zone of weathering. Besides these, tourmaline is an abundant accessory in some slides, and apatite, zircon, titanite, pyrite, and chlorite commonly occur.

The original character of the mica-schists is wholly indeterminate. They may have been clastic, but if so they no longer contain any material which can be proved to be in its original form, and in view of the complete recrystallization, for which the evidence is clear and striking, this could not be expected. The recrystallization may be referred with probability to the period of quiescence following the faulting and folding, during which also occurred the recomposition of the older Algonkian formations.

(4) The hornblende-gneisses are widely and abundantly represented in the Archean. Microscopically they are black or dark-green rocks of medium to fairly coarse grain, the fresh fractures of which glisten with the cleavage surfaces of hornblende, which is much the most abundant and often the only recognizable constituent. They are universally foliated parallel to the foliation of the associated gneisses, and exhibit, but in a more marked degree, the same varieties of structure. The foliation is easily recognized by the eye as due to the parallel arrangement of the hornblende prisms. Depending mainly upon the position

of the hornblendes relative to the other constituents, the structure is either of the plane-parallel or the linear-parallel type, the latter often superbly developed.

The essential constituents of these rocks are common green hornblende, plagioclase, biotite, and quartz. The structure is thoroughly crystalline. The hornblende occurs in long prisms, 3 to 10 mm. in length, which lie close together, and inclose, partially surround, and abut against smaller angular grains of plagioclase. The plagioclase is quite unstrained and is usually fresh and clear, and entirely without crystal boundaries. Brown biotite is generally present in small amount in long plates parallel with the foliation. It does not seem to be an alteration product from the hornblende. Quartz is the least abundant constituent. It is crowded with fluid cavities and needles of rutile, and often incloses minute crystals of hornblende. The plagioclase, from its high extinction angles and alteration products, is evidently basic. A little magnetite is present, but titanite has not been observed.

The amphibolites occur in comparatively narrow bands of indefinite length in the granites and gneisses. The width usually does not exceed 8 to 10 feet, and their dip is always at high angles. The boundaries are invariably sharp, and frequently cut the foliation of the amphibolite within and of the gneisses without somewhat obliquely. There is a general uniformity of grain throughout the width; the wider bands are not coarser than the narrower.

The composition of the amphibolites and their field relations leave little room for doubt that they are old dikes of basic rock. Their present crystallization is, of course, not that due to original cooling, since, among other reasons, it bears no relation either to their thickness or to distance from the walls. The evidence of complete recrystallization in place after consolidation which they thus afford, and the unquestionable community of origin between their foliation and that of the gneisses, throw much light on the metamorphic history of the Archean of this district.

It is for this reason that they are described with the Archean and not with the intrusives. Whether they are really Archean intrusions, and not of Algonkian age, can not perhaps be known with certainty. Basic rocks having approximately the same composition are known to have penetrated the Algonkian, but they have not undergone the same recrystallization. These last, besides, have their known analogues, equally unmetamorphic, in the Archean itself. For these reasons it seems probable that the amphibolites were intruded into the Archean before the Algonkian rocks of this district were deposited.

SECTION IV.—THE STURGEON QUARTZITE.

The lowest member of the Algonkian in the Felch Mountain district is a formation consisting mainly, but not exclusively, of coarse vitreous quartzite. Typical exposures of this formation, as well as one of the rare contacts between it and the underlying Archean, occur along the Sturgeon River, and it is therefore named the Sturgeon quartzite.

DISTRIBUTION.

The Sturgeon formation, after the Randville dolomite, is the most widespread member of the Algonkian series in the Felch Mountain trough. Its general distribution throughout the area mapped is in two parallel zones, of varying width, immediately adjoining the northern and southern Archean, except when displaced from this position for relatively short distances by faults. These zones extend east and west for the whole length of the range. Their surface width varies with the complexity of the structure and the depth of erosion. In part of sec. 35, T. 42 N., R. 29 W., the higher formations have been entirely removed and the two zones come together, leaving the quartzite as the only Algonkian rock at the present surface.

FOLDING AND THICKNESS.

It is extremely difficult in most cases to determine directly the attitude of the Sturgeon formation, owing to its generally massive and homogeneous character. This is due, as will be shown hereafter, to the completeness of the recrystallization, in consequence of which the ordinary sedimentary features that it originally possessed have been almost entirely obliterated. Faint color-banding, itself of secondary development, but no doubt preserving a distinction in original composition, alone remains, and that only here and there, as a guide to the former stratification. By scattered indications of this sort, and by the better evidence afforded by the overlying dolomite, often very distinctly banded, it is known that the southern zone of quartzite on the whole dips toward the north. Southward dips also occur in this belt, by which it is known that subordinate folds occur within the quartzite itself. From the considerable variations in the surface width of the formation one is led to suspect the existence of more of these little folds than can be proved. However, the secondary syncline, which extends from the offset already referred to in sec. 35, T. 42 N., R. 30 W., for 6 miles to the east, to sec. 35, T. 42 N., R. 29 W., and includes no formation higher than the quartzite, is very definitely determined.

In the northern belt of the Sturgeon formation the indications of dip are generally northward at very high angles. These indications, not in themselves conclusive, are reenforced by a corresponding attitude in the overlying dolomite, and it is therefore probable that there is a general, or at least a widespread, overturn in the dip of the northern belt.

Since the contacts of the Sturgeon formation with the underlying Archean and with the overlying dolomite are (except in one case) covered, it is impossible to obtain the data for very accurate determination of its thickness. The uncertainty in most outcrops as to the dip of the quartzite introduces an additional difficulty. However, in sec. 35, T. 42 N., R. 30 W., on the west end of the range, and in sec. 33, T. 42 N., R. 28 W., 11 miles farther east, the covered intervals to the limiting formations are not great, and if the contacts are not faulted (which is far from certain) the minimum thickness is determinable within a reasonable limit of error.

In the western locality the surface width of the zone probably underlain by quartzite is about 500 feet. The quartzite itself is structureless, but the overlying dolomite dips northward at an average angle of about 70°. If the same dip holds in the quartzite its true thickness is about 470 feet. In the eastern locality similar data indicate a thickness of nearly 430 feet. In these two sections the quartzite zone is much narrower than it is elsewhere, either because undetected faults have reduced it or because it is not complicated by subordinate folds. It is probably safe to conclude, in view of the uncertainties, that the average thickness of the formation is not less than 450 feet, and may be considerably more. In a preliminary paper on the Michigamme district,[1] written before the field notes were fully analyzed, I have placed the thickness of the quartzite at about 700 feet, but this figure is probably too large.

PETROGRAPHICAL CHARACTER.

The Sturgeon formation includes a few very closely related rock varieties, of which quartzite furnishes the great majority of the exposures. The quartzites are usually light gray in color, and break with a coarsely granular or glassy fracture. To the eye quartz is often the only recognizable constituent in the body of the rock, although the numerous joint and shearing planes shimmer with little silvery plates of muscovite. Occasionally a weathered surface is dotted with minute specks of an opaque pinkish substance which leads one to suspect the presence of feldspar. Chlorite is also now and then visible in the darker varieties.

The quartzites are almost uniformly massive except for the secondary fractures above mentioned. At scattered localities, however, a faint color banding, due to the presence of layers of a pinkish hue, which are independent of the secondary fractures, seems to indicate the original stratification. The color bands are generally only vaguely defined; occasionally, however, they are numerous and sharp.

Closely associated with the massive quartzites are sheared quartzites, or micaceous quartz-schists. These rocks are merely varieties of the quartzite in which secondary shearing planes, with their attendant growths of new muscovite, are more abundant than usual. The shearing surfaces almost invariably intersect, with the result that the new structure tends toward the linear-parallel type, and is often as similar in appearance as it is in origin to the structure already described in connection with the sheared granites.

In a locality already referred to, on the south bank of the Sturgeon River, in sec. 36, T. 42 N., R. 29 W., where the Sturgeon formation is

[1] Relations of the Lower Menominee and Lower Marquette series in Michigan (preliminary), by H. L. Smyth: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 217.

in visible contact with the Archean, the quartzite is underlain by a considerable thickness of very fissile muscovite-biotite-gneiss, which incloses rather sparingly obscure pebbles of granite and quartz. This gneiss, which no doubt was formerly an arkose rich in feldspar, has recrystallized and afterwards was crushed; the coarse micas to which the fissility is due, together with other new minerals, have grown between the fractured surfaces and recemented the broken mass. It affords beautiful examples of foliation parallel to a line.

The thin sections of the Sturgeon quartzite are of exceptional interest. The principal constituent is, of course, always quartz; with the quartz are associated, in much smaller amounts, and not necessarily all in the same section, numerous accessories, including muscovite, biotite, chlorite, microcline, orthoclase, plagioclase, titanite, rutile, zircon, apatite, and the iron ores. The relations of the quartz to the other constituents present very unusual features, and indicate that the changes by which the present completely crystalline rock has been made from an original granitic sand have proceeded along lines not hitherto distinctly recognized in the formation of rocks of this character.

Among the large number of slides examined, a broad distinction can at once be made between those which show the effects of stress in a pronounced degree and those in which such effects are subordinate or hardly noticeable. Connecting these two classes is a perfectly graded series, and it is therefore certain that those of the first are merely the more or less modified varieties of an earlier stage, represented more nearly by the second.

In the slides in which the effects of pressure are least apparent the microscopic characters are as follows: The background is composed of large irregular grains of quartz, the edges of which interlock with the most minute and sharp interpenetrations. The longest dimensions of these grains range from 1.5 to 6 mm., averaging perhaps 2.5 or 3 mm. They often have a rather vague parallel elongation, which corresponds to the alignment of the minerals which they inclose. Scattered very abundantly through these large quartz grains are the accessory minerals, some predominating in one slide, others in another, but the micas and chlorite occurring in all. Through each slide the accessory minerals, with the exceptions noted below, lie with their long axes in a common direction, and they frequently cross the serrated boundaries between adjacent quartzes. The inclusions in many cases have the form and other characters of clastic minerals, and thus preserve the only microscopic evidence of the original nature of the rock. These inclusions, which need not here be described in detail, consist of biotite, muscovite, microcline, orthoclase, plagioclase, titanite, and zircon. Besides the above minerals of usual occurrence, quartz grains of different orientation from the matrix are very rarely found included in the large quartzes of the general background. Two or three such cases only have been observed, and in these the included grain is surrounded almost wholly by thin plates of mica. It is believed that these are original clastic grains, which perhaps, because protected by a film of material now represented by the micas, have escaped the general fate of their neighbors.

One or two composite inclusions, made up of microcline, the micas, and quartz, have also been noticed. These seem to represent original pebbles of granite or a crystalline schist.

The pressure effects begin with the appearance of optical strain and decided elongation in the large quartzes of the groundmass. This is followed by fracture either along or quite independent of the original sutures, the crack often halting in the interior of a grain. The fractures preserve very roughly the same general direction, but frequently intersect at very acute angles or come together in sweeping curves. The breaking is followed by movement, and this results in the production of a fine-grained quartz mosaic between the parted surfaces. In the final stages shown in the series of slides in my collection the rock is made up of long narrow lenses, each of which is an enormously strained quartz individual, separated by narrow anastomosing zones of very finely subdivided quartz. After the fracturing took place there seems to have been no further distortion of the lenses, for the edges of the adjacent individuals follow similar curves, which are often reversed, and in many cases could be brought together with an accurate fit.

If the Sturgeon quartzite represents an original sandstone, it is evident from the facts stated above that the old quartz grains have undergone complete recrystallization. The usual conception, since the time of Sorby, of the process by which quartzites are formed from original deposits of sands is that new quartz is deposited around each fragmental quartz grain, in similar crystallographic orientation with it, and that neighboring grains thus enlarged finally interlock by mutual limitation of one another's growth. This explanation evidently can not account for the background of large interlocking quartz areas in these rocks, for if it were true it would be necessary to assume that the quartz grains were less numerous in the original deposit than those of almost any other mineral, in some slides even than the titanite or chlorite. There seems to be but one escape from the conclusion that the large quartz areas must each represent a number of original fragmental quartz grains, which as deposited must have lain in the rock with their crystallographic axes disposed entirely at haphazard, and that is the hypothesis that this quartzite was not originally a sandstone, but consisted mainly of soluble and easily replaceable material, such as limestone, with the fragmental particles scattered through it, and that the large quartzes of the background have replaced this soluble substance. I have been able to find no positive evidence to support this hypothesis, and I am compelled to believe that the rock was a sandstone in which in some way not easy to understand considerable numbers of adjacent quartz grains have united to form or have been absorbed into a new individual, leaving absolutely no trace of their former separate existence. The introduction of new silica, or the separation of silica from decomposing silicates in the rock itself, may well have been essential factors in the recrystallization. I shall make no attempt to explain the process further than to point out again its probable analogy with the process by which the new microclines were formed in the Archean mica-schists.

The close alignment of the clastic minerals inclosed in the large quartz areas, their frequent fracture, and their occasional separation indicate that the time of recrystallization probably followed a period of stress, while the very vague parallel elongation of the individuals of the background in the unstrained sections would seem to show that they crystallized under static conditions. Unquestionable proof of a period of stress later than the crystallization is given by the numerous slides in which these grains are seen to have suffered fracture and distortion. The microscopical study of the quartzites thus supplies important evidence, not afforded by the outcrops, as to the orographic history of the district.

SECTION V.—THE RANDVILLE DOLOMITE.

The Sturgeon quartzite is succeeded by a formation consisting, so far as is known, almost wholly of crystalline dolomitic rocks. Excellent exposures belonging to this formation are situated within a short distance of the Randville station on the Milwaukee and Northern Railway, and it may therefore conveniently be named the Randville dolomite.

DISTRIBUTION.

Owing both to its great thickness and to its intermediate position in the series, the Randville dolomite in the Felch Mountain tongue covers a larger share of the surface than any other member of the Algonkian succession. The overlying formations are frequently interrupted because of the changes in direction of pitch of the secondary synclines in which they occur. In these gaps the dolomite covers the whole interior of the synclinorium. Where the higher formations are present they divide the dolomite into two or more parallel east-west belts, one of which lies south of the northern quartzite and the other north of the southern. Only in portions of secs. 35 and 36, T. 42 N., R. 29 W., where the rise in the axis of the main syncline has lifted it above the present surface of denudation, is the dolomite entirely absent from the main trough.

RELATIONS TO STURGEON FORMATION.

No actual contacts between the Sturgeon and Randville formations have been found, but from their close association and continuity, as well as from the structural characters, when these are determinable, they seem everywhere to be strictly conformable. Near the quartzite the dolomite becomes distinctly more impure and contains a larger proportion of silicates and quartz. It is altogether probable that between them come transition beds, as, indeed, is shown by some of the drill records. In one of these "talcky mica-schists, micaceous limestone, altered actinolite-schists, and quartzite" are described as being interbedded near the junction.

THICKNESS.

The determination of the thickness of the Randville formation is beset with the same difficulties that are encountered in the case of the quartzite, namely, the uncertainty as to the exact position of the contacts and the possibility of faults and subordinate folds within the formation itself. The best sections give a wide range of values, from a minimum of about 500 feet near Felch Mountain to a maximum of nearly 1,000 feet in the western part of the district. While the discrepancies may be due partly to lack of precision in the data, it is probable that the thickness of the formation is not uniform, but really increases from east to west. On the Fence River, 18 miles northwest of Randville, the thickness is probably about 1,500 feet. Accordingly, accepting each of these determinations as approximately correct, 700 feet may be taken as a fair estimate of the average thickness of the Randville dolomite within the Felch Mountain range.

PETROGRAPHICAL CHARACTERS.

The outcrops of the Randville formation consist exclusively of dolomite, more or less pure and always thoroughly crystalline. A few comparatively thin layers of schists, probably both micaceous and amphibolitic, and also of quartzite, are mentioned in certain drill records to which I have had access, as occurring interbedded with the dolomite; and while the lithological determinations are perhaps not entitled to much weight, they at least prove the existence of rocks which are not dolomite within the formation. In the field, however, such interbedded layers do not outcrop, and they must constitute an extremely small part of the total thickness. From the results of our work the Randville formation appears as a lithological unit.

Macroscopically, the dolomites are rather coarse-grained marbles, of various colors, of which pinkish or bluish white are the most common. They always inclose, more or less abundantly, large flakes and aggregates of tremolite, which are particularly noticeable from their projection above the weathered surface. Occasionally, tremolite and other silicates are the most abundant, and sometimes for small thicknesses essentially the only constituents. Quartz and chlorite are also often present, but in much smaller amounts. The weathered surface is usually dulled to a light brown or creamy yellow, in a thin, superficial skin, but is not deeply iron-stained, except when the silicates containing ferrous iron are present.

The following partial analyses of three specimens from different parts of the range show that the carbonate is normal dolomite. The insoluble portion consists chiefly of tremolite. These analyses were made for me by Mr. G. B. Richardson, a graduate student in geology in Harvard University.

Partial analyses of three specimens of Randville dolomite.

	I.	II.	III.
Insol. in HCl	2.0	9.7	29.1
Fe_2O_3	1.2	2.1	2.2
$CaCO_3$	53.2	48.9	39.3
$MgCO_3$	42.3	38.0	27.7
Total	98.7	98.7	98.3

The outcrops, while often entirely massive, usually possess decided structural features. These are indicated by color-banding, by differences in texture, and by the banded arrangement of the components. Slight variations in the body color of the rock, proceeding from no distinguishable variation in composition, often occur in alternate parallel layers, which are persistent within the limits of observation. With the color-banding often go variations in texture, which, however, are neither so regular nor nearly so persistent. The characteristic form taken by these is thin layers, which, as they continue, open out into nodules. Such layers consist of closely packed crystalline grains, very much coarser than the body of the rock, which have grown normal to the boundaries. Adjacent layers are not strictly parallel, and sometimes cross each other. They are believed to represent ancient fracture and slipping surfaces, following very closely the original bedding, in which the new carbonate individuals have had room for larger growth. The arrangement of the accessory minerals, especially the tremolite, also is usually a banded one. Layers rich in tremolite alternate with layers poor in tremolite, while within the layers the orientation of the tremolite individuals is usually at random. The structure brought out in these various ways is, on the whole, a parallel structure. It corresponds with the strike and dip in all the localities where these can be independently confirmed by the attitude of the adjacent formations, and the layers have also been thrown into minor folds. I therefore regard the structure as having originated partly in chemical differences in the material originally deposited and partly in secondary growths in the open spaces and rubbing zones determined by relative movements along the surfaces of easiest fracture at the time of the earliest folding, and for both reasons preserving in the subsequent metamorphism the true stratification of the formation.

Under the microscope the dolomites show no features of special interest. They are thoroughly crystalline rocks, composed chiefly of coarse grains of dolomite, with which are associated a considerable number of accessory minerals. Of these the most important are tremolite, diopside, chlorite, muscovite, phlogopite, quartz, and rutile, while apatite, tourmaline, pyrite, and magnetite are rare. The dolomite is by far the most abundant constituent in most of the slides, and furnishes the general background for the accessories. The shape of the grains in many sections is decidedly oval, and the long axes lie in the same direction, thus producing a foliation.

Tremolite is abundant in some of the sections, and is entirely absent from none. It occurs in long-bladed individuals and aggregates, usually bounded by the prism, but one or both pinacoids are also sometimes present. It includes portions of the carbonate background. Diopside is rather rare. It occurs usually in small single individuals with sharp crystal outlines. It is sometimes surrounded by tremolite, from which it is distinguished by its high obliquity of extinction and almost rectangular cleavage. Partings parallel to both pinacoids, as well as a transverse parting in prismatic sections, are also observable. Quartz occurs in irregular grains, completely interlocking with the dolomite and in some cases with tremolite. In the slides examined it is in all cases a secondary as well as a rare constituent. In no case is there any indication that it is clastic. Chlorite is an abundant constituent of some of the slides, while from others it is entirely absent. Muscovite in little frayed plates is plentiful in some sections. Quite possibly some of these may be original clastic particles. The most interesting mica, however, is phlogopite, which is very abundant in one locality near the base of the formation. It occurs in large, cleanly bounded plates, each of which is a multiple twin and evidently a product of secondary crystallization. Some of these plates have been strongly bent, thus showing that the dolomite, like the quartzite, has been deformed since it crystallized.

The thin sections therefore show that the rocks of this formation have experienced even more nearly complete reconstruction than is shown in the case of the quartzites, for here none of the constituents, except possibly some of the smaller micas, are present in their original form. The evidence of disturbance after crystallization is of similar character and equally strong. Accordingly, a close agreement in the sequence and in the character of the principal events thus indicated in the history of the two rocks may be recognized. These considerations make it quite certain that the recrystallization of the two formations was essentially contemporaneous. From the character of the accessory minerals in the dolomite it is probable that the crystallization was not accompanied by the introduction of foreign material from outside, in notable quantities, but consisted in a mineralogical rearrangement of the elements present in the rock from the beginning.

SECTION VI.—THE MANSFIELD FORMATION.

Above the Randville dolomite comes a formation composed chiefly of fine- to medium-grained mica-schists. Owing to their exceedingly soft character and small thickness, these rocks are exposed naturally in only a few localities in the Felch Mountain area. A series of phyllites, less metamorphic, but otherwise similar and occupying the same stratigraphic position immediately above the dolomite, outcrop characteristically at the Mansfield mine, and especially north of it, near the Michigamme River, in T. 43 N., R. 31 W. For these reasons it is convenient to name the formation from the Mansfield locality.

DISTRIBUTION.

The existence of the Mansfield formation in the Felch Mountain trough is known mainly from test pits and from records of diamond-drill borings and early explorations. Fortunately, these are so widely distributed that the persistence of the formation is well proved. Many drill holes have passed through it into the dolomite. Immediately above it comes the magnetic Groveland formation, which, even when covered, betrays its presence to the compass needle. With the upper and lower limits thus determined, and with the large body of data supplied by the test pits and records, there is no difficulty in indicating its approximate boundaries for the greater part of the map.

PETROGRAPHICAL CHARACTERS.

The hand specimens from the various test pits, the drill cores, and the few small outcrops, indicate that the Mansfield formation is quite uniform in character throughout the Felch Mountain area. The great majority of the specimens are fine-grained mica-schists, the color of which varies from light to dark according as muscovite or biotite is the predominant mica. In some localities garnets are very abundant, especially near the contacts with intrusives. It appears from the records of explorations that thin seams of jaspery iron ore interlaminated with the schists have been encountered in occasional drill holes and test pits, but no specimens of such occurrences have been obtained. Their existence is of interest as showing the likeness in an important character of these more altered rocks with the slates occupying the same relative position in the Iron Mountain and Norway areas of the Menominee district.

The outcrops and specimens are frequently well banded in lighter and darker layers, the color banding in same cases not coinciding with the schistosity. Just south of the Groveland mine, in a test pit which was being sunk at the time of my visit, the color bands which mark the true stratification, as shown by the contact with the underlying dolomite, are closely crumpled and cut by the foliation of the rock, which is much the more distinct of the two structures.

Near the contact with the overlying Groveland formation the mica-schists become both more siliceous and more ferruginous than usual, and there is accordingly a distinct passage between the two formations. This does not necessarily signify a transitional character in the original sediments, but may be altogether due to the downward transportation of silica and iron from the upper rock.

The mica-schists are generally very tender rocks, and material on the dumps of test pits sunk in them is usually far gone in decomposition after a few years' exposure to the weather. Even from the freshest specimens the little flakes of mica often rub off on the fingers. Where penetrated by intrusions, however, as in sec. 35, T. 42 N., R. 30 W., and in sec. 31, T. 42 N., R. 28 W., they become very much harder.

Under the microscope the rocks of this formation are seen to be in the main thoroughly crystalline though very fine-grained aggregates of biotite, muscovite, chlorite, quartz, and feldspar, with the iron ores, rutile, tourmaline, and apatite as the accessories. Garnets are abundant in some of the sections, and with these also occur actinolite, epidote, titanite, and an undetermined colorless amphibole in stout single prisms. In the eight thin sections which have been examined from this formation I have found no material which is certainly original and fragmental, although almost every slide contains grains that may possibly be such. On the other hand, it is evident that the large majority of the individual grains have formed in place. The schistose structure is determined by the general parallelism of the long axes of the constituent grains. Since the greater part, if not demonstrably all, of these grains have formed in this position, and have not been forced mechanically into it, the cases in which the schistosity cuts the bedding support the inference as to the time of the general recrystallization of the series grounded on the facts observed in the lower formations, namely, that this time followed a period of great stresses. A period of still later stress has affected the recrystallized constituents of the schists, just as it has those of the quartzite and dolomite. It is shown by lines of fracture crossing the slides, along which ferric iron has infiltrated, and by occasional straining and bending of the quartz and mica.

SECTION VII.—THE GROVELAND FORMATION.

The ferruginous rocks which compose this formation are well exposed in the central portion of sec. 31, T. 42 N., R. 29 W., in the vicinity of the abandoned Groveland mine, and thus may properly be termed the Groveland formation.

DISTRIBUTION.

The magnetite, which is always an abundant constituent of the Groveland rocks, has made it possible to trace them for long distances throughout the trough, by means of the disturbances effected in the compass needles. The same disturbances had led to the sinking of a great number of test pits by former explorers for iron ore, and the material thrown out of these has served to check and substantiate the inferences from the magnetic attractions. Finally, in several localities, excellent natural exposures of the iron-bearing rocks occur. So, altogether, the available data as to the surface distribution of the Groveland formation are fairly satisfactory.

PETROGRAPHICAL CHARACTERS.

The rocks of the Groveland formation have a general family likeness, which makes it very easy in the field to distinguish them from all the other members of the Algonkian series. Among them two varieties may be recognized, the usual one of which consists of quartz and the anhydrous oxides of iron, while the other, much rarer, is made up essentially of an iron amphibole, quite similar to the grünerite of the Marquette range, with quartz and the iron oxides as associates.

As seen in the field, the rocks of the first kind are generally siliceous, heavy, and dark colored, the weight and color, which has a tinge of blue, being due to the presence of abundant crystalline iron oxides. A large part of the silica is easily recognized as crystalline quartz, in some instances, indeed, in the form of detrital grains. The visible iron oxides occur both as little spangles of specular hematite and in irregular dark-blue masses and single grains, the latter often having the crystalline form of magnetite. Many, if not most, of these last, however, seem to be really martite, as they give a dark-purple streak, and in fine powder are not attracted by a hand magnet.

In the first kind there is much variety in external appearance determined by the variable proportions in which the chief constituents occur and by the different ways in which these constituents are arranged. Considerable areas, for example, consist mainly of granular quartz, merely darkened by the intimately mixed iron oxides, and in these, so far as the eye can judge, the rock is a ferruginous quartzite. Closely connected with such occurrences, or included most irregularly in them, are others in which the ferruginous constituents are so abundant and the quartz is so subordinate that they would pass for lean iron ores. Between such rare extremes we find all intermediate proportions of mixtures of the quartz and the iron oxides.

One form of arrangement of the constituent minerals is in narrow parallel bands, in which the quartz and the iron oxides alternately predominate. Such alternations are sometimes so frequent and regular as perfectly to reproduce the lean "flag ores" of the Marquette range. Regular banding, however, is not common. Usually the light or dark bands are suddenly cut off as if by faulting, or taper to thin edges, or occur in separated pebblelike forms. Neighboring lenses and fragments of bands are most frequently roughly parallel with one another, but often they are jumbled together in the greatest confusion. They no doubt represent an original, more continuous banding, which has suffered brecciation. Masses thus shattered are also traversed and cemented by numerous small veins filled chiefly with quartz, chalcedony, and specular hematite. The positions in which the separated patches of the Groveland formation now survive—namely, in and near the bottoms of synclines, and therefore at the points where sharp turning and crowding together have taken place—sufficiently explain the extensive brecciation observed in these brittle beds.

Very prevalent in all the varieties of the first kind of rock, in massive banded and brecciated alike, is the occurrence of some of the constituents in small roundish spots, which give to the whole formation a very detrital aspect. In the quartzitic phases, as well as in the most ferruginous bands, the eye recognizes, besides the little grains of clear quartz, which seem to be unquestionably detrital, numerous small dots of blue hematite and bright-red dots of jasper. These are more abundant in some layers than in others, but seem never to be entirely absent, and are exceedingly characteristic of the formation wherever found.

In a few localities the iron constituent is almost entirely in the form of little micaceous scales of specular hematite which have a parallel arrangement. Hematite-schists, however, are not very common. The best examples occur in the northern part of sec. 36, T. 42 N., R. 30 W., along the northern syncline.

The grünerite-schists have been found in small thickness and in only one locality, namely, in the southern parts of sec. 33, T. 42 N., R. 28 W., where they underlie, in a series of small anticlines and synclines, banded siliceous beds composed of quartz and magnetite or martite.

Under the microscope the essential constituents of the first or prevalent kind of rock of the Groveland formation are quartz, magnetite, martite, and hematite. With these much smaller quantities of chlorite and epidote are generally associated as accessories. Of rarer occurrence are calcite and probably siderite, sericite, tremolite, grünerite, apatite, pyrite, limonite, chalcedony, rutile, titanite, tourmaline, microcline, and plagioclase.

Quartz occurs in two ways; first, as rounded detrital particles, and, secondly, as grains which have crystallized in place. The detrital grains, which are easily recognized by their form, size, and freedom from inclusions of the ores, consist of single individuals, often surrounded with rims of later growth. They are also usually larger than the neighboring indigenous grains. While detrital quartz is not abundant, and indeed is often entirely absent from the thin sections, its occurrence is of interest as conclusively establishing the sedimentary origin of the iron-bearing formation.

The secondary quartz grains are the most abundant constituents of the thin sections, and form the general background for the other minerals. They always inclose separate crystals of the iron oxides, usually in great abundance, and often also chlorite and little prisms of apatite. These grains usually have the shape of irregular polygons bounded by straight lines, frequently with reentrant angles, and adjacent grains completely interlock. In size the secondary quartz grains range from about 0.03 to 0.4 mm. in diameter. Grains of approximately the same size occur together in bands or in the rounded areas to be mentioned later.

The iron ores include both magnetite or martite and crystalline hematite, the former being much the more abundant. The magnetite and martite can not be distinguished in thin section, as their color in reflected light and their crystalline form are the same. They occur in irregular bands composed of aggregates of crystals, the edges of which interlock with the adjoining and inclosed areas of quartz, and show the triangular, rhombic, and square sections of magnetite individuals. Magnetite also occurs in isolated irregular aggregates interlocking with the secondary quartz grains, and of similar dimensions to these, but is especially abundant as single minute crystals interposed in the grains of secondary quartz, ranging in size from such as are barely recognizable under a No. 9 objective to octahedra 0.03 to 0.05 mm. in diameter. A single quartz grain 0.25 mm. in diameter may inclose a hundred or more such minute individuals. Hematite is much rarer than magnetite, and seems to be found only in the secondary quartz grains or in veins. In the former it occurs in separate crystalline plates, of deep-red color in transmitted light, under the same conditions as to number and size as the magnetite crystals. Throughout some sections, and in certain bands and rounded areas in other sections, it is more abundant as inclosures than magnetite. Such rounded areas formed of several quartz individuals, each of which thus holds a great number of hematite plates, appear microscopically as the little jasper dots already described. Chlorite and apatite are also often embedded in the secondary quartz grains, the former in thin plates and the latter in small hexagonal prisms. Epidote is quite common in small irregular areas intercalated between the quartz grains or in the magnetite bands.

Many of the slides contain a small amount of a rhombohedral carbonate, much if not all of which is calcite. It occurs chiefly in the quartz bands, in irregular grains which interlock with the secondary quartz grains and, like them, inclose little crystals of magnetite and hematite. Specimens, the slides from which contain carbonates, effervesce freely in scattered spots with cold dilute acid. Most of the carbonates are clear white under the microscope, and are evidently calcite. Sometimes, however, the carbonate areas have a very light brown tint and are partially surrounded with a limonite border and penetrated by brownish filaments along the cleavages. In such cases it is difficult to decide whether they are calcite stained with limonite or siderite partially oxidized to limonite. However, if part of these areas are siderite it is nevertheless certain that the small magnetite and hematite crystals which they inclose have not been derived from them. These little crystals are inclosed in the carbonates just as they are in the adjoining grains of secondary quartz, while the alteration of the siderite, if it is siderite, is to limonite. Carbonates also occur with tremolite, quartz, chalcedony, epidote, and hematite in the numerous thread-like veins which traverse some of the thin sections.

The feldspars have been found in only a few thin sections, as well-scattered but minute angular grains of microcline and plagioclase. Many slides, however, contain areas of matted sericite and quartz, which probably represent original grains of feldspar.

Rutile and tourmaline are also occasionally inclosed with the iron ores in the grains of secondary quartz. Small roundish areas of titanite, probably detrital, occur very sparingly in a few of the thin sections.

The most interesting features of the thin sections are certain very distinct structural arrangements of the quartz and iron ores. In almost every slide, in ordinary polarized light (with the analyzer out), the minute interpositions of the iron ores are seen not to be equally distributed throughout the background, but to be concentrated in round or oval areas never exceeding a millimeter in diameter. These oval forms are confined to the more siliceous bands, and are much more distinct in some of the slides than in others. Often the outlines are reenforced by rims of closely-set magnetite individuals, somewhat coarser than the dust-like crystals within. The long diameters of adjacent ovals are parallel to one another and to the band in which they lie, and are often closely packed, like pebbles. Occasionally the little grains of iron ore within the ovals have a distinctly concentric arrangement.

Between crossed nicols these areas are seen to have had in some instances a distinct influence on the crystallization of the secondary quartz. When they are large and closely packed each oval includes a large number of interlocking quartz grains, and occasionally in such cases there is some difference in size between the quartz grains inside and those outside the ovals. In the triangular and quadrangular areas lying between the larger ovals and bounded by curving segments of their perimeters the secondary quartzes are frequently larger than those within, and are placed normal to the boundaries, precisely as if they had grown outward from the ovals into free spaces. Often, however, a single individual of secondary quartz lies partly within and partly without the oval. On the other hand, when the ovals are small one or more may be completely or partially inclosed within a single quartz individual. The interlocking quartz grains within the large ovals show no indications of having formed in open spaces, even when the included iron ores have a tendency, as occasionally happens, to a concentric arrangement. The faulting and brecciation so plainly seen in many of the thin sections have also displaced and separated the oval areas. It seems perfectly clear to me that these forms represent a structure originally possessed by the rock from which the various phases of the iron formation have been derived, and which has been preserved through the subsequent metamorphism.

From the facts described above it is evident that the Groveland formation is made up of highly metamorphic rocks, which still, however, retain some original clastic material as well as certain original structural characters. With the exception of the rather rare clastic grains of quartz, titanite, feldspar, etc., the minerals which now chiefly compose these rocks—namely, quartz and the crystalline iron oxides—are not clastic, but have crystallized in place. It is a matter of great interest, therefore, to determine, if possible, in what form these constituents were present in the original deposit. On this question the microscopic structure seems to me to have a distinct bearing.

Forms similar to the ovals in these rocks occur in the iron-bearing formations of other districts in the Lake Superior region. In the Gogebic district of Michigan and Wisconsin, Irving and Van Hise have supposed [1] that such forms have resulted from processes of solution and redeposition after the rock was formed, and are therefore concretionary. They regard that portion of the formation in which such forms occur—which they have named ferruginous chert—as an alteration product from an original deposit of cherty carbonate of iron. On the other hand, Spurr has shown [2] that similar forms are exceedingly abundant throughout the iron-bearing formation of the Mesabi range of Minnesota, and are there original. In the least altered stages, Spurr has found that these oval and roundish areas are filled with a green substance which chemically is a hydrous silicate of iron, in composition very close to glauconite, with which also it is optically identical. The oval and rounded forms, moreover, are those characteristic of glauconite in green sands of all geological ages. Starting with this original substance, which is very unstable when exposed to oxidizing and carbonated waters, Spurr has traced an interesting series of changes, the final result of which along one line is the complete oxidation of the iron to hematite or magnetite and the separation of the silica as chalcedony and quartz. Throughout these changes the original form of the glauconite grains is preserved in the new minerals. Without going into the details of these changes and without accepting Spurr's conclusions in their entirety as to the steps involved, he has clearly shown, as I have satisfied myself from the study of the large number of Mesabi slides in my own collection, that the green glauconitic substance is the source of the iron and silica of the ferruginous cherts of the Mesabi range, and that the peculiar spotted structure of these cherts is inherited from the original forms of the glauconite grains.

Between the ferruginous quartzites of the Groveland formation and the ferruginous cherts of the Mesabi range there is a very close resemblance, especially in structure. The essential difference is that the former contain little or no chalcedony, the silica being crystallized quartz, while the latter have a great deal of chalcedonic silica. The

[1] The Penokee-Gogebic iron-bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, Vol. XIX, 1892, pp. 254–257.

[2] The iron-bearing rocks of the Mesabi range in Minnesota, by J. E. Spurr: Bull. Geol. and Nat. Hist. Survey Minnesota, No. X, 1894.

former contain small amounts of detrital material which the latter generally lack; but the essential difference between them is one of degree of crystallization only.

If the silica of the Mesabi cherts had originally crystallized entirely as quartz, or if, after passing through the stage of mixed chalcedony and quartz, it had subsequently crystallized as quartz, there would be no difference between the iron formations of the two districts.

There are, then, at least two possible forms in which the iron and silica of the Groveland formation may have been deposited originally, as indicated by the conclusions of observers who have studied the similar iron-bearing formations in other districts of the Lake Superior region in which these formations are less altered than here. Either of these forms—namely, a cherty iron carbonate, as on the Gogebic range, or a glauconitic green sand, as on the Mesabi range—could give rise, under the action of vigorously oxidizing waters, to rocks of the mineralogical composition of those in question, and, since no trace of either original form has been found in the Groveland formation, the choice between them may perhaps be regarded as still open. My own opinion, based on the microscopic structure, which, as I interpret it, shows that the Groveland formation was in the beginning largely made up of rounded particles having the same general form as the glauconite grains of the Mesabi range, is that the iron and silica were originally present largely in the form of glauconite.

SECTION VIII.—THE MICA-SCHISTS AND QUARTZITES OF THE UPPER HURONIAN SERIES.

Through the eastern part of sec. 32, T. 42 N., R. 28 W., and entirely across sec. 33 runs a belt of mica-schists and thin-bedded ferruginous quartzites which seem to have unconformable relations with the formations just described.

The general relations indicate that the ferruginous mica-schists and quartzites are part of an upper series which overlies unconformably the Groveland and all the lower formations. This series has not been found elsewhere in the Felch Mountain area.

PETROGRAPHICAL CHARACTERS.

The rocks of this formation, as seen in the outcrops, are principally soft and deeply iron-stained mica-schists, in which occur frequent thin beds of ferruginous and micaceous quartzite.

Under the microscope the schists are composed mainly of biotite, quartz, muscovite, and magnetite. Chlorite as an alteration product of the biotite is frequently abundant, and garnets also occur in some sections. These schists are much coarser in grain than those of the Mansfield formation, and are wholly crystalline. No clastic material has been recognized in the thin sections.

The quartzites also are thoroughly recomposed rocks without recognizable clastic particles. Quartz is the most abundant constituent, and with it muscovite, biotite, and magnetite are constantly associated. The micas and the magnetite are frequently inclosed in a background of large interlocking quartz grains, which is very similar to the background of the Sturgeon quartzite. Such inclosures lie in general alignment throughout the thin sections, but, unlike many of the inclusions of the Sturgeon quartzite, they seem not to be clastic particles, but to have crystallized in place.

The rocks of the upper series, like those of the lower series, are greatly altered. From their mineralogical composition and structure it is evident that as originally deposited they consisted of beds of mud separated by thinner beds of sand; but as they now stand they have been as greatly changed from their original condition as the bedded rocks below. Also, since the time of metamorphism they have been subjected to stress, as is clearly shown by the optically strained condition of the secondary quartz grains and the bending and twisting of the micas.

From these facts we may reasonably infer that the general metamorphism of both series was accomplished after the deposition of the upper series and before the latter was folded. Reconstruction so complete as that shown by the upper series is not believed to take place except at considerable depths below the surface, and hence the part of the upper series now visible must then have been deeply covered by overlying rocks, which afterwards were entirely swept away before the deposition of the Cambrian. In the earth movements which folded this mass of material and brought it up within the reach of denuding agents, we may recognize the causes which have strained and broken the secondary minerals of both series alike.

SECTION IX.—THE INTRUSIVES.

The Algonkian formations of the Felch Mountain area have been cut by later intrusives, among which both acid and basic rocks are represented. The latter have also been recognized in the Archean, in which, indeed, the freshest and least altered occurrences have been found.

The acid rocks consist of fine to medium grained pink granites, occurring in narrow dikes. A number of these dikes have been found in the Sturgeon formation, both in the area of fine exposure on the south side of sec. 35, T. 42 N., R. 30 W., and in secs. 34 and 35, T. 42 N., R. 29 W.

Two granite dikes are also known in the highest member of the lower series, but none have been detected in the Randville or Mansfield formations. One of these occurs on Felch Mountain; the other, a very coarse pegmatite, is found cutting the Groveland formation in the southern part of sec. 33, T. 42 N., R. 28 W.

Basic dikes and intrusive sheets are found in many localities. Some are highly schistose and greatly altered; others are massive and but little changed. They probably belong to many eras of eruption. The least altered are diabases, in one occurrence of which from the Archean the augites are almost intact.

CHAPTER IV.

THE MICHIGAMME MOUNTAIN AND FENCE RIVER AREAS.

By a reference to the general map, Pl. II, it will be seen that an oval-shaped Archean area, about 11 miles long from northwest to southeast and having an extreme breadth of nearly 4 miles, runs through portions of Ts. 44, 45, and 46 N., Rs. 31 and 32 W. The country to be described in the present chapter includes that portion of this Archean mass (together with the younger rocks on its eastern border) which lies east of the line between Rs. 31 and 32 W., as well as the territory to the south in the prolongation of the axial line, as far as the south line of T. 43 N., R. 31 W. A gap about 6 miles broad not covered by our work intervenes between this arbitrary southern boundary and the western termination of the Felch Mountain work at Randville.

In the northern portion of the area now under consideration (which lies along and is twice crossed by the Fence River) the geological structure is exceedingly simple, while in the southern portion, especially in the neighborhood of Michigamme Mountain, it is rather complex. The boundary between these two divisions falls in the neighborhood of the mouth of the Fence River, in sec. 22, T. 44 N., R. 31 W. It is therefore convenient in what follows to refer to the northern portion as the Fence River area and to the southern as the Michigamme Mountain area.

The broad geological structure of the whole territory of which the above-mentioned Archean oval is the center is evident at a glance. It is an anticlinal dome the core of which is Archean, around which the younger Algonkian formations run in a series of concentric rings, on all sides dipping outward from the nucleus. In the Fence River area, on the eastern long side of the dome, the Algonkian formations have a constant eastward dip and are free from important secondary folds. In the Michigamme Mountain area, however, which lies in the prolongation of the main axis of the dome, these encircling formations fall away gently to the south in a series of waves, produced by several concentric minor folds transverse to the main axis. Of these minor folds but one is at all distinct on the east side of the general anticlinal axis, while to the west of this axis at least three are well made out within the Michigamme Mountain area. The much greater breadth of the Algonkian formations on the west side of the dome than on the east is probably due to the persistence of these minor folds toward the northwest.

The general character and aspect of the formations of the two areas and their succession are in so many respects identical with those of the formations of the Felch Mountain range that no doubt can be entertained that they are really the same formations. Nevertheless, certain differences mark these rocks with a distinct individuality, and these differences will be considered in detail in the descriptions of the several formations. In general they may be summarized as involving a great reduction in thickness of the Sturgeon formation, with a corresponding increase in the Randville dolomite, the appearance of surface igneous rocks at the Mansfield horizon in the Fence River area, and a less uniform and complete metamorphism in the whole Algonkian series.

SECTION I.—THE ARCHEAN.

The rocks of the Archean core are well exposed through the west-central sections of T. 44 N., R. 31 W., while farther north, in T. 45 N., R. 31 W., outcrops are few and scattered. Much less attention was paid to this area than to the Felch Mountain Archean. Our work, as a rule, stopped with the location of the boundary, and therefore the following brief statements as to its character embody observations along the southern and eastern margins only.

The prevalent rock in the Archean is granite, varying from medium to coarse grain, and often carrying very large porphyritic Carlsbad twins of flesh-colored microcline. Banded gneisses and mica-schists, such as are so abundant in the Felch Mountain Archean, are rare, but not entirely absent. While in many localities the granites are much crushed, and even sheeted along adjacent parallel fractures, their originally massive character is sufficiently evident. They have the composition and structure of typical igneous granites. The primary minerals are entirely without definite arrangement.

In the Archean areas granites of two ages have been found, the younger in the form of narrow dikes. Basic igneous rocks, also in dike form, are rather abundant. One of these under the microscope proves to be a slightly altered diabase, in which the augite is always intact. These acid and basic intrusions are probably connected with the surface flows of like character which are so abundant at the Mansfield horizon along the Fence River.

Of much interest is the occurrence of a small mass of porphyry in contact with the Archean and below the lowest Algonkian sedimentary formation. The locality is in sec. 21, T. 44 N., R. 31 W., in the southeast quadrant of the Archean oval. The upper surface of contact of this sheet with the lowest sediments is covered, and hence it is not entirely certain whether it is intrusive or extrusive, and therefore whether it belongs to Archean or Algonkian time. The general relations, however, appear to indicate that it is a surface flow which suffered erosion before the deposition of the basal Algonkian member, and is therefore to be classed with the Archean. The exposure is 250 feet long by 100 broad. The lower portion of the porphyry contains a number of fragments of the underlying granite, one of which is over 4 feet in length.

SECTION II.—THE STURGEON FORMATION.

The Sturgeon formation as a distinct member of the Algonkian series is hardly known in this district, apart from the Randville formation. Nevertheless, purely clastic sediments unmixed with the carbonates of calcium and magnesium were deposited and are now visible along one section between the Archean granites below and the dolomites above, and for these it is convenient to retain the name, although their total thickness is so small and their continuity so uncertain that they can not be shown on the geological map. The general conditions of sedimentation here were such, perhaps in consequence of the low relief of the neighboring land, that limestones began to form a relatively short time after the submergence of the Archean surface, so that the two lower Algonkian formations probably by no means represent equal periods of time with the same formations in the Felch Mountain range. The time represented by both together is probably not greatly different in the two areas, but since in the entire absence of fossil evidence it is impossible to draw the line of equivalence, while at the same time the lithological break is a sharp one, it seems desirable to carry over the Felch Mountain names, extending the Randville dolomite downward to the lower limit of limestone deposition, and retaining the name Sturgeon formation for the basal sediments which are free from carbonates.

These basal sediments are found only in sec. 15, T. 44 N., R. 31 W., where they are exposed in low-lying outcrops in the banks and bed of the Fence River. Elsewhere, throughout the 10 or 12 miles through which the Archean extends in this area, no outcrops have been found in the flat and generally swampy belt which intervenes between it and the dolomite above.

The exposures referred to consist of soft light-weathering slates and graywackes, with which are interbedded layers of coarser texture. They are very evenly banded in pale shades of yellow, red, and green, and the structure thus brought out dips eastward at an angle of 52°. Besides this, a secondary cleavage is quite prominent, especially in the finer-grained beds, also dipping eastward, but at a considerably higher angle. At the eastern side of the exposure the slates are overlain by the lowest marble beds, here extremely impure, and highly charged with chlorite and quartz sand. The thickness of slates exposed is about 100 feet, and between the Archean and the most western outcrops there is room for about as much more. The total thickness, then, can not exceed 200 feet.

A thin section of a specimen from one of the coarser layers shows it to be a graywacke, the most prominent constituent of which is quartz in small roundish and oval grains. These are embedded in a groundmass composed of chlorite in minute irregular plates, ferric oxide, and kaolin. The quartz grains, while having generally clastic shapes, are bounded by minutely rough edges which interlock with the fibrous minerals of the groundmass. Evidently much new quartz has been deposited round the original grains.

SECTION III.—THE RANDVILLE DOLOMITE.

DISTRIBUTION AND EXPOSURES.

In the Fence River area the dolomite, as already stated, lies on the east side of the Archean, and occupies a belt over half a mile in width, which extends from the mouth of the Fence River on the south for about 10 miles to the north and west, to the western boundary of the area, near the northwest corner of T. 45 N., R. 31 W. In this distance it is twice crossed by the river, and on these natural sections and in their neighborhood the only known outcrops of the dolomite have been found. The northern river section passes through secs. 22 and 28, T. 45 N., R. 31 W., and discloses an excellent series of closely connected exposures for a distance of about 2,900 feet measured at right angles to the strike. The southern section is 5 miles farther south, and is much less continuous, laying bare only the extreme upper and lower portions of the formation. Elsewhere through the dolomite belt the rock surface is concealed by swamps or glacial drift, to which last it contributes but few scattered bowlders of noticeable size.

South of the Archean dome in the Michigamme Mountain area the dolomite tops the low arch in a broad crumpled sheet, in the minor synclines of which the higher formations are more and more implicated as we go south. This broad sheet, with its included tongues of phyllite, extends to the south line of T. 44 N., R. 31 W., beyond which it disappears beneath the higher formations, except in a single narrow belt which continues along the main axis for about a mile farther south. Exposures sufficient in number to indicate several minor folds are found along the Michigamme River and scattered through secs. 28, 32, and 33, T. 44 N., R. 31 W., and sec. 4, T. 43 N., R. 31 W.

FOLDING AND THICKNESS.

In attitude, the Randville formation in the Fence River division of the district is an eastward-dipping monocline, the inclination of which is generally moderate. The rocks are usually heavily bedded and nearly always show distinct alternations in coarseness and color, so that structural observations are made with much more certainty than in the Felch Mountain range. The more conspicuous minerals secondarily developed here, coarse carbonates and tremolite, have formed chiefly in the old planes of bedding. Oblique structures are generally absent, except in the close vicinity of the basic dikes, which intersect it along the upper river section. The surfaces of contact with the dikes stand at high angles, and nearly parallel to these the neighboring dolomite has well-developed cleavages, along which new minerals have formed, intersecting the true bedding. It is evident that the stronger igneous rocks in these cases have furnished resistant surfaces against which the dolomite has been kneaded in the general tilting of the series.

The eastward-dipping monocline is a simple one, yet the observed angles of inclination are by no means uniform. Thus, along the upper river section the dip ranges from 25° to 60°, with 40° as the mean of about a dozen observations. The variable dips are so scattered through the cross section as to indicate no widespread roll in the formation as a whole, but rather a great number of minor undulations, probably distributed throughout its thickness. Such undulations are visible in some favorable localities, as on the north bank of the river in the NW. ¼ of the NW. ¼ sec. 28, T. 45 N., R. 31 W., where fresh surfaces have been exposed in blasting for a dam. The light-blue and pearly white layers of the beautiful marble here seen are thrown into a series of unsymmetrical folds. The western sides of the little anticlines are short and overturned, while the eastern sides are long and gently inclined. Evidently, if the same system of secondary folding holds throughout the entire thickness of the formation, surface observations would show everywhere eastward dips, at variable angles dependent upon the portion of the fold which happened to constitute the particular outcrop, and gentle dips would be more abundant than steep ones. This would completely explain the observed variations.

Similar lack of regular sequence in the dips is found in the southern river section. Five good observations range between 20° and 58°, all eastward, but none of the exposures is sufficiently extensive to show minor folds. The mean of these observations is about 40°.

The surface width of the dolomite zone on each section is a little less than 3,000 feet, assuming that a fair proportion of the covered zones on each side is underlain by the same formation. If the average observed dip is taken to represent the average dip of the rock, the thickness in each case would be a little over 1,900 feet. This is probably too great, and is certainly too great if the same kind of internal crumpling visible in parts of the upper river section is characteristic of the formation throughout. The average dip evidently would more nearly be represented by the dips of the long eastern limbs of the little anticlines. Assuming that these are less than the mean, we find the average of the dips below 40° to be 30° for each section. This gives a thickness of about 1,500 feet, which still is probably beyond the truth, but is doubtless much nearer it than the first value.

It is interesting to compare this result with the thickness of 500–1,000 feet obtained on the two Felch Mountain sections. A part of the apparent increase is probably due, as already explained, to the earlier beginning of limestone deposition in the Michigamme area. But an important part of it is certainly not depositional at all, but is the result of plications. The whole series here is but gently tilted as compared with the walls of the Felch Mountain trough, and hence the strong horizontal pressures have acted in a direction but slightly inclined to the bedding. The result has been the secondary crumpling within the formation, which must contribute in an important degree to its present apparent thickness.

In the scattered outcrops of the Michigamme Mountain area the dolomite strikes and dips toward all points of the compass. This irregularity is caused by the gentle arching over the general northwest-southeast axis, combined with much sharper local folding about a series of axes which run more nearly east and west. The best-defined east-west folds occur west of the main axis in sec. 32, T. 44 N., R. 34 W., in which three synclines and three anticlines are found along a north-south section 4,000 feet long. The two southern synclines are sufficiently deep to include the overlying Mansfield phyllites. These secondary folds die out toward the main north-south axis and broaden toward the west. East of the main axis but one secondary fold has been recognized—the syncline which forms Michigamme Mountain. This is the deepest of the secondary folds, and the only one containing the Groveland formation.

PETROGRAPHICAL CHARACTERS.

The Randville formation in the Fence and Michigamme Mountain areas is richer in lithological varieties than in the Felch Mountain range. As originally deposited, a much larger proportion of sand and mud was mingled with the carbonates, and the progress of subsequent metamorphism also has been less uniform. Depending upon the interaction of these two factors, there occur, as the extremes of variations, on the one hand coarse saccharoidal marbles, sometimes very pure but most often filled with secondary silicates, and on the other hand fine-grained little-altered limestones, which occasionally are so impure as to be rather calcareous or dolomitic sandstones and shales. The more impure varieties occur, as might be expected, near the contacts with the adjacent formations.

On the Fence River, in sec. 16, T. 44 N., R. 31 W., the base of the dolomite rests on the Sturgeon formation. The rock is filled with grains of quartz and feldspar and scales of chlorite, and is so soft that it may be crushed between the fingers. In sec. 32, T. 44 N., R. 31 W., the top of the formation is in contact with the Mansfield slates, and between them is a complete series of transition beds. Near the junction the limestone becomes dark colored and contains thin bands in which the clayey material greatly exceeds the carbonates. These are succeeded by alternating beds of slate and impure limestone in nearly equal volume, and it is only high up in the slate member that the calcareous bands completely disappear. Apart from these belts of extreme impurity at the base and top of the formation, the presence of scattered fragmental grains of quartz and feldspar is rather general throughout.

The prevalent colors are white, various shades of pink, both light and deep blue, and pale green. Where the rocks are weathered, the usual colors are light brown or buff. The lighter-colored rocks in general are characteristic of the Fence River area, where metamorphism is more uniform and more intense, and the deeper colors of the Michigamme Mountain area, to which the less crystalline forms are wholly confined. Bands, differently colored, are nearly always present in the same outcrop.

In the Michigamme Mountain area the torsional stresses attendant upon the formation of folds in two directions have developed two systems of fracture in the dolomite. In these secondary quartz has formed, occasionally in large amount. Of much interest is the occurrence, in close connection with such vein quartz, of occasional thin bands of pegmatite, doubtless arising from the action of deeply derived waters. In similar spaces coarse secondary carbonates, tremolite, and oxides of iron also have commonly formed. Over the small anticlinal axes and domes of this area the original bands of the rock have often been shattered, and are now recognizable only in displaced fragments cemented together by the new minerals.

In the Fence River area the general secondary folding has been attended with differential movements along the bedding, which left narrow open spaces where the adjacent surfaces failed to fit in their final position of rest. These spaces are now indicated by coarsely crystalline carbonates and silicates arranged normal to the original walls. Where the space was a wide one the outer walls are usually lined with coarse calcite, while the interior is filled with quartz.

In the Michigamme Mountain area certain pink bands of the dolomite have a beautiful oolitic texture, which is most clearly brought out in weathering by the geometrical regularity of distribution of the harder shells or cores of the little rounded grains. The forms are not different from and are quite as distinct as those in the oolitic limestones of recent deposition.

Under the microscope the chief differences in the various thin sections are in degree of metamorphism and in the quantity and character of the foreign fragments. The least-altered varieties are those highest in the series from the Michigamme Mountain area. These consist of a background of extremely fine-grained calcite, with a few rounded fragmental quartz grains and scattered particles of chalcedony. Mixtures of small quartz particles, chalcedony, and calcite, slightly coarser than the background, occur in short vein-like gashes. The prevalent deep color of these rocks is due to the even sprinkling through the background of a black opaque pigment, which may be carbonaceous. Altogether, the microscopic characters are those of a little-altered, slightly cherty limestone.

The more crystalline varieties of the dolomite contain several secondary minerals—tremolite, diopside, chlorite, muscovite, phlogopite, pyrite, and the oxides of iron. Of these, tremolite is very common and abundant, especially in the Fence River area, where the rarer pyroxene diopside also is found. Phlogopite comes in but two of the thin sections, while muscovite occurs in nearly all. The general habit of these silicates is precisely the same as in the dolomite of the Felch Mountain trough. They are developed pari passu with the passage of the unaltered limestone into marble.

The fragmental inclusions within the dolomite are of interest. These are little pebbles of quartz, feldspar, mica, titanite, magnetite, and augite, and are evidently derived mainly from preexisting granites or gneisses. Titanite and augite are very rare; the others are represented in almost every slide. The quartz grains are seldom more than a millimeter in diameter, and commonly are much smaller. While the general shape is oval or rounded in most cases, the perimeters are usually extremely irregular and interlock with the carbonate grains of the background, which indicates that they have been enlarged since deposition by the formation of new silica. This is very evident in the few instances in which the original smooth outline, or part of it, is preserved by a film of different material inside the present perimeter. The feldspar pebbles include orthoclase, microcline, and plagioclase, microcline being the common species. They are usually much decomposed and iron-stained. The feldspars are especially abundant in the slides from the Fence River area.

The clastic pebbles give us striking proof of the general and severe internal strains suffered by the dolomite, the effects of which have healed over without a scar in the carbonate matrix. The pebbles are always optically strained. Very often they are fractured and the parts separated, and sometimes they have been reduced to small fragments. In these cases the breaks have been completely healed by the flow or redeposition of the groundmass in the interstices. These effects are found in greater or less degree in every thin section.

The oolitic varieties are very interesting under the microscope. They consist of little oval or round areas, averaging 2 mm. in diameter, packed together as closely as possible. Each oval consists of a single or compound nucleus, surrounded by several thin and very even concentric layers. The nucleus in a few cases is a single roundish quartz individual, evidently a clastic grain. In most cases, however, it is composed of a great number of minute quartz grains, or of several coarse calcite grains, with films of iron oxide between. The disposition of these separate quartz and calcite individuals is such as to indicate that they have filled interior cavities. The surrounding thin layers are calcite in all cases. Sometimes two adjoining nuclei, each within its own rim of several layers, are together included within a common series of shells. In one such case the outside rim traversed the edges of the rings surrounding one of the nuclei with a decided unconformity, as if the latter had been eroded before the deposition of the former. The oolitic structure, I believe, has not hitherto been noted in limestones of undoubted pre-Cambrian age.

SECTION IV.—THE MANSFIELD FORMATION.

The typical locality of the Mansfield formation is the Michigamme River valley in the vicinity of the Mansfield mine, which lies a mile west of the borders of my field of work and is described by Mr. Clements. The same formation, however, is present in the Michigamme Mountain area, where its relations to the adjacent formations are clearly defined. In the Fence River area rocks of very different character and derivation occur at the Mansfield horizon. These are seen in typical development in the area to the west described by Mr. Clements, on the Hemlock River, and are hence called the Hemlock formation.

The Mansfield rocks of the Michigamme Mountain area consist of phyllites or mica-slates of various colors. They are found in the series of east-west synclines, which have already been described in connection with the Randville formation. The best exposures occur in sec. 32, T. 44 N., R. 31 W., between the center and the west quarter post, and still farther north along the south bank of the Michigamme, in the northwest quarter of the section.

The geological position of the rocks of the area is free from doubt. In the principal syncline of sec. 32 they are seen to overlie the dolomites, and to pass downward into them by a relatively slow gradation, while on the borders of the Michigamme Mountain syncline they are proved to underlie the Groveland formation. The passage to the higher formation likewise is graded, though more rapidly, and is marked in certain bands by an increase in clastic quartz grains and by changes in the character of the matrix in which these are set.

FOLDING AND THICKNESS.

The folding of the Michigamme Mountain rocks, so far as it can be determined in this area, has already been described in the account of the preceding formation. The rocks are known only in the secondary synclines which lie transverse to the general direction of the main axis south of the Michigamme River. In the southern of these synclines, in sec. 32, T. 44 N., R. 31 W., between the limestone rims on the north and south, a superficial width of about 1,800 feet of phyllites is exposed. The most southern exposures dip northward at a low angle. On the northern rim the true bedding is nearly vertical. Elsewhere the vertical cleavage structure alone is distinguishable. The upper limit of the formation is not found in this syncline. Making the most liberal estimate for possible minor crumples, it is improbable that a less thickness than 300 to 400 feet occurs here. On the eastern side of the main axis the phyllites below the Groveland formation are very much thinner than this, the thickness at the Interrange exploration, for example, being only about 100 feet. But there, as well as along the whole western edge of the Michigamme Mountain syncline, the lower contact with the dolomite is probably faulted. It seems entirely safe, therefore, to place the average thickness of the Mansfield formation in the Michigamme Mountain area at not less than 400 feet.

PETROGRAPHICAL CHARACTERS.

The Mansfield formation in the Michigamme Mountain area consists almosts entirely of very fine-grained mica-slates or phyllites. The prevailing colors are dark green, black, and light olive-green. These are often mottled irregularly with red, due to the infiltration of iron oxides along the secondary cleavages. The cleavage surfaces have a dull luster, caused by the parallelism of the micaceous minerals, which are too minute, however, to be distinguished by the eye or lens.

The phyllites are often finely banded in different colors and shades. Near the base of the formation bands of limestone and near the top thin bands of graywacke are interbedded, as has already been stated. Quartz and calcite lenses are not unusual in the minutely puckered portions of the formation.

The secondary cleavage is the prominent structure, and indeed the only structure of the outcrops where the color and texture bandings do not appear. Its general direction is transverse to the main arch, or nearly east and west, and its dip is almost vertical. The north-south compression thus appears to have been the stronger or to have been active somewhat later in point of time than the east-west compression.

Under the microscope the phyllites are seen to be composed principally of fine leaves of muscovite and chlorite, often also with a little biotite, and with a variable and usually small amount of quartz, feldspar, and sometimes calcite. Magnetite, ilmenite, and limonite are usually rather abundant. Pyrite also occurs in a few grains in nearly every slide. The differences in color depend mainly upon the relative proportions of the chlorite and muscovite, the former being characteristic of the dark colored, the latter of the light colored rocks. The very dark green or black varieties contain also an opaque and perhaps organic pigment in very minute particles. The quartz and feldspar grains are usually very small and irregularly shaped. The larger, however, of which a few occur in the slides from the less compressed rocks, have well-rounded contours. In other cases extremely flattened and strung-out lenses composed of many small particles represent what were doubtless originally single clastic grains.

Two varieties of cleavage are well illustrated in the thin sections—that caused by the parallelism of the component minerals, and ausweichungs-clivage. The former is characteristic of the coarser-grained varieties, and the latter of the finer-grained, where the direction of pressure has made a large angle with the bedding. In some cases the little leaves of muscovite outline parallel and equal folds, less than 0.2

mm. from crest to crest, each of which is ruptured, sometimes with slight displacements, sometimes with none, entirely across the slide. The structure is most distinct in the red phyllites, in which the fractures and the arrangement of the muscovite plates are clearly outlined by the ferruginous stain. Each kind of cleavage tells, in a different way, the story of extreme pressure.

SECTION V.—THE HEMLOCK FORMATION.

The Mansfield formation of the Michigamme Mountain area changes along the strike into rocks of an entirely different character, which, as already said, have been named the Hemlock formation.

DISTRIBUTION.

The Hemlock formation in the Fence River area consists of several varieties of schists, which occupy a belt between 2,000 and 3,000 feet in width, between the dolomite on the west and the Groveland formation on the east. The best exposures occur on the two river sections already referred to (p. 126), but outcrops are by no means lacking elsewhere.

FOLDING AND THICKNESS.

No secondary folds have been detected within the Fence River area of the Hemlock formation, and, on account of the metamorphism and cleavage, structural observations are not possible from which they might be inferred. The only clear evidence as to the attitude of the rocks obtained within the area was afforded by the contact at one locality between beds of amygdaloid and agglomerate. There the dip is eastward at an angle of 50°. The surface width of the formation varies between 2,000 and 3,000 feet. If 50° be taken as the dip, the thickness would be from 1,500 to 2,300 feet. If the average dip be assumed to be 40°, or the average of the observed dips of the underlying dolomite, the thickness would be from 1,300 to 1,900 feet. Or if 30° be taken, the average of the lower dips of the dolomite, the thickness would be 1,000 to 1,500 feet. South of the southern river section the thickness diminishes rapidly.

PETROGRAPHICAL CHARACTERS.

The exposures through sec. 10 and the northern part of sec. 15, T. 44 N., R. 31 W.—the southern river section—give a nearly complete sequence across the Hemlock formation, the principal gaps being on the extreme east and west, thus leaving the details of the relations with the dolomites below and the iron formation above undisclosed. In this section of 3,000 feet length the rocks are chiefly chloritic and epidotic schists, with which are associated schists bearing biotite, ilmenite, ottrelite, and amphibole, greenstone conglomerates or agglomerates, and amygdaloids. These rocks are characterized by a generally fine and even grain, a lack of sedimentary characters, and a double structure. In most of the varieties minerals which have formed quite independently of and later than these structures are macroscopically conspicuous. The prevailing color is green, passing to dark purple and black in the varieties in which biotite, hornblende, and magnetite abound.

The distinction made in the field between the several varieties of the schists is a rough one, indicating the predominating minerals rather than implying the absence of the others. In fact, all the varieties are intimately related. The chlorite-schists are very fine-grained green rocks, usually from their color evidently very epidotic. They weather to greenish or pinkish white. The cleavage surfaces are often plentifully sprinkled with little flakes of biotite. Frequently also black needles of ilmenite, brilliant plates of ottrelite, and large clusters of actinolite run irregularly through them, quite independent of the cleavages. The biotite-schists are much darker, and lack the green coloring. Through them also the same metamorphic minerals are frequently interlaced. By an increase in these minerals the passage to the other varieties in limited exposures is a very easy one.

Greenstone conglomerates and amygdaloidal rocks occur in a few exposures. In the former, light green or gray aphanitic inclusions of angular shapes, ranging from an inch to 2 or 3 feet in long diameter, are inclosed in a matrix of chlorite-schist or biotite-schist. The chlorite-schists hold round or lense-shaped eyes of epidote and epidote and quartz. That these are filled cavities can in most cases be shown only by the microscope; yet some of the larger amygdules have a banded structure evident to the naked eye. These rocks are of structural interest, since they are the only members of the area which possess undoubted bedding. The plane of contact between an amygdaloid and a layer of greenstone conglomerate in the southeast quarter of sec. 10, T. 44 N., R. 31 W., dips eastward at an angle of 50°.

Two well-marked systems of cleavage traverse all the rocks of the southern river section. The angle between their strikes is always acute toward the north, varying from 5° to as high as 34° in different exposures, while the direction of the bisectrix is almost constant at N. 8°–10° W. The dip of both systems is toward the east at about the same angle, namely, 50° to 60°. The two systems are usually both well developed, so that the outcrop-edges break down by weathering along zigzag lines. The character of the cleavages varies from fine partings which divide the surface into rhombs, sometimes extremely regular in the more aphanitic rocks, to a single perfect schistosity capable of minute subdivision, along which the component minerals are visibly aligned in the more crystalline. Along the cleavages seams of quartz and calcite have frequently formed.

Along the upper river section the rocks are distinctly more crystalline, and are chiefly biotite-schists and biotite-hornblende-schists, the latter often very coarse. They are sometimes banded, but very irregularly, the lenticular character of the banding suggesting the rhombic cleavages of the southern section. Some of the finer-grained biotite-schists contain round or elongated areas of quartz and epidote, which resemble amygdules. With these are associated considerable thicknesses of sericite-schists, full of little eyes of blue quartz. These are evidently metamorphic acid eruptives. The width of the northern section is about 2,000 feet.

Under the microscope the Hemlock schists of the Fence River area have a general porphyritic habit. Two main divisions only are clearly distinguished. One of these is the fine-grained mica-schists (sericite), which are characterized by the presence of muscovite as well as biotite in the microcrystalline groundmass, and true phenocrysts of feldspar, and bipyramidal quartz. The other embraces all the other varieties, which, diverse as they undoubtedly are, have yet certain important characters in common, and are connected by gradations. The sericite-schists are obviously metamorphosed acid lavas, and need not be described in detail here.

The origin of the second division, however, is far more obscure. The least altered of these rocks possess an exceedingly fine-grained microcrystalline groundmass, made up of very pale chlorite and a colorless aggregate with feeble double refraction which seems to be quartz. Between crossed nichols the groundmass is almost isotropic, and it is by no means improbable that certain reddish patches here and there may really be glass. Little crystals of magnetite are abundantly scattered through the groundmass, and are often arranged in parallel curving lines, very suggestive of the flowage lines brought out on the surface of weathered rhyolites by the ferruginous stains. In many sections the groundmass includes minute lath-shaped plagioclase feldspars, much altered and with indistinct boundaries, which are often arranged in parallel lines. The groundmass also is generally sprinkled with little irregular grains of epidote and calcite.

In this groundmass are included in variable combinations and proportions much larger crystals and grains of common hornblende. actinolite, biotite, ottrelite, calcite, ilmenite, epidote, and zoisite. Of these biotite, calcite, ilmenite, epidote, and zoisite are the most constant and abundant.

Biotite is present in all or nearly all of the thin sections. It is always brown, and is characteristically developed in stubby individuals, very thick for their basal dimensions. These individuals are large and lie scattered through the slides. They frequently inclose portions of the groundmass. The mica cleavage most frequently stands across the cleavage of the rock. In many of the darker-colored schists, however, biotite plates intermediate in size between the large porphyritic individuals and the small chlorite plates of groundmass are present in large numbers, constituting a sort of secondary groundmass. These are generally aligned with the cleavage of the rock and are sometimes gathered in bands, but in color and stubby habit are similar to the phenocrysts.

Ilmenite in brownish-black prismatic sections is a common constituent. It usually lies at random through the slide. It incloses the quartz and epidote grains of the groundmass. Epidote and zoisite are exceedingly abundant, often in well-formed crystals. Many of the epidote and zoisite individuals contain darker-colored inner nuclei, the nature of which is uncertain. In some cases the nuclei are irregular in shape, and have the characteristic pleochroism of epidote, but are more strongly colored than the surrounding zones. In other cases they have sharp crystal boundaries, isomorphous with epidote, are brown in color, and inclose grains of magnetite; these may be allanite. The nuclei are too small, however, for determination. Generally they do not extinguish exactly with the surrounding zones. It is probable that many of these nuclei represent an early generation of epidote, like the small irregular grains of the groundmass, which were subsequently enlarged to porphyritic size. Inclosures of zoisite are not uncommon in the large epidote individuals. Large lenticular aggregates of epidote with calcite, chlorite, and biotite are found partially replacing feldspar individuals, which were no doubt original phenocrysts. Similar aggregates unmixed with the remains of feldspar are not infrequent, and may reasonably be attributed to the same source. Epidote with quartz is also the common filling of the amygdaloidal cavities.

Common hornblende, actinolite, and ottrelite are very common as porphyritic constituents of the schists. Hornblende occurs in very large, well-formed single crystals and clusters, placed at random through the groundmass. It is characteristically associated with ottrelite and biotite, and often has formed somewhat later than the latter. It is always crowded with inclusions, which in the laminated varieties carry the structure through without reference to the position of the host. Ottrelite is abundant in some of the sections, and is distinguished by its characteristic pleochroism. It occurs in large individuals and multiple twins, and, like the large hornblendes and biotites, is full of inclusions.

The general characteristics of these schists, then, are: First a groundmass composed of chlorite, quartz, magnetite, epidote, and in some cases plagioclase microlites, and secondly the presence in this groundmass of much larger porphyritic individuals of several secondary minerals. The varieties are determined by the varying ratio of the porphyritic constituents to the groundmass, by the nature of the predominant secondary minerals, and by the differences in grain of the groundmass. This, while generally extremely fine-grained, is much coarser, but without mineralogical change on the northern river section, where the schists are more distinctly crystalline. The cleavage of the schists is determined by the arrangement of the minute particles of the groundmass, and not by the parallelism of the large secondary minerals.

These last, furthermore, are never faulted or broken, and in general are unstrained optically. They must have formed, then, after the compression and tilting of the series.

ORIGIN.

The origin of these schists, I think, is not doubtful. As important points of evidence we have, first, the absence of rocks possessing any sedimentary characters throughout the whole section. Next we have the undoubted presence of lavas in the series, shown by the sericite-schists, amygdaloids, and greenstone conglomerates or agglomerates. Furthermore, the minerals which compose the schists are those which would result from the alteration in connection with dynamic metamorphism of igneous rocks of basic or intermediate chemical composition. Finally, the grain and character of the groundmass, and in some slides the presence therein of plagioclase microlites disposed in flow lines, point directly to an igneous origin and to consolidation at the surface.

Clements[1] has reached similar conclusions for the formation above the Randville dolomite on the western side of the Archean dome (see pp. 48, 123). There metamorphism seems to have progressed less far than in the Fence River area, and among the more basic rocks he states that he has recognized basalts.

SECTION VI.—THE GROVELAND FORMATION.

This formation was originally named by me the Michigamme jasper.[2] The name Michigamme was subsequently used for one of the Upper Marquette formations in the preliminary report on the Marquette district,[3] distributed in 1896. I now abandon the old name, although it is entitled to stand by the rules of priority, in order to avoid the confusion which would necessarily arise from its retention.

DISTRIBUTION.

The Groveland formation in this area, as in the Felch Mountain range, consists mainly of siliceous iron-bearing rocks, which hold much fragmental material, together with certain subordinate schists. While it is of wide extent throughout the area, its known outcrops are limited to three localities—the vicinity of Michigamme Mountain, in sec. 33, T. 44 N., R. 31 W., and sec. 3, T. 43 N., R. 31 W.; the exposures and test pits at the Sholdeis exploration in sec. 21, T. 45 N., R. 31 W.; and the test pits at the Doane exploration in sec. 16, T. 45 N., R. 31 W. The last two localities are 1 mile apart, and the more southern is 8 miles north of Michigamme Mountain.

In spite of the poverty of the formation in outcrops, its distribution throughout the area has been well determined through its magnetic

[1] Volcanics of the Michigamme district of Michigan, by J. Morgan Clements: Jour. Geol., Vol. III, 1895, p. 801.
[2] Am. Jour. Sci., March, 1894.
[3] Fifteenth Ann. Rept. U. S. Geol. Survey.

properties. Adjacent to the Fence River area of the Hemlock formation it gives rise to a strong magnetic line which passes through the outcrops and test pits of the Sholdeis and Doane explorations. To the north this line was followed to the southern side of sec. 32, T. 46 N., R. 31 W., where it is said to connect with a magnetic line followed by Clements completely around the northern side of the Archean dome. To the south it continues into the Michigamme Mountain area to within a mile of the outcrops of Michigamme Mountain. There the magnetic line gives way to a broad zone of disturbance, feeble and difficult to interpret, but consequent, I believe, mainly upon the flattening of the formation as it begins to pass over the general northwest-southeast anticlinal axis. This zone connects directly with the exposures of Michigamme Mountain, which produce similar irregular disturbances of the needle, and which visibly constitute a thin crumpled sheet, on the whole but gently inclined.

FOLDING AND THICKNESS.

In the Fence River area there is no reason to suppose that the Groveland formation contains within itself minor folds of any importance. Our knowledge of its attitude is supplied almost wholly by the magnetic observations, and these indicate that it has a general eastward dip, like the underlying members of the succession. Here and there it may be divided into two or more parts by sheets of intrusive material, and also may be slightly crumpled, but on the whole it must be regarded as a single persistent sheet, having a general eastward dip.

At Michigamme Mountain the Groveland formation caps the hill in a well-marked syncline, the axis of which runs northwest and southeast. The structure is distinctly shown by the attitude both of the ferruginous rocks and of the underlying phyllites. At the Interrange exploration, half a mile south, a secondary embayment of the same syncline, but more open, is found. These are the only folds of the Michigamme Mountain area sufficiently deep to include the iron-bearing rocks. The thickness of the formation can only be guessed at, as no complete section is exposed, and the data for determining its upper limit are decidedly shadowy. The magnetic observations indicate a breadth of from 400 to 600 feet, and, as in the Fence River area, it is certainly much thinner than the two lower formations, its thickness may be approximately 500 feet.

PETROGRAPHICAL CHARACTERS.

In general aspect the iron-bearing formation in these areas is strikingly like that of the Felch Mountain range, and all the varieties there found are represented here. It is therefore unnecessary to repeat the detailed descriptions already given. In the way of broad comparison, however, it may be said that the formation contains less iron than in the Felch Mountain range, and consequently the lighter-colored varieties are more abundant; that it contains more detrital material, and that in the Michigamme Mountain area the texture is generally closer and less granular. Moreover, in passing north from the Michigamme Mountain area to the Fence River area, we find at the Sholdeis and Doane explorations that the lower portion of the formation is composed of ferruginous quartzite, which is succeeded higher up by actinolite-schist and grünerite-schist, similar in all respects to the characteristic rocks of the Negaunee iron formation in the western Marquette district. In this change in character, as the Marquette district is approached, is found the lithological support for the view—first suggested by the distribution of the lines of magnetic attraction—that the Groveland formation is the southern equivalent of both the Abijik quartzite and the Negaunee formation of the Marquette district. The passage to a more crystalline condition in going from south to north is also in accord with the like changes noted in the lower formations of the area under discussion.

Under the microscope the close texture of the Groveland rocks of Michigamme Mountain is seen to be due to the minuteness of the quartz grains of the groundmass and to the abundance therein of chalcedony. The coarse quartz grains are all detrital, and are often beautifully enlarged. In many slides feldspar pebbles occur, and in many also sericite and chlorite are prominent in the groundmass. The iron oxides, including both magnetite and hematite, in single crystals and also in aggregates, are well distributed, as in the Felch Mountain sections. A grouping of these in round pebble-like areas, as in the Felch Mountain tongue, is also beautifully shown. In one slide the matrix is a rhombohedral carbonate, probably calcite, in which are embedded quartz grains and the iron ores in single crystals and irregular aggregates.

The most interesting feature of the thin sections from Michigamme Mountain are the pressure effects. In many slides the detrital quartz grains are strained to an extraordinary degree. In one case the stage was rotated 45° before the black wave of extinction completely traversed a little pebble 0.3 mm. in diameter. Almost every section is crossed in several directions by fractures healed by the deposition of coarse quartz and the iron oxides.

In the Fence River area the lower portion of the formation consists of quartzite, more or less ferruginous and micaceous. It contains beautifully rounded and enlarged grains of quartz, and also, less abundantly, rolled grains of microcline. Muscovite, biotite, and epidote occur, with the general background of interlocking later quartz. The more ferruginous layers have a groundmass almost exclusively of hematite, in which the clastic particles are set. The hematite is in parallel micaceous scales, which completely cover the cleavage surfaces. Above these layers come crystalline actinolite-schists and grünerite-schists, the former with garnets, and both carrying particles of the iron oxides. These rocks are not distinguishable in the field or in thin sections from certain varieties of schists of common occurrence in the Negaunee formation of the Marquette district.

CHAPTER V.

THE NORTHEASTERN AREA.

From the northernmost outcrops of the Fence River area to the northern end of the Republic trough the distance is about 11 miles in an air line. This intervening territory, on one side of which we find the typical formations of the Menominee district, and on the other the typical formations of the Marquette district, remains to be described in this chapter. It may conveniently be referred to as the Northeastern area.

As was shown in the report on the Marquette district,[1] in the productive portion of the Marquette range, between Negaunee on the east and Republic on the west, the Lower Marquette series consists of two or three clearly marked formations, which perhaps may be further subdivided according to individual taste. The lowest of these, the Ajibik[2] quartzite, which rests on the Archean complex, is fragmental in origin, and is prevailingly a white vitreous quartzite, which in one or two localities is conglomeratic near the base. Often it is represented by a muscovite-schist, as the result of the dynamic metamorphism of the original arkose. In the eastern part of the productive area of the Marquette district and along the northern side of the main fold in the western part of the district this formation is overlain by the Siamo[3] slates. Elsewhere the slates are not present, or are not known.

The next formation is the Negaunee[4] iron formation. This rock, which has many phases, is clearly marked off from the lower quartzite by its great richness in iron and by the fact that over the whole Marquette district it nowhere appears to contain fragmental material except in the transitional zone between it and the lower formations.

Above these conformable formations comes the uncomformably placed Upper Marquette series, the base of which rests now on one member, now on the other, or on the Archean.

East and south of Negaunee, and extending thence to the shore of Lake Superior at Marquette, is a series of rocks which resemble lithologically neither the Upper nor the Lower Marquette series in the productive area. It consists, in ascending order, of quartzite with basal conglomerates, dolomite, and slates, and thus bears a close resemblance lithologically and stratigraphically to the three lower members of the

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[1] Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 221.
[2] Loc. cit., pp. 528, 529.
[3] Loc. cit., pp. 313–315.
[4] Loc. cit., pp. 328–407.

district discussed. This series, named by Wadsworth the Mesnard series, has been regarded by him as belonging with the Upper Marquette series, or at least as overlying the Lower Marquette formations just described. Maj. T. B. Brooks had earlier correlated the dolomite with the Lower Marquette quartzite, and had supposed that there was a gradual passage from one into the other along the strike. Van Hise has recently stated that its position is below the Ajibik quartzite.

This series in its full development is found only in the eastern part of the Marquette area, between Goose Lake and Lake Superior, a distance of about 8 miles. Elsewhere, over by far the greater part of the Marquette district, no member of it has been recognized.

The geological structure of the Marquette range presents the general features of an east-west-striking complex syncline or synclinorium. The pre-Cambrian sedimentary rocks, with their associated intrusive and extrusive igneous rocks, occupy the trough, in which there is much local complexity of structure. The trough is flanked on the north and south by the older Archean crystallines.

At the western end of the district the peculiar Republic[1] trough of Algonkian rocks branches from the main synclinorium and runs southeast into the Archean rocks for 6 or 7 miles, having a nearly constant width of about one-half to three-quarters of a mile. In this trough the Algonkian rocks have been so closely compressed that they stand essentially on edge. The interior is occupied by the younger Upper Marquette quartzites and schists, between which and the underlying Archean walls the older Lower Marquette iron formation and quartzite here and there occur.

The northwestern end of the Republic trough is about the western limit of mining development, though not of exploration, on the south side of the Marquette synclinorium. Up to this point outcrops, producing mines, and old explorations are sufficiently abundant to permit the separate formations to be traced and mapped with comparative ease, and to indicate at least the larger structural features.

At this northwestern end of the Republic trough the Lower Marquette series makes an abrupt turn to the south, and may be followed for a mile or more by occasional outcrops and test pits. The Negaunee iron formation is persistently present beneath the Upper Marquette quartzite, and gives rise to a very strong and persistent line of magnetic attraction, which was followed in our work for about 12 miles to the south and southeast. For about 4 miles from the sharp turn at the mouth of the Republic trough it runs nearly due south; afterwards it turns somewhat to the east of south, and follows that course for about 6 miles, after which it turns more and more toward the east, and finally, where we left it, its course was only slightly south of east. That this magnetic line is caused by and marks the position of the

[1] Mon. U. S. Geol. Survey, Vol. XXVIII, 1897, p. 525.

Negaunee iron formation there can not be the slightest doubt, for that rock outcrops in a few scattered localities, occurs abundantly in the drift, and has been found in occasional test pits and drill holes throughout this distance. The underlying quartzite outcrops beneath the iron-bearing formation near the northern end of the line; but farther south it is entirely covered by the drift, so far as the territory has been examined. The overlying Upper Marquette rocks are also known to be present just west of the Negaunee formation as far south as sec. 19, T. 46 N., R. 30 W.

The magnetic line which accompanies the Negaunee formation may be called the "A" line. Taking into account the connected Republic trough and its exposures of the Lower Marquette rocks, it is seen that the "A" line partially surrounds a dome of the Archean crystallines, and that in going from the interior of this dome outward across the "A" line we pass from older to younger rocks. The dip along the "A" line is therefore on the whole toward the west, although the observed dips at the few localities where determinations have been made are either vertical or slightly inclined toward the east. The southern part of the "A" line, as far as it has been traced, passes through secs. 5, 8, 9, 15, and 16, T. 45 N., R. 30 W. In sec. 5 it is just 5 miles east of the Groveland formation, which, as was shown in earlier chapters, is a magnetic rock occupying a definite place in the Menominee succession, and is underlain by other typical Menominee formations, and finally by the Archean.

Between the "A" line and the magnetic line caused by the Groveland formation, which may be called the "C" line, is a third magnetic line, which may be called the "B" line. This was traced, parallel to the "A" line and less than half a mile away, from near the south end of the latter to the north end, and finally entirely around an elliptical area, closing again upon itself at the starting point, the perimeter of the ellipse being 25 miles in length. Throughout this entire distance not a single outcrop could be discovered along the "B" line. Within the inclosed area, however, in secs. 6 and 7, T. 45 N., R. 30 W., and in sec. 19, T. 46 N., R. 30 W., several exposures of granites and crystalline schists were found, which left no doubt that the greater part of the area inclosed by the "B" line is occupied by Archean rocks of the same general character as those partially inclosed by the "A" line on the east and entirely by the "C" line on the west. The area between the "A" and "B" lines as far south as sec. 19, T. 46 N., R. 30 W., has been proved to contain the basal member of the Upper Marquette series. The southwestern quadrant of the "B" line ellipse is nearly parallel to the "C" line and only 1½ miles away.

The known facts with reference to the "B" line, then, are these: (1) It represents a magnetic rock; (2) this magnetic rock completely encircles an Archean core. It may further be inferred with practical certainty that this formation which carries such constant magnetic properties for 25 miles must be sedimentary. With regard to its structure, the foregoing considerations would necessarily involve the conclusion that it dips away from the Archean core on all sides, and this conclusion is fortified by the unsymmetrical separation of the horizontal maxima on the magnetic cross sections. It follows, therefore, that on the eastern side of the oval, where the formation is parallel to the "A" line, it dips toward the east, and on the western side, where it is parallel to the "C" line, it dips toward the west. This conclusion is further supported by the dips within the ellipse in the outcropping Archean rocks that show structure. These all happen to lie east of the major axis, and all dip toward the east.

East of the "B" line, and between it and the "A" line, is found the basal member of the Upper Marquette series. The rock which is manifest in the "B" line must therefore be older than any member of the Upper Marquette series, and both are younger than the Archean. They are both strongly and persistently magnetic. For 8 or 10 miles they run parallel to each other and less than half a mile apart. Their broad structural relations to the Archean basement of the region are precisely similar. Therefore, although the rock that gives rise to the "B" line has never yet been seen, it may be concluded with the utmost confidence that it is the Negaunee iron formation, and that the "A" and "B" lines represent this rock brought up in the two limbs of a narrow and probably deep synclinal fold.

This conclusion carries the Negaunee iron formation 3½ miles farther to the west, and in the northeast part of T. 45 N., R. 31 W., leaves a gap of but 1½ miles between the Lower Marquette and the Felch Mountain series.

Here, between the "B" and "C" lines, is precisely the same situation as between the "A" and "B." One magnetic rock, represented by the "B" line, dips west; the other, the Groveland formation, represented by the "C" line, dips east. Between them no magnetic disturbances can be found. The area between them must have a synclinal structure, and if they are not one and the same formation, then each must undergo an extremly rapid and precisely similar change in lithological character (the loss of magnetite) in a very short distance, and be represented on the opposite side of the synclinal fold by a nonmagnetic formation. Each of these rocks is persistently magnetic in the direction of the strike for great distances. That each should independently lose its magnetite in the direction of the dip in this particular locality is very improbable. Therefore the grounds for the conclusion that the "B" and "C" lines represent one and the same formation are quite as firm as those upon which rests the conclusion that the "A" and "B" lines represent the same formation.

The greater portion of the Northeastern area is without outcrops, yet, through the structural and lithological results of the magnetic work, we are able to bridge over the gap and to show with a high degree of probability that the Negaunee iron formation of the Marquette range is identical with the Groveland iron formation. Further, when we recall the differentiation of the Groveland formation in the northern part of the Fence River area into a ferruginous quartzite at the base and grünerite schist in the upper portion, it would seem probable that the Groveland formation represents the underlying Ajibik quartzite as well as the Negaunee formation of the western part of the Marquette range.

This conclusion has an important bearing on the interpretation of the early geological history of what is now the Upper Peninsula of Michigan. If the formations which constitute the whole of the Lower Marquette series over the 25 miles or more of the productive and best-known portion of the Marquette range are represented in the Menominee district and the intervening area by a single formation, and that the highest in the Menominee succession—namely, the Groveland formation—then the Menominee formations below the Groveland formation are all older than the Marquette rocks and do not occur at all within the productive portion of the Marquette range. Why are these lower formations absent?

To this question there seems to be two answers which are a priori possible. It is conceivable that the Menominee quartzite, dolomite, and slates, or some of them, may have been deposited in a succession of unbroken sheets over the whole Marquette area, in continuity with the similar Mesnard formations on the east, and that afterwards the main Marquette area was elevated above the sea and entirely stripped of these formations by long-continued denudation. Finally, when the time of deposition of the Groveland formation came round, this elevated area had again been reduced to sea level and subsided below it, so that the Ajibik quartzite and the Negaunee iron formation, and their southern equivalent, the Groveland formation, were deposited in an unbroken sheet over the whole. If this hypothesis be correct, two consequences should follow from it. First, we ought to find some discordance between the Groveland formation or the Lower Marquette quartzite and the lower formations in the marginal areas between the Menominee and Marquette areas, or at least a gradual cutting out of these lower formations by the iron-bearing members and the lower quartzite. And secondly, we ought to find, in the lack of discordance, rocks present in the areas of continuous deposition which represent the time of denudation.

With regard to the first of these consequences no verification is possible, at least in the territory between the Marquette and Fence River districts, because of lack of outcrops. Throughout the Northeastern area, from the northwestern end of the Republic trough in T. 47 N., R. 30 W., to the "C" line in T. 45 N., R. 31 W., there are no exposures whatever of the Algonkian rocks which underlie the Groveland formation. Somewhere in this distance of about 11 miles the lower formations disappear, but whether by unconformity or overlap is an unanswerable question. Nor, for the same reason, can it be definitely settled whether elsewhere farther within the southern area there is any discordance. That there is general parallelism between the Groveland formation and the lower rocks, and strict conformity in some places, is true, but this is not at all inconsistent with a period of erosion between them, if that erosion antedated the later and more severe orogenic disturbance.

In the Mesnard area the observed relations have been interpreted by Van Hise to mean that the lower formations disappear by overlap. The facts at present known on the Menominee side are capable of the same interpretation, but they are not sufficiently definite to exclude the possibility of a period of erosion below the iron-bearing formation.

With regard to the second consequence—the deposition in the submerged areas of formations which would represent the erosion period in the elevated area—the evidence at hand is decidedly against the existence of such formations.

The alternative hypothesis is that the lower quartzite, dolomite, and slate formations of the Menominee and Mesnard areas were never deposited over the western Marquette area, but disappear toward the north and west by overlap; and this hypothesis is much more likely to be the true one. We can suppose, as I have already pointed out,[1] that this part of the Upper Peninsula was a slowly subsiding area, the central portion of which, now occupied by the Marquette rocks, stood initially at a greater elevation above the encroaching sea than the rest. While the quartzite-dolomite-slate triad was going down in the Mesnard area on the east and the Menominee area on the south and west, the central Marquette area remained above the sea. At last, when the Groveland formation began to be deposited in the Menominee area, the Marquette highland was finally submerged, and covered, as the sea marched over it, first with a sheet of arkose, made up of its own disintegrated débris, and finally with the same nonclastic sediments as chiefly compose the Groveland and Negaunee formations.

[1] Relations of the Lower Menominee and Lower Marquette series in Michigan, by H. L. Smyth: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p 222.

CHAPTER VI.

THE STURGEON RIVER TONGUE.

By William Shirley Bayley.

The Sturgeon River tongue of Algonkian sediments extends eastward from the west sides of Ts. 42 and 43 N., R. 29 W., to the east sides of secs. 6 and 7, T. 42 N., R. 27 W. At its east end it is only a mile wide. To the west it broadens rapidly, being at least 5 miles in width in the west line of R. 28 W. Beyond this point it is not very definitely marked, so that its width can not be accurately determined. It is, however, more than 6 miles wide. In general shape the tongue is triangular, with its narrowest point east and its base running almost east and west.

On the north the sedimentary area is bounded by granites and schists, which probably stretch northward to the south side of the Marquette district, where the rocks have been shown to be pre-Algonkian. On the south it is also bounded by a granite-schist complex, which here separates this tongue from the Felch Mountain tongue of sediments, about 3 miles farther south. At the eastern end of the tongue Paleozoic sandstone and limestone cover the Algonkian rocks, and to the west these are buried beneath glacial deposits.

Within the tongue, entirely surrounded by the sedimentary rocks, are two small areas of granite, one in sec. 3, T. 42 N., R. 29 W., and the other in secs. 7 and 8, T. 42 N., R. 28 W., and sec. 12, T. 42 N., R. 29 W. Between the rock of the second area and the clastics surrounding it is a fairly well-defined unconformity, with the granite on the under side. No contacts between the rock of the other area and the sediments have been observed; but since this rock is identical in all its features with the granite in the more easterly area, it is concluded to be of the same age as this, i. e., pre-Algonkian or Archean.

THE BASEMENT COMPLEX.

The rocks of the Basement Complex comprise granites, hornblende-schists, and biotite-schists that are cut by dikes of greenstone and by veins of granite and quartz. None of them, except the biotite-schists, present any peculiar features. They are similar in all respects to corresponding rocks in the Basement Complex elsewhere. The granites are coarse-grained pink varieties, that are always more or less schistose. The hornblende schists are fine-grained lustrous schists, whose characteristics seem to indicate that they have originated from basic igneous rocks.

The biotite-schists are only rarely observed. They are dark-gray, evenly banded schists, resembling very closely banded "augen-gneisses." Through them are scattered here and there a few small rounded quartz phenocrysts and many small feldspar phenocrysts, lying with their long axes parallel to the banding. The greater portion of the phenocrysts consists of untwinned feldspar. Twinned feldspar borders the untwinned variety, fills cracks penetrating it, and is, moreover, distributed irregularly through it. From its characters and its relations to the untwinned material, the twinned feldspar is thought to be secondary.

The groundmass in which the phenocrysts lie is a fine-grained aggregate of biotite, quartz, and plagioclase. The banding noticed in the hand specimen is due to the presence of large biotite flakes in certain layers and its absence from others. The quartz and plagioclase occur in small grains that appear to be intercrystallized in the manner that characterizes the secondary matrix of many greenstones. The quartz grains are nearly always crossed by strain shadows, and the plagioclase grains by interrupted and bent twinning bars.

From the composition and microstructure of the biotite-schists, we may conclude that they were probably originally porphyritic lavas or intercalated flows. Their present schistosity, and probably their banding, is the result of mashing.

The intrusives in the granite-schist complex are granites and greenstones. The former are plainly apophyses of the gneissoid granites that constitute such a large part of the complex. The greenstones are schistose diabases, gabbros, or other basic rocks that have usually suffered a considerable amount of alteration.

THE ALGONKIAN BEDS.

The tongue of sedimentary rocks embraced between the northern and the southern complexes is structurally a westward-pitching syncline. The rocks comprised within it are conglomerates, arkoses, quartzites, slates, and certain dark banded rocks that are believed to consist partly of tuffaceous material, dolomites, calcareous slates and sandstones, and breccias. These may be divided into a conglomerate formation and a dolomite formation. The relation of the former to the latter can be inferred only from the distribution of their exposures, since the two formations are nowhere in contact. The conglomerate outcrops are limited to the extreme eastern portion of the tongue, and to that portion of it between the central granites and the Southern complex. The exposures of the dolomite formation, on the other hand, are found only in the country north of the central granites. Between the northernmost of these exposures and the southernmost ledges of the Northern Complex is an interval devoid of ledges of any kind. The country is so thickly drift covered that all the rocks are deeply buried. On the supposition that the tongue is synclinal, this interval is underlain by members of the conglomerate formation.

A comparison of the sediments of the Sturgeon River tongue with those of the Felch Mountain tongue, only a few miles distant to the south, shows that the dolomites in the two districts are identical and that the conglomerate of the Sturgeon River tongue is similar in all essential respects to the principal conglomerate underlying the dolomite in the Felch Mountain tongue. This conglomerate is shown in another place to be at the base of the Lower Huronian in this district, and the dolomite, known as the Randville dolomite, to be conformably above it. The members of the Sturgeon River tongue must thus also be Lower Huronian, with the conglomerate beneath the dolomite.

THE CONGLOMERATE FORMATION.

The conglomerate formation of the Sturgeon River tongue consists of much-squeezed conglomerates, arkoses, quartzites, slates, and a few beds of the banded rock referred to above as probably tuffaceous. These are cut by greenstones.

All the members of the formation strike in a nearly uniform direction a little north of east and dip at angles varying from 65° to 90° S. They are also nearly all schistose, the strike of the schistosity being approximately parallel to that of the bedding, and its dip being in all cases nearly vertical. From the slight differences noted in the dips of the beds at various points and the great width of the formation, it is evident that the series must be folded, although it appears to constitute a consecutive sequence of conformable beds.

The most favorable place at which to observe the conglomerates and their associated rocks is at the dam of the Sturgeon River, near the northwest corner of sec. 17, T. 42 N., R. 28 W. Here they form a continuous ledge of well-bedded conglomerates and arkoses, striking N. 83° E. and dipping 85° S. The conglomerates are pink in color. They contain great numbers of white quartz pebbles and bowlders, fewer and smaller ones of pink granite, and many fragments of red feldspar, in a matrix composed of moderately coarse-grained granite débris. All the fragments and pebbles are elongated in the plane of the rock's schistosity. In the least schistose beds the structure of the groundmass is plainly fragmental. In the more schistose phases it appears to be thoroughly crystalline in consequence of the development in it of great quantities of sericite. In the most schistose phase the groundmass has the appearance of a typical sericite-schist.

Interstratified with the conglomerates are many nonconglomeratic beds. These are always more schistose than the conglomeratic ones. In many cases they are well-defined arkoses; in others they are sericite-schists. Between these limits all gradations from plainly fragmental rocks to clearly marked schists are observable.

Near the dam are noted several long ledges of coarse-grained and fine-grained greenstones, whose relations to the sedimentary rocks appear at first glance to be those of interbedded flows. Upon close inspection, however, some of the masses disclose intrusive features.

Although often extending as narrow bands for considerable distances approximately parallel to the bedding of the conglomerates, they nevertheless sometimes cut across the layers in such a way as to leave no doubt of their intrusive character.

As might naturally be expected, the least schistose of the conglomerates and arkoses exhibit the fewest evidences of alteration when their thin sections are viewed under the microscope. In addition to the pebbles in the conglomerates, these rocks consist of rounded and angular grains of quartz, microcline, orthoclase, and various plagioclases, and a few of microperthite, embedded in a finer-grained aggregate of the same minerals, tiny flakes of green biotite and of colorless muscovite or sericite, a few plates of chlorite, particles and crystals of magnetite, and little nests and isolated grains of epidote, with occasionally some calcite. Many of the feldspar grains are altered into sericitic products, colored red by small particles of various iron oxides and by red earthy substances.

The composition and microstructure of the highly schistose arkoses and of the schistose matrices of the conglomerates vary greatly in different specimens, being determined largely by the original composition of the different beds and the amount of mashing they have suffered. They are made up of an interlocking mosaic of fairly large quartz grains that appear to have crystallized in situ, large and small spicules and plates of sericite, crystals of magnetite, and a few needles of chlorite and other secondary substances. Between these, again, is often a cement of what seems to be secondary quartz. The schistosity of these rocks is due to the arrangement of the sericite in approximately parallel position and the elongation of the quartz grains in the same direction.

The smaller quartz pebbles in the conglomerates are crossed by strain shadows, and many of the larger ones have been changed to a mosaic of interlocking grains. In some of the most intensely compressed varieties the pebbles have been mashed into thin plates, several of which often unite, forming broad sheets.

There has evidently been a great deal of recrystallization of the original material of both arkoses and conglomerates, which, together with the mashing to which they have been subjected, have changed them into what are now, in many instances, well-defined schists.

The quartzites, slates, and sandstones interstratified in the series possess no noteworthy features. They are like similar rocks elsewhere.

The banded tuffaceous beds are referred to in the description of the igneous rocks (pp. 150–151).

THE DOLOMITE FORMATION.

The dolomite formation is an interbedded series of pink, yellow, and white dolomitic marbles, calcareous slates and sandstones, a few quartzites, and a few breccias.

Good exposures of the series may be found in the NW. ¼ sec. 6, T. 42 N., R. 28 W.; in the NW. ¼ sec. 1, T. 42 N., R. 29 W., and in the

SE. ¼ sec. 35 of the same township. In the first locality, which may serve as a sample of all, the rocks are flesh-colored dolomitic marbles, spotted here and there by little quartz grains, dolomitic breccias, red sandstones, and red slates, in interstratified layers varying in thickness from an inch to many feet. There are slight differences in the strikes and dips of neighboring ledges that indicate the existence of minor folds in the formation, but these are so few and are so irregularly distributed as to afford no clews from which to work out the structure.

In thin section the dolomites appear as very close-grained aggregates of calcite and dolomite, with here and there scattered through the carbonates a rounded quartz grain and a varying quantity of the same mineral in little nests. Occasionally the components are elongated in a common direction, producing a schistose structure.

The quartzites, sandstones, and slates interbedded with the dolomites are all calcareous. The breccias consist of fragments of dolomite embedded in a quartzitic groundmass.

THE IGNEOUS ROCKS.

The igneous rocks associated with the sedimentary ones are all greenstones or greenstone-schists. They are probably all intrusive, with the exception of the banded schists that were referred to above as occurring in the conglomerate formation.

The intrusive greenstones are essentially like those that cut the Basement Complex. Some are massive, and others are schistose. Some are coarse grained, others fine grained. A few occur in the form of small bosses, some are clearly dikes, though for the most part these dikes follow the bedding planes of the sedimentary beds, while others may be interleaved sheets.

The greater part of the greenstones are massive, though on their edges they frequently pass into schistose phases, presenting the structure and appearance of chlorite-schists. They are usually of a dark bluish-green color, and many of them exhibit in the hand specimen the texture of diabases.

In the thin section all of the intrusive greenstones exhibit practically the same characteristics. Their original constituents have largely disappeared. Most of the plagioclase has passed over into epidote and quartz, and the augite into hornblende. Small crystals of magnetite and a few irregular grains of ilmenite or of some other titaniferous iron oxide are frequently scattered through these products. The epidote is especially abundant. It is present in large plates and small crystals in the altered plagioclase and hornblende, in some specimens constituting complete pseudomorphs of the former mineral.

The banded rocks included with the greenstones are composed partly of fragmental sedimentary material and partly, apparently, of basic igneous material. The rocks consist of alternating dark and light bands, the former of which, in some cases, look as though composed of pure amphibole, and the latter appearing like bluish-black quartzites or cherts. In some of the lighter-colored bands there are lenticules of white quartz that resemble the flattened pebbles in a squeezed conglomerate or the drawn-out parts of quartzose layers in a mashed bedded rock.

Under the microscope the lighter-colored layers are found to be composed of very irregularly outlined and rounded quartz grains cemented by masses of smaller quartzes and small grains of zoisite, little clumps of chlorite, some decomposed feldspar, and particles of magnetite. Occasionally a plate of yellowish epidote occurs in the midst of this aggregate, and now and then a large plate of cellular green hornblende. The quartz grains are usually small, separate, and independently orientated, but frequently little groups of them with the outlines of sand grains are met with.

In the darker layers the proportion of hornblende is much greater. Indeed, some bands consist almost exclusively of this mineral in large cellular plates and in radial groups, only the small interstitial spaces between the hornblende being filled with an aggregate of quartz, zoisite, small hornblende and biotite needles, and magnetite. In some bands schistosity is plainly marked, and in these the large hornblende plates often lie athwart the schistose planes. The lines of biotite and of hornblende needles that produce the schistosity pass around the plates exactly as they would do were the latter present in the rock before it was squeezed.

The composition and the structure of the lighter layers indicate that their origin was principally sedimentary, while the composition of the basic layers points to an igneous origin for their material. The present structure of the dark bands is certainly a secondary one produced by alteration of basic minerals. It is thus probable that these banded rocks are mixed sediments and basic tuffs that have been metamorphosed.

THE PALEOZOIC BEDS.

At the eastern end of the Algonkian trough, and at many places in its interior, the highly tilted Algonkian beds are overlain by sandstones, which, wherever they can be seen, are horizontal. An unconformity must exist between the two series, the sandstone being the overlying rock. This sandstone presents all the characteristics of the Lake Superior sandstone, which is believed to be Potsdam. Above it, apparently conformably, are limestones in which, some distance to the south, Lower Silurian fossils have been found.

THE SLATE BELT OF EASTERN NEW YORK AND WESTERN VERMONT

BY

T. NELSON DALE

CONTENTS.

ILLUSTRATIONS.

OUTLINE OF THIS REPORT.

This report presents the results of the work of several colaborers. The map herewith (Pl. XIII) is a revision and extension of the paleontologic reconnaissance map published by Mr. C. D. Walcott in 1888.[1] It covers the geology of about 700 square miles lying east of Lake Champlain and the Hudson, west of the Taconic Range, and north of the Hoosic River, one of the eastern tributaries of the Hudson. The region is of economic interest on account of the numerous quarries of green, purple, red, and black roofing slates within it, which yield about a quarter of the entire roofing-slate product of the United States. The slate belt proper covers about 320 square miles in Washington County, New York, and Rutland County, Vermont. The map shows the location of 252 slate quarries within this area. The region is also of paleontological interest on account of its early Cambrian fauna, and of stratigraphical interest on account of the variety of its strata and the intensity of the successive movements which have affected them.

This report endeavors to promote the ends of economic geology as well as those of purely scientific geology. Bibliographies of the local geology and of slate in general, both economic and scientific, are prefixed.

The general map shows a surface of only two formations, Lower Cambrian and Lower Silurian or Ordovician, whose areas are dovetailed into or surround one another. The Lower Cambrian is represented, in ascending order, by olive grits, green and purple roofing slates, black grits, black shales, and a ferruginous quartzite, with some limestone and quartzite interspersed in nearly all these horizons. At the base of the overlying and apparently conformable Ordovician are a few feet of "Calciferous" limestone and shales, with Bryograptus, Dichograptus, Dictyonema, etc. Then comes a complex of Hudson grits (black), white weathering shales, graptolite shales (Normanskill fauna), red and green Hudson shales and slates, with or without small quartzite beds. Some of these replace one another along the strike. In the western part of the tract the Ordovician is represented by limestone with Trenton fossils, but at the east by a mass of schist over 1,200 feet thick; and there appears to be, for a space of 6 miles along the strike, a transition from the Ordovician grits and slates into this schist. Several members of both Cambrian and Ordovician series are intermittent. The map (Pl. XIII) gives 104 Ordovician fossil localities and 239 Lower Cambrian ones. The Cambrian exposed is estimated as measuring at least 1,400 feet in thickness and the Ordovician up to 1,200 feet or over, both formations approximating a minimum of 2,600 feet. Each member of both Cambrian and Ordovician is described in detail, with the aid of thin sections, and localities where each is typically developed are pointed out.

Ten sections have been constructed at important points across portions of the slate belt (Pl. XVI and fig. 10), and are accompanied by photographs illustrating interesting structural features. From these the general structure of the region is shown to consist, on the east, of a closely plicated and cleft (slip-cleavage) schist mass in broad undulations, but crowded over westward into a somewhat sharp anticline along its western edge, followed by an adjacent mass of Cambrian slate, etc., in

[1] The Taconic system of Emmons and the use of the name Taconic in geologic nomenclature: Am. Jour. Sci., 3d ser., Vol. XXXV, 1888, Pl. III, p. 399.

close and more or less westwardly overturned folds, with easterly dipping slaty cleavage in the finer beds. At the north quartzite beds are more abundant within the roofing slate than at the south, where the slate beds are more distorted by cleavage and where also the cleavage is more perfect. Several such folds form compound anticlines, and alternate with similar compound synclines, which are often capped by corresponding structures of Ordovician age. Special structural features are described, illustrated, and explained under the following heads: *Bedding, cleavage, "false cleavage," "grain," joints, faults, "hogbacks"* (shear zones), *cleavage-bands, veins,* and *nodules.* Diagrams showing the structure at a number of the quarries are given (Pls. XXXIII and XXXIV); also a table of structural observations taken at 66 quarries.

The petrographic characters of the dikes of camptonite and augite-camptonite, which traverse both Cambrian and Ordovician, are described by Dr. Florence Bascom. Twenty-two distinct dikes are shown on the map.

The slates are then taken up, and each commercial variety—sea-green, unfading green, purple, variegated, red, and black—is described at length; first is given its complete chemical analysis by Dr. W. F. Hillebrand, then its microscopic analysis, which is illustrated by colored lithographs. The discoloration of the sea-green is found to be due to the alteration of microscopic rhombs of carbonate of lime, iron, and magnesia, the carbonate of iron passing into hydrated oxide of iron. The relative durability in color of the unfading green is found to be due to its much smaller number of rhombs. A microscopic analysis of mill stock slate is given. The purple and red slates with green spots are investigated, both chemically and microscopically, and the spots are ascribed to chemical changes consequent on the decay of marine organisms. The various minerals which occur associated with the slates in larger than microscopic quantities are found to be quartz, calcite, chlorite, pyrite, rhodochrosite, barite, and, rarely, galenite. Analyses of eight European slates and of one Pennsylvania slate are introduced for comparison; also microscopic analyses of Penrhyn, Festiniog, Cilgwyn Nantlle, Lehigh, Bangor, and Maine slates. All the analyses of slate from New York and Vermont are then summarized, and the average percentages of their chemical constituents are given. The mineral composition of each variety is also briefly given. The geological and geographical distribution of each commercial variety is then outlined.

The next heading is devoted strictly to economic geology. Maps (Pls. XL and XLI), on a scale of two inches to the mile, show the location and horizontal dimensions of nearly all the quarries, and, in some cases, by symbols, their structural features. The many difficulties in slate quarrying are enumerated, and suggestions are offered on the following subjects: How to distinguish bedding from cleavage, quartz veins from quartzite beds; the relations between joints, dikes, and "hogbacks" (shear zones) in this region; the use of geological map and compass in prospecting for slate; and a complete method of prospecting. The various methods used for testing the qualities of slate are described. These qualities are: *Sonorousness, cleavability, cross fracture, character of cleavage surface, calcareousness, durability of color, argillaceousness, absence of marcasite, strength, elasticity, density, porosity, corrodibility, chemical and mineral composition.* Finally, the outline of a technical description of a slate quarry is offered for economic purposes.

The last heading is devoted to scientific geology. The present state of science on the chemical and physical constitution and history of roofing slate is reviewed, with references to the literature. A paragraph is given to each of the following subjects: *Relation of cleavage dip to dip of inclosing hard bed, joint planes, grain, relation of cleavage to axes of folds, secondary cleavage, faulting along cleavage planes, shear zones, curvature of cleavage, slate folds, quartz veins in cleavage foliation, concretions of pyrite and quartz.* A general résumé of the chemical and microscopic work on the New York and Vermont slates is presented. The elements are referred to their respective minerals, and the clastic and authigenous minerals are separated.

The difficult relations of the Cambrian and Ordovician in the region are then discussed, and the question as to a great longitudinal overthrust along the western margin of the slate belt is considered in connection with the overthrust at Burlington, Vermont. The cause of the absence of the Upper and Middle Cambrian between the Olenellus zone and the Calciferous or Hudson is then sought. Some indications of an unconformity between the Lower Cambrian and the Lower Silurian are noted, and the possibility of the unconformity having been so slight as to have been concealed by the mid-Silurian orogenic movement is suggested. The peculiar relations of the Ordovician schists of the Taconic Range to the Stockbridge limestone (Trenton, Chazy, Calciferous, and Olenellus) on its eastern side and to the Hudson formation and the Olenellus slates on its western side are shown, and are explained by changes of sedimentation analogous to those occurring in the Hoosac schists of northwestern Massachusetts. The structure of the slate belt in its broader aspect is then considered. The Taconic synclinorium changes its trend to the north-northwest at the transverse cut between Castleton and West Rutland. The southern and northern terminations of the Ordovician and Cambrian areas west of the range are attributed to southward or northward pitching anticlines or synclines, but if an unconformity existed between the two formations some of the present geological boundaries may be due to geographical relations in Ordovician times. An explanation is sought for the thinning out of the Ordovician series on the slate belt itself; also for the simultaneous formation of slate at the west and schist at the east, as well as for the easterly dip both of the slaty cleavage and of the axial planes of the folds. In closing, as much of the geological history of the slate belt as is fairly well established is condensed into a dozen paragraphs. Some chemical notes on the composition of the slates by Dr. W. F. Hillebrand are appended, and a glossary of a number of geological and slate-quarrying terms is added.

THE SLATE BELT OF EASTERN NEW YORK AND WESTERN VERMONT.

By T. Nelson Dale.

INTRODUCTION.

ACKNOWLEDGMENTS.

This paper is composite in character, for it embodies the results of the labors of several geologists, paleontologists, chemists, and petrographers as well as topographers. Mr. Charles D. Walcott's geological reconnaissance maps of the Taconic region,[1] made without the aid of a contour map, which cover the larger part of the territory here described and give many fossil localities, have afforded starting points and clews in tracing out the geological boundaries. In many places, indeed, it was only necessary to verify his work or locate it correctly on the contour map prepared by the topographers of the Survey. In a region of such small and generally overturned folds, where also rocks of different formations often resemble one another very closely, such a paleontological map is indispensable. In field work the writer has had the assistance of Mr. Louis M. Prindle during the summers of 1895, 1896, and part of 1894, and of Mr. Frederick H. Moffit during the summers of 1895 and 1896. Dr. Florence Bascom spent a month of 1895 in constructing a section from the eastern shore of Lake St. Catherine across the schist mass east of the slate belt to East Wells and in carefully going over about 15 square miles of the mass. The writer spent the summers of 1894, 1895, and 1896 in the field, and visited nearly all the slate quarries himself. The topographical division has supplied a quarry map on a scale of 2 inches to the mile, with all the working and many of the idle quarries accurately located.

Mr. Walcott has determined all the fossils found in the course of the work excepting the graptolites, which were referred to Dr. R. R. Gurley. Most of these fossils were found by Mr. Prindle. Mr. Walcott has also contributed two photographs (Pls. XV and XVII), taken by himself in the course of his work.

[1] The Taconic system of Emmons and the use of the name Taconic in geologic nomenclature: Am. Jour. Sci., 3d ser., Vol. XXXV, 1888, p. 399, Pl. III, besides an unpublished MS. map, giving more fossil localities.

VIEW OF THE SCHIST HILLS FROM THE WEST PAWLET SLATE QUARRIES, LOOKING NORTHEAST.

The United States National Museum has loaned 64 thin sections of slates from the region, originally prepared in connection with the Tenth Census. These have been supplemented by about 150 new sections of slate, besides sections of 150 other sedimentary rocks and 58 eruptives from the same region. All the slate sections were examined by the writer, but 25 of the more difficult slides were referred to Dr. J. P. Iddings. Miss Bascom has determined all the dike rocks and her petrographic notes are here published.

Dr. W. F. Hillebrand has made for this report 16 complete chemical analyses of roofing slates, and Mr. George Steiger has made several partial ones and two complete ones of minerals. Dr. Hillebrand has also offered several suggestions on the composition of the slates, which are given in their place, and some important notes on the same subject, which appear as an Appendix. The specific gravity determinations were made at the physical laboratory of Williams College.

Mr. John L. Ridgway, of the Division of Illustrations, United States Geological Survey, has supervised the preparation of the microscopic paintings of thin sections of slate which are here reproduced.

The writer's work about the quarries was greatly facilitated by the intelligent cooperation of both owners and foremen.

LOCATION AND AREA OF THE SLATE BELT.

The slate belt of eastern New York and western Vermont lies between the Taconic range on the east and Lake Champlain and the Hudson on the west, and chiefly between the Hoosic River, one of the eastern tributaries of the Hudson, on the south, and the towns of Benson and Hubbardton, in Vermont, on the north, or between latitudes 42° 58′ and 43° 45′, a stretch of about 55 miles; but slate is said to continue as far north as Cornwall, making an extreme length of 68 miles. As, however, good slate is hardly obtainable south of Shushan and Greenwich, in Washington County, the actual length of the slate belt is about 45 miles. Its width at the north is about 11 miles and at the south about 6 miles, averaging a little over 7 miles. The area in which slate of not a little economic value is known covers, therefore, about 320 square miles, which lie within the counties of Washington, New York, and Rutland, Vermont. The general map (Pl. XIII) shows the topography and geology of this belt and of some 400 square miles of adjacent territory.

The slates are green of various shades, purple, variegated (that is, mixed green and purple), red, and also black. They are used for roofing and other purposes. The value produced in New York and Vermont in 1897 amounted to $749,614, or about one-quarter of the entire slate product of the United States.[1]

[1] The stone industry in 1897, by William C. Day: Part VI (continued) of this annual report, p. 254. See also, by same author, Eighteenth Ann. Rept. U. S. Geol. Survey, 1896-1897, Part V (continued), Mineral Resources U. S. 1896, Nonmetallic Products except Coal, p. 992. Slate: Seventeenth Ann. Rept. U. S. Geol. Survey, 1895-1896, Part III, p. 770; Slate: Sixteenth Ann. Rept. U. S. Geol. Survey, 1894-1895, Part IV, p. 476.

Not only is this region thus of economic importance, but it is also rich in scientific interest. It forms part of the battle field of the "Taconic controversy." Here also Mr. Walcott gathered many of his materials for the study of the early Cambrian fauna, and the poverty in life-forms which impresses the cursory observer of these ancient rocks has been converted by patient and laborious exploration into one of the richest Cambrian faunas.[1] Furthermore, the slates and their associated rocks are a mine of information to the structural geologist on the principles governing not only the structure of the northern Appalachians, but of slate everywhere. The belt also lies along the zone of transition from unaltered sedimentary rocks to highly metamorphic ones, and is traversed by numerous dikes of Paleozoic or later age.

The character of this report grows out of the nature of the region. Its object is two-fold; first, to render some practical aid to the slate industry by means of better topographical maps, structural sections, microscopical and chemical analyses, etc., and, second, to aid in the solution of the geological problems which the region propounds. In order to make the report more serviceable in both of these directions the portions of a purely economic character have been separated from those of a purely scientific one. Such a separation, however, has not been practicable, nor was it thought desirable, in describing the areal and structural geology, although it has been carried out in several of the subordinate headings. To make the report still more useful, a glossary of the more common geological terms used in it and of a number of terms in common use among slate quarrymen has been added, and a list of all the more important works on slate has been prefixed.

PREVIOUS WORK OF GEOLOGISTS.

Without undertaking to enumerate all the minor papers relating to portions of this region attention is directed to the following more important and general pieces of work: That of Ebenezer Emmons and that of William W. Mather on the geological survey of New York State, published in 1843; that of Hitchcock and Hager in their report on the geology of Vermont, published in 1861, which also included a geological map; Logan and Hall's general map of Canada and the northeastern part of the United States, dated 1866, which embodied the results both of the New York State survey and of the explorations of the Canadian survey within the United States; C. H. Hitchcock's geological map of New Hampshire and Vermont, 1877, in which all previous work in Vermont was correlated; the same author's sections across New Hampshire and Vermont, published in 1884; and, finally, C. D. Walcott's map of the Taconic region, published in 1888, already referred to. W J McGee's map of New York State, compiled under

[1] The origin of the oldest rocks and the discovery of the bottom of the ocean, by W. K. Brooks: Jour. Geol., Chicago, 1894, pp. 455-479.

the direction of James Hall in 1894, simply incorporated Mr. Walcott's work and left some doubtful areas blank.

While the presence of the Lower Silurian rocks was early recognized, Cambrian ones were at first confounded with them. It was not until long after the discovery of an older series that it was placed in its present stratigraphical position in the Lower Cambrian. The work of the early surveys had the merit of covering a large territory in a general way at little expense. Nothing approaching scientific satisfactoriness was done, however, till the publication of Mr. Walcott's paleontological map in 1888, in which Cambrian and Silurian fossil localities were indicated, so that the geological boundaries of previous surveys could be corrected thereby; but even this still lacked an adequate topographical base. In 1893 Kemp and Marsters described the dikes of the Lake Champlain region, and included two of those of the slate belt.[1] As to economic geology, little has been done hitherto beyond the publication of several incomplete analyses of the slates and a few brief references to the slate quarries. These are mostly in the Vermont Survey Report. But the statistics of slate production have been for a number of years systematically collected and published by the Division of Mineral Resources of the United States Geological Survey.

BIBLIOGRAPHY.

Four lists are here given. The first includes the more important geological papers on the region to be described; the second embraces only cyclopædia articles or chapters in text-books treating of slate in general; the third comprises, it is believed, all the more important scientific papers and memoirs on slate and slaty cleavage, while the last is devoted to works of an economic character only. In the preparation of these lists utility has been sought rather than bibliographic completeness.

LOCAL BIBLIOGRAPHY.[2]

EMMONS (EBENEZER). Agriculture of New York, Vol. I; Albany, 1843.

Range and extent of the black and Taconic slates, p. 71. Analysis of slates from Washington County, New York, and from Maine, p. 345; from Salem, New York, and Fair Haven, Vermont. p. 356.

HALL (JAMES). Geology of New York; Part IV, Survey of the fourth geological district; Albany, 1843.

Map of the Middle and Western States.

MATHER (WILLIAM W.). Geology of New York; Part I, First geological district; Albany, 1843.

Champlain division in Washington County, pp. 381, 404, 417, 420. Age of Taconic rocks, pp. 438, 464.

LOGAN (W. E.). Geological survey of Canada; Report of progress for 1843; Montreal, 1845.

[1] The trap dikes of the Lake Champlain region, by J. F. Kemp and V. F. Marsters: Bull. U. S. Geol. Survey No. 107.

[2] Arranged chronologically.

EMMONS (EBENEZER). A historical, topographical and agricultural survey of the county of Washington.

Transactions New York State Agricultural Society for 1849-50.

HITCHCOCK (E. and C. H.) and HAGER (ALBERT D.). Report on the geology of Vermont; descriptive, theoretical, economical, and scenographical; 2 vols.; Claremont, N. H., 1861.

Roofing slate, Vol. I, pp. 359-365, 489-492; Vol. II, pp. 795-802, and geological map.

LOGAN (W. E.) and HALL (JAMES). Geological map of Canada and part of United States; Montreal, 1866.

HITCHCOCK (C. H.). The geology of northern New England.

Geological map of New Hampshire and Vermont, 1877.

HITCHCOCK (C. H.). Geological sections across New Hampshire and Vermont.

Bull. Am. Mus. Nat. Hist., Vol. I, pp. 155-179 and Pl. XVI; Secs. IV, V, VI; New York, 1884.

WALCOTT (CHARLES D.). The Taconic system of Emmons and the use of the name Taconic in geologic nomenclature.

Am. Jour. Sci., 3d ser., Vol. XXXV, Apr.-May, 1888, pp. 307, 394; map, Pl. III.

KEMP (J. F.) and MARSTERS (V. F.). On certain camptonite dikes near Whitehall, Washington County, New York.

Am. Geologist, p. 97, Aug., 1889.

WALCOTT (CHARLES D.). The value of the term Hudson River group in geologic nomenclature.

Bull. Geol. Soc. Am., Vol. I, Apr., 1890, pp. 335-356.

WALCOTT (CHARLES D.). The fauna of the Lower Cambrian or Olenellus zone.

Tenth Ann. Rept. U. S. Geol. Survey, 1888-9; Part I: Geology, pp. 509-763, 1890.

WALCOTT (CHARLES D.). Correlation papers—Cambrian.

Bull. U. S. Geol. Survey No. 81, 1891. Northern Appalachian district, pp. 91, 148, 275.

KEMP (J. F.) and MARSTERS (V. F.). The trap dikes of the Lake Champlain region.

Bull. U. S. Geol. Survey, No. 107, 1893.

McGEE (W J). Preliminary geological map of New York, exhibiting the structure of the State so far as known; prepared under the direction of James Hall; published by the legislature of the State of New York; Albany, 1894.

DALE (T. NELSON). Structural details in the Green Mountain region and in eastern New York.

Sixteenth Ann. Rept. U. S. Geol. Survey, 1896. (Washington County, New York, pp. 559-565.)

WALCOTT (CHARLES D.). Fossil Medusæ.

Mon. U. S. Geol. Survey, Vol. XXX, 1898. Fossil Medusæ of the Lower Cambrian terrane of eastern New York, pp. 41-46.

BIBLIOGRAPHY OF SLATE.

WORKS OF A GENERAL CHARACTER.

CAMPBELL (DONALD). Slate.
Encycl. Britannica, ninth ed., Vol. XXII; 1887.

GEIKIE (ARCHIBALD). Cleavage.
In article "Geology, VI," Encycl. Britannica, ninth ed., Vol. X; 1887.

GREEN (H. H.). Geology. Part I, Physical Geology; London, 1882.
Sec. VII: Some structures impressed on rocks after their formation; pp. 269–279, figs. 100–103.

HARKER (ALFRED). Petrology for students; an introduction to the study of rocks under the microscope; Cambridge, England, 1895.
Chap. XVII. Argillaceous rocks. Second edition, 1897.

KALKOWSKY (ERNST). Elemente der Lithologie für Studirende bearbeitet; Heidelberg, 1886.
Familie der Thonschiefer, pp. 255–265.

ROSENBUSCH (H.). Elemente der Gesteinslehre; Stuttgart, 1898.
Thonschiefer, pp. 422–429. Phyllite oder Thonglimmerschiefer, pp. 429–438. Analyses, pp. 425, 433.

ROTH (JUSTUS). Allgemeine und chemische Geologie. Berlin, 1879–1890.
Analyses, Vol. II, pp. 585, 593.

ZIRKEL (FERDINAND). Lehrbuch der Petrographie, 2d édition, Leipzig, 1894.
Vol. III, Phyllit, pp. 295–319; Thonschiefer, pp. 744–753.

SPECIAL SCIENTIFIC PAPERS AND MEMOIRS.

ANGER (FRIED. ARNO.). Mikroskopische Studien über klastische Gesteine.
Min. Mittheil. ges., v. G. Tschermak; Vol. 3, 1875, pp. 153–174.

BAYLEY (W. S.). Slate from Monson, Piscataquis County, Maine.
Bull. U. S. Geol. Survey No. 150. The educational series of rock specimens collected and distributed by the U. S. Geological Survey, 1898, pp. 308–313.

BARROIS (CHARLES). Recherches sur les terrains anciens des Asturies et de la Galice; Lille, 1882.
Phyllades du terrain Cambrien, pp. 22–28.

BAUR (————). Über die Lagerung der Dachschiefer, über Wetschiefer und über die von der Schichtung abweichende Schieferung der Thonschiefer im nordwestlichen Theile des Dürener Bergamts-Bezirks.
Archiv für Min. Geogn., etc. Von Karsten und von Dechen, Vol. XX, p. 351, Pl. V; Berlin, 1846.

BECKER (GEO. F.). Finite homogeneous strain, flow, and rupture of rocks.
Bull. Geol. Soc. Am., Rochester, N. Y., Vol. IV, 1893, p. 13.

BECKER (GEO. F.). Schistosity and slaty cleavage.
Journal of Geology, Chicago, Vol. IV, May–June, 1896, p. 429.

BISCHOF (GUSTAV). Lehrbuch der chemischen und physikalischen Geologie, 2d edition, Bonn, 1866.

Cause of discoloration, *Vol. II, pp.* 350–351, *footnote.*

CHANCE (H. M.). The slate quarries [on the Delaware and Lehigh rivers in Pennsylvania] in 1875; with four cross sections.

Second Geol. Survey Pa., Report of Progress D3; Vol. I, Lehigh and Northampton counties, pp. 148–160, 1883.

CREDNER (G. R.). Das Grünschiefersystem von Hainichen im Königr. Sachsen.

Zeitschr. für ges. Naturwissenschaften, Vol. XLVII; Berlin, 1876.

DALE (T. NELSON). The Rensselaer grit plateau in New York.

Thirteenth Ann. Rept. U. S. Geol. Survey, 1891–92. The structure in black slate at the Lebanon Springs quarry, pp. 319–321 and Pl. C.

DAUBRÉE (A.). Expériences sur la schistosité des roches et sur les deformations des fossiles, corrélatives de ce phenomène; conséquences géologiques de ces expériences.

Bull. Soc. Géol. France, 3d ser., Vol. 4, p. 529, 1876. Also Comptes Rendus Acad. des Sciences, Vol. 82, pp. 710–716; Paris, 1876.

DAUBRÉE (A.). Études synthétiques de géologie expérimentale, pp. 333–336, 392–432, 442–445; Paris, 1879.

DE LA BECHE (HENRY T.). Geological Observer, 2d edition; London, 1853.

GEINITZ (E.). Der Phyllit von Rimogne in den Ardennen.

Tschermaks Min. Mittheil., III, pp. 533–540, 1880.

GOSSELET (J.). Les schistes de Fumay.

Annales de la Société géologique du Nord, Vol. X, pp. 63–86; Lille, 1884.

GOSSELET (J.). L'Ardenne.

Mémoires pour servir à l'explication de la carte géologique détaillée de la France, pp. 26–28, 33–35, 54, 60–62; Paris, 1888.

GOSSELET (J.) et MALAISE. Sur la terminaison occidentale du massif ardoisier de Fumay.

Ann. Soc. Géol. du Nord, Vol. XXII, pp. 59–64; Lille, 1898.

GÜMBEL. Geognost. Beschreib. des Fichtelgebirges; Gotha, 1879.

HARKER (ALFRED). On slaty cleavage and allied rock structures, with special reference to the mechanical theories of their origin.

Rept. Brit. Assoc. Adv. Science (1885), 1886.

HARKNESS (ROBERT) and BLYTH (JOHN). On the cleavage of the Devonians of the southwest of Ireland.

Edinb. New Phil. Jour., new series, Vol. II, No. 4, Oct., 1855.

HAWES (G. W.). Clay slate (argillite).

Geology of New Hampshire, by C. H. Hitchcock and others, Vol. III, Part IV, pp. 236–238.

HOPKINS (W.). On the internal pressure to which rock masses may be subjected, and its possible influence on the production of the laminated structure.

Trans. Camb. Phil. Soc., Vol. VIII, pp. 456–470; Cambridge, England, 1849.

HOSKINS (LEANDER MILLER). Flow and fracture of rocks as related to structure.

Sixteenth Ann. Rept. U. S. Geol. Survey, 1894-95, Part I, 1896. (Cleavage and fissility, pp. 868-874.)

HUTCHINGS (W. MAYNARD). Clays, shales, and slates.

Geol. Mag., Dec. IV, Vol. III, No. VII, p. 309, and No. VIII, p. 343. On slates, pp. 312-314, 343, 344; London, 1896.

INOSTRANZEFF (A.). Studien über metamorphosirte Gesteine im Gouvernement Olonez (Russia).

Thonschiefer, pp. 137-144; Leipzig, 1879.

JANNETAZ (ED.). De la propagation de la chaleur dans les corps; de ses relations avec la structure des mineraux, (2) le métamorphisme des roches.

Bull. Soc. Géol. France, 3d ser., Vol. III, pp. 499-510. Experiments with slate, p. 505. See also Vol. II, p. 264.

JANNETAZ (ED.). Relation entre la propagation de la chaleur et l'élasticité sonore dans les roches et dans les corps cristallisés.

Bull. Soc. Géol. France, 3d ser., Vol. V, pp. 410-426, 1877. Experiments with slate, p. 416.

JANNETAZ (Ed.). Mémoire sur les connexions de la propagation de la chaleur avec leurs différents clivages et avec les mouvements du sol qui les ont produits.

Bull. Soc. Géol. France, 3d ser., Vol. IX, p. 196, 1880-81.

JANNETAZ (Ed.). Mémoire sur les clivages des roches (schistosité, longrain) et sur leur reproduction.

Bull. Soc. Géol. France, 3d ser., Vol. XII, p. 211, 1883-84.

LESLEY (J. P.). A summary description of the geology of Pennsylvania.

Geol. Surv. Pa., Final Rept., Vol. I (Chaps. XLV-XLIX, Formation No. III and the roofing-slate beds); Harrisburg, 1892.

LORETZ (H.). Ueber Schieferung.

Bericht über die Senckenbergische naturforschende Gesellschaft, pp. 61-116, 1879-80; Frankfurt a. M., 1880.

LORETZ (H.). Ueber Transversalschieferung und verwandte Erscheinungen im Thüringischen Schiefergebirge.

Jahrb. Königl. Preuss. geol. Landesanstalt und Bergakademie, pp. 258-306 and Pl. VII (1881); Berlin, 1882.

MALLARD (E.). Sur l'examen microscopique de quelques schistes ardoisiers.

Bull. Soc. Minéralogique de France, Vol. III, No. 4, p. 101, 1880.

MAW (GEORGE). On a new section of the Cambrian rocks in a cutting of the Llanberis and Carnarvon Railway and the banded slates of Llanberis.

Geol. Mag., Vol. V, pp. 121-125 and Pls. VI, VII; London, 1868.

MAW (GEORGE). On the disposition of iron in variegated strata.

Quart. Jour. Geol. Soc., Vol. XXIV (p. 379 on variegated Cambrian slates, Pl. XIV, figs. 29, 31, 32); London, 1868.

McCREATH (ANDREW S.). Analysis of Peach Bottom slates.
Geol. Survey of Pennsylvania, Report of Progress for 1877, Vol. CCC, pp. 269, 270; Harrisburg, 1880.

MÜLLER (FRIEDRICH ERNST). Die normalen Schiefer des Hennbergs.
In article: Die Contacterscheinungen an dem Granite des Hennbergs bei Weitisberga. Neues Jahrb. für Min., Geol., etc., Vol. II, 1882, pp. 205-248.

PHILLIPS (JOHN). On a group of slate rocks ranging east-southeast between the rivers Lune and Wharfe, from near Kirby, Lonsdale, to near Malham; and on the attendant phenomena.
Trans. Geol. Soc. London, 2d ser., Vol. III, Part I, pp. 16, 17, on the stratification of slate; p. 8, on "bate;" London, 1829.

PHILLIPS (JOHN). Report on cleavage and foliation in rocks, and on the theoretical explanation of these phenomena.
Report Twenty-sixth Meeting Brit. Assoc. Adv. Science (Cheltenham, 1856), Part I, pp. 369-396; London, 1857.

PHILLIPS (J. ARTHUR). On the chemical composition and microscopic constitution of certain Cornish rocks.
Analyses and description of Delabole roofing slate, London, Edinb., and Dublin Philos. Mag. and Jour. Sci., 4th ser., No. 271, pp. 95, 96, Feb., 1871.

RAMSAY (A. C.). The geology of North Wales.
Memoirs of the Geological Survey of Great Britain and of the Museum of Practical Geology,[1] Vol. III, 2d ed., pp. 102, 103, 179, 190, 230-233, 237-239, 246, 247; London, 1881.

READE (T. MELLARD) and HOLLAND (PHILIP). The phyllades of the Ardennes compared with the slates of North Wales. Part I [England], 1898.

RENARD (A. F.). Recherches sur la composition et la structure des phyllades ardennais.
Bull. Mus. roy. d'hist. nat. de Belgique, Vol. I, No. 3, 1882, p. 215, Chem. Analyses; Vol. II, 1883, pp. 127-152 and Pl. VI, Vol. III, 1884, pp. 231-268 and Pl. XII, XIII, Microscopic examinations.

ROGERS (HENRY DARWIN). Geology of Pennsylvania; a government survey.
Slate and slaty cleavage, Vol. I, pp. 188, 247, 249, and Vol. II, pp. 902-916; Phila., 1858.[2]

ROSENBUSCH (H.). Die Steiger Schiefer und ihre Contactzone an den Granititen von Barr-Andlau und Hohwald.
Abh. zur Geol. Specialkarte von Elsass-Lothringen, Vol. I, pp. 84-125; Strassburg, 1877.

ROSENBUSCH (H.). Microscopical physiography of the rock-making minerals. (Transl. by Joseph P. Iddings, New York, 1889.)
Slate needles, p. 149 and Pl. XV, fig. 4.

SANDERS (R. H.). The geology of Lehigh and Northampton counties.
Second Geol. Surv. Pennsylvania, Report of Progress D3, Vol. I, Chap. II, The Slate Region (figs. on pp. 95, 119, 127, and Pl. I.), 1883.

[1] Some of the theories advanced by Ramsay are now discarded.
[2] Some of the theories advanced by Rogers are now discarded.

SAUER (A.). Rutil als mikroskopischer Gemengtheil in der Gneiss und Glimmerschieferformation, sowie als Thonschiefernädelchen in der Phyllitformation.

Neues. Jahrb. für Min. Geol., etc., Vol. I, pp. 227–238, 1881.

SAUVAGE (——). Recherches sur la composition des roches du terrain de transition.

Annales des Mines, 4th ser., Vol. VII, pp. 411–462, Paris, 1845. Also Comptes Rendus, Vol. XXI, pp. 228–233, 1845.

SEDGWICK (ADAM). Remarks on the structure of large mineral masses, and especially on the chemical changes produced in the aggregation of stratified rocks during different periods after their deposition.

Trans. Geol. Soc. London, 2d ser., Vol. III, Pt. III, pp. 461–486, 1835. Abstract in Proc. Geol. Soc. London, Vol. III, No. 40, p. 181, 1835.

SHARPE (DANIEL). On slaty cleavage.

(Second communication) Quart. Jour. Geol. Soc. London, Vol. V, p. 111, 1849.

SORBY (HENRY CLIFTON). On the origin of slaty cleavage.

Edinb. New Phil. Jour., Vol. 55, No. 109, pp. 137–148, July, 1853.

SORBY (HENRY CLIFTON). On the theory of the origin of slaty cleavage.

Lond., Edinb., and Dublin Phil. Mag., 4th ser., Vol. XII, No. 77, pp. 127–129, August, 1856.

SORBY (HENRY CLIFTON). On some facts connected with slaty cleavage.

Rept. British Association Adv. Science, p. 92, 1857.

SORBY (HENRY CLIFTON). On the structure and origin of noncalcareous stratified rocks.

Quart. Jour. Geol. Soc. London, Vol. XXXVI. On shales and slates, pp. 67–77, 1880.

TEALL (J. J. HARRIS). A faulted slate.

Geol. Mag., new ser., Dec. III, Vol. I, Pl. I, London, Jan., 1884.

TYNDALL (JOHN). Comparative view of the cleavage of crystals and slate rocks.

A lecture at Roy. Inst., June, 1856, Lond., Edinb., and Dublin Phil. Mag., 4th ser., Vol. XII, No. 76, pp. 35–48, July, 1856. (See also Proc. Roy. Inst.)

UMLAUFT (W. L.). Beiträge zur Kenntniss der Thonschiefer.

Jahresb. des Natur. Histor. Vereines "Lotos" (1876), 29 pp., Prague, 1876.

VAN HISE (CHARLES RICHARD). Principles of North American pre-Cambrian geology, Sec. III, cleavage and fissility.

Sixteenth Ann. Rept. U. S. Geol. Surv. (1894–5), Part I, 1896, pp. 633–668. Sec. VII, Slate and mica-slate, p. 705.

VAN HISE (CHARLES RICHARD). Deformation of rocks, cleavage, and fissility; studies for students.

Jour. Geol., Vol. IV, pp. 195, 312, 449, 593; Chicago, Feb.–Aug., 1896.

ZIRKEL (F.). Über die mikroskopische Zusammensetzung von Thonschiefern und Dachschiefern.

Poggendorff, Annalen, Vol. CXLIV, 1871, p. 319.

WORKS OF AN ECONOMIC CHARACTER.

BENNETT (H. D.) [U. S. Vice-Consul at Nantes, France.]. The slate quarries of Angers.
U. S. Consular reports No. 124, p. 115. Jan. 1891.

BÖTTINGER (C.). Zusammensetzung und Verhalten von Dachschiefer.
Chem. Zeitung, Vol. XIX, p. 19, 1144, 1895.

BOWER (JOHN). Slate quarries as an investment, [England], 1865.

BRUNNER (H.). Valuation of roofing slates.[1]

Abstract in English from Wochenschrift für Pharm., 1889, in Jour. Soc. Chem. Indust., Vol. IX, p. 393, London, Apr. 30, 1890.

DAVIES (D. C.). A treatise on slate and slate quarrying, scientific, practical, and commercial; 3d ed., London, 1887, p. 186.

DAY (DAVID T.). Report on mineral industries in the United States at the Eleventh Census, 1890.
Slate, distribution of quarries, production, labor, and wages, pp. 662–665, 1892.

DAY (DAVID T.). Mineral resources of the United States, calendar year 1893, U. S. Geol. Survey.
Slate in U. S., p. 549; in Great Britain, p. 551, 1894.

DAY (WILLIAM C.). The slate industry.
Sixteenth Ann. Rept. U. S. Geol. Survey, Part IV. Mineral resources U. S. (1894), nonmetallic products, pp. 473–482, 1895.

DAY (WILLIAM C.). Slate and the slate industry.
Seventeenth Ann. Rept. U. S. Geol. Survey, Part III, continued. Mineral resources U. S. (1895), nonmetallic products, pp. 770–775, 1896.

DAY (WILLIAM C.). Slate.
Eighteenth Ann. Rept. U. S. Geol. Survey., Part V, continued. Mineral resources U. S. (1896), nonmetallic products except coal, pp. 992–1011, 1897.

DAY (WILLIAM C.). Slate.
Nineteenth Ann. Rept. U. S. Geol. Survey, Part VI—continued. Mineral resources U. S., 1897, pp. 248–264.

FRAZER (PERSIFOR, Jr.). Geology of Lancaster County, Pennsylvania.[2]

Second Geol. Survey Pa., Report Progress, 1877, Vol. CCC; Harrisburg, 1880. Roofing slate quarries of Lancaster County, pp. 179, 80.

FRESENIUS (R.). Uber die Prüfung der Dachschiefer auf den Grad ihrer Verwitterbarkeit.
Zeitschr. für Analyt. Chemie, Vol. VII, pp. 72–78; Wiesbaden, 1868.

HULL (EDWARD). A treatise on the building and ornamental stones of Great Britain and foreign countries; London, 1872.

[1] See in connection with this paper Reverdin and De la Harpe, beyond.

[2] For other reports on Pennsylvania slates, see scientific bibliography, pp. 169–171.

KELLOW (JOSEPH). The slate trade of North Wales [England], 1868.

LANGLEY (ALFRED A.) and BELLAMY (CHARLES J.). Slate quarrying in the Festiniog district, North Wales.

Proc. Inst. Civ. Eng., Vol. XLVI, p. 211 and pl. 21; London, 1876.

MERRILL (GEORGE P.). The collection of building and ornamental stones in the U. S. National Museum. A handbook and catalogue.

Ann. Rept. Smithsonian Institution, June 30, 1886, Part II. Early history of slate industry in U. S., p. 291. The slates of the various States and Territories, pp. 466–471.

MERRILL (GEORGE P.). Stones for building and decoration.

Argillaceous and fragmental rocks. The slates, pp. 293–313; New York, 1891.

MERRILL (FREDERICK J. H.). Mineral resources of New York State.

Bull. N. Y. State Museum, Vol. III; Albany, 1895. Geology and geographic distribution of building stone in New York, by John C. Smock, revised by F. J. H. Merrill, Slate, pp. 421–423.

MERRIMAN (MANSFIELD). The strength and weathering qualities of roofing slates. With discussion.

Trans. Am. Soc. Civ. Eng., Vol. XXVII, No. 3, pp. 331–349, Sept., 1892. For continuation of discussion, see No. 6, Dec., 1892, p. 685.

NIVOIT (EDMOND). Notions élémentaires sur l'industrie dans le département des Ardennes (France), 1869.

PATTISON (S. R.). Slate and slate quarries geologically and commercially considered.

Letters to the Mining Journal (Engl.), 1866.

REVERDIN (F.) and DE LA HARPE (C.). The examination of roofing slates.

Chem. Zeitung, Vol. 14, pp. 64–65, 94–95, 126–127. Abstract in English in Jour. Soc. Chem. Industry, Vol. IX, p. 394, London, Apr. 30, 1890.

SAUVAGE et BUVIGNIER. Statistique minéralogique et géologique du département des Ardennes (France), 1842.

SHALER (N. S.). Slates, description of quarries and quarry regions.

Tenth Census U. S., 1880, Vol. X, Part II, Report on the building stones of the United States and statistics of the quarry industry, pp. 168–174.

SMITH (THOMAS COOPER). Slate quarries in Wales, 1860.

Two later editions.

SPEER (F. W.). Quarry methods: The working of slate.

Tenth Census U. S., 1880, Vol. X, Part II, p. 38.

WATRIN (N.). Les ardoisières des Ardennes. . Description et exploitation du schiste ardoisier, fabrication des ardoises, lever des plans d'ardoisières. Charleville, 1898.

WILLIAMS (J. FRANCIS). Tests of Rutland and Washington County slates.

(Purple and green from Fair Haven, Vermont. Red from Granville, New York.) Van Nostrand's Engineering Magazine, Vol. XXXI, pp. 101–103, July–Dec., 1884.

[ANONYMOUS]: The slate quarries of North Wales.

Reprint of letters to Carnarvon Herald, 1873.

PHYSIOGRAPHY.

The main physical feature of the region is the Taconic Range, which is bordered on its west side by the slate belt and on its east side by a belt of marble. From almost every high knoll within the slate belt the spurs and foothills of the Taconic Range may be seen on the east, giving a varied and picturesque outline to the horizon. (See Pls. XII and XIII.) Now and then one of the higher summits of the range becomes visible. The range consists of schist, with rare areas of conglomerate or quartzite. Its general trend is north-northeast, but north of the latitude of Castleton and West Rutland the trend changes to north-northwest. The schist range is deeply dissected by erosion, and thus broken up into numerous masses more or less separated by longitudinal and transverse valleys or ravines. There are two conspicuous deep transverse cuts—that of the Battenkill, east of Shushan and Greenwich, and that of the Castleton River, east of Castleton. East of Granville the schist mass forms a line of bold cliffs and steep slopes about 6 miles long and from 500 to 900 feet high, with several transverse hollows. Toward the north end of these lies Lake St. Catherine (altitude 477 feet), with a roundish slate ridge on its western side. About 8 miles farther north lies the still larger but hardly less picturesque Lake Bomoseen (altitude 413 feet), with slate masses on both sides. Still another lake, Cossayuna, of about the size of Lake St. Catherine, occurs in Argyle, in the southwestern part of the belt. The area west of the range consists mainly of hills and hillocks ranging from 1,000 to 1,600 feet above sea level, rarely exceeding 1,400, alternating with valleys and hollows, while the lower levels along the western edge range from 400 down to 200 feet above tide water. The rock surface varies greatly in hardness from quartzite to slate, limestone, and shale, and is covered to a considerable extent with glacial drift and terrace material. The lower hills usually have a roundish outline, but now and then a bold cliff comes to view, as in Zion Hill in Hubbardton, Wallace Ledge in Castleton, or the cliffs in Benson. These are generally quartzite, or are capped by a thick bed of it. Where the hills of the slate belt have a well-defined trend its direction is also north-northeast. The unequal operation of erosion on materials of such unequal hardness and the accumulations of drift, not to mention the complex structure of the rock masses themselves, are sufficient to account for the irregular surface features of the belt. The drainage is effected by the Poultney and Mettowee rivers, both flowing into Lake Champlain, and farther south by the Battenkill, flowing into the Hudson.

AREAL AND PETROGRAPHICAL GEOLOGY.

THE GEOLOGICAL MAP.

The geological map herewith (Pl. XIII) represents the rock surface only; the Quaternary deposits are supposed to be removed. The formations shown are but two—Lower Cambrian and Lower Silurian (Ordovician). The larger part is Cambrian. This includes the "sea green," the "unfading green," the purple, and the mottled slates, while the "red slates," with the accompanying "bright green" slates, are in the Ordovician. An area of about 8 square miles in Benson containing black roofing slates is of uncertain age—certainly Cambrian or Ordovician, quite possibly Ordovician. The Ordovician areas are very irregular—in some places isolated lenticular masses, compound synclinal in structure, surrounded by and overlying the Cambrian. Some very small isolated Ordovician areas—as near Hillsdale, west of Middle Granville, and west of Lake St. Catherine, near the Wells and Poultney line—probably represent single and overturned synclines. The Ordovician also surrounds lenticular masses of Cambrian, probably compound anticlinal in structure, which protrude through the Ordovician. The central belt of Ordovician sends out long, narrow spurs into the Cambrian area, which alternate with tapering, bay-like recesses of Cambrian, the formations being thus dovetailed into one another. On the eastern side the Cambrian slate series comes into contact with the Ordovician schist mass of the Taconic Range; but north of Rupert and east of West Pawlet, Vermont, for a space of 6 miles there appears to be a transition from the Ordovician slate into the Ordovician schist[1]. This is one of the more interesting features of the map. The Central Ordovician belt, with all its complex ramifications, thus appears to be merely a continuation of the mass of the Taconic Range itself, and 40 miles south, in Petersburg, Rensselaer County, New York, a continuation of the same Ordovician area again merges into the schists of the Taconic Range. Hudson graptolites also occur quite close to the schist mass in Pawlet (see map, Pl. XIII).

The boundaries between the different formations are of unequal value. That between the Cambrian and the Ordovician schist is in very many places difficult to define. The passage from slate to schist is sometimes gradual. While fossils do occur in the Cambrian they are wanting in the schist. In the northern part schists apparently also occur in the Cambrian area. Petrographical distinctions between

[1] The term *slate* is used throughout this report in its ordinary, popular sense to denote a rock with a more or less perfect slaty cleavage adapting it to various commercial uses, and in which the constituent particles can not usually be distinguished except in thin sections under the microscope. The word *schist* is used to denote a rock sometimes of identical chemical and microscopical compositione with the commercial slate, but more or less plicated (wavy) and usually characterized by slip cleavage (quarry man's false cleavage). In the schist the mica scales can frequently be discovered by th aid of a magnifying glass. The schist is always here a phyllite. The slates, as will be shown beyond, possess some of the features of a phyllite and some of those of a clay slate. The sediments out of which both rocks were formed may have been identical, but the processes to which they were subjected were different in intensity if not in kind.


LEGEND
RELIEF
(printed in brown)
2405
Figures
(showing heights above mean sea level instrumentally determined)
Contours
(showing height above sea, horizontal form, and steepness of slope, of the surface)
DRAINAGE
(printed in blue)
Streams
Lakes and ponds
Swamps
CULTURE
(printed in black)
Roads
Villages
Railroads
State boundary lines
MAP OF THE SLATE BELT OF EASTERN NEW YORK AND WESTERN VERMONT
1894-96.
Topography by U.S. Geological Survey
Geology by T. Nelson Dale (L.M. Prindle, and F.H. Moffit Assistants) being a revision and extension of a reconnaissance map published in 1888 by C.D. Walcott.
(Dikes S.S.E. of L. St. Catherine, and Sec. VIII by Miss F. Bascom)
B Benson black slate (Cambrian or Ordovician)
Sl Lower Silurian (Ordovician) slate, shale, grit, rarely limestone
S Lower Silurian (Ordovician) limestone
Sb Berkshire schist, lower Silurian (Ordovician)
Partly synchronous
Єl Lower Cambrian; upper and lower Olenellus zone slate, quartzite, grit with some limestone and sandstone
Section lines
Dikes of camptonite, augite camptonite, or analcitite
+ Fossil localities; of the 343 given, 189 are from C.D. Walcott's Manuscript map. Those on Ordovician areas are mostly graptolites; those on Cambrian areas belong to Olenellus zone
• Slate quarries worked or abandoned. Those on Sl areas (with one exception in Poultney) are red slate; those on Єl areas (with one exception in Benson) are green or purple slate
For data of numbered quarries see pp 218-221
Note: Red slate is to be sought only within the Sl areas; green ("sea" and unfading") only within the Єl areas; black within the B areas although it occurs occasionally within the "Sl and Єl" areas
The boundary between Sl and Sb on Rupert Mountain and the Pattern in Rupert and Pawlet, Vermont, represents a gradual transition from grit, slate, and shale into schist
Scale
1 0 1 2 3 Miles
1/115 385
Contour interval 100 feet
JULIUS BIEN & CO. LITH. N.Y.
PUTNAM
BENSON
HUBBARDTON
DRESDEN
WEST HAVEN
FAIR HAVEN
CASTLETON
WHITEHALL
HAMPTON
POULTNEY
FORT ANN
GRANVILLE
WELLS
HARTFORD
PAWLET
HEBRON
RUPERT
ARGYLE
SALEM
GREENWICH
JACKSON
CAMBRIDGE
WHITE CREEK

these formations are thus often impossible.[1] Accumulations of drift and agricultural land cover the rock surface, and fossils, even in the Cambrian, are generally but the reward of patience, time, and practice. In order to show how far the boundaries are justified by paleontological evidence, 343 fossil localities are shown on the map. Of these 239 are Cambrian and 104 Ordovician. One hundred and fifty-four localities were found by Director Walcott and 189 in the course of this work.[2] The map also shows the approximate location of most of the quarries, 252, whether worked or abandoned. Within the Ordovician areas such quarries, with but one exception, are in red slate, which occurs frequently associated with graptolite shales; and within the Cambrian areas the quarries, whether in green, purple, or mottled slate, are, from the association of these slates with a Cambrian fossiliferous limestone, distinctively Cambrian, so that the evidence from the quarry locations is to be considered along with that from the fossil localities.

The question as to the possible existence of unconformity or faulting between the Cambrian and Ordovician will be discussed later. Both formations are traversed by numerous dikes, which will be fully described.

Although this geological map has the advantage of a topographic base adequate to its scale, yet any very extensive development of the slate industry would require one on a scale large enough to permit the separation of the different members of the Cambrian and Ordovician series. Yet, in view of the irregularities of sedimentation and of structure and the distribution of drift and of arable land, it is questionable whether a really satisfactory map of that kind could be constructed.

THE STRATIGRAPHICAL SERIES.

Owing to excessive and minute folding, as well as cleavage and the friable character of some of the shales, it has been found very difficult to construct an entirely satisfactory columnar section of the strata. The relative position of some of them is doubtful, owing to their intermittent character and the possibility of their merging along the strike into other members of the series. The thickness of several of them is uncertain, owing to scarcity of measurable sections. As the lower limit of the Cambrian is nowhere reached within the slate belt the section starts with an uncertainty, and the prevalence of shales in the Ordovician makes the top of the column indefinite. However, some things in the succession have been established. The accompanying table is arranged in natural (descending) order. Probable synchronous relations are shown by the parallel arrangement. On the

[1] An old slate quarry one-half mile north of the first road corner east of Granville may be in the Ordovician or in the Cambrian area, and thus the Cambro-Ordovician boundary as shown on the map may be an eighth of a mile out of place.

[2] Two Cambrian fossil localities of Mr. Walcott's—between Lake St. Catherine and West Pawlet—could not be more definitely located, and therefore do not appear on the map.

map one symbol (Sl) has been used for all the Lower Silurian (Ordovician) except the schist (Sb), where the local designation (Berkshire schist), adopted by the Geological Survey in western Massachusetts, has been preserved. Nor have the Cambrian zones or other subdivisions been designated on the map, Ꞓl (Lower Cambrian), embracing them all. The fossils enumerated are, excepting when otherwise stated, those found by the writer's assistants or himself.

THICKNESS OF THE FORMATIONS.

Estimates of the thickness of the formations, in some cases based upon careful measurements, in others on pacings and dip observations, are given in the preceding table. These result in a maximum of 830 feet for the Lower Cambrian, and from 1,000 to 1,200 feet for the Ordovician. Such partial estimates, however, are quite likely to leave out beds of a transitional character between the more easily distinguished members of the series. A more comprehensive estimate, made on Hebron Mountain, on the western half of the Cambrian anticline which plunges under the Ordovician near Fitch Point, gives about 1,400 feet for the Cambrian (Lower Cambrian); and another, across the narrow Cambrian belt east of North Granville, about Truthville, yields about the same thickness. Mr. Walcott's measurement of the Cambrian in the town of Georgia, near St. Albans, in northern Vermont, gives 1,000 feet for the Lower Olenellus zone, and several thousand more for the Upper Olenellus zone.[1] The Lower Olenellus beds there dip in one direction at angles ranging from 15° to 20°, and are continuously exposed for a mile, so that the conditions for measurement are almost as favorable as could be desired. In the Green Mountains in Massachusetts the thickness of the Lower Cambrian quartzite is estimated at from 800 to 900 feet,[2] and the writer's measurement of the Lower Cambrian part of the overlying Stockbridge limestone in the Vermont Valley is 470 feet,[3] which, added to the Green Mountain quartzite, gives from 1,270 to 1,370 feet for the Lower Cambrian. These results agree fairly well with those obtained within the slate belt. But it should be borne in mind that as we do not know the thickness of the basal member (A) of the slate belt, the total thickness of the Lower Cambrian there may easily exceed the maximum, 1,400 feet.[4] At any rate, from 335 to 1,400 feet of it are exposed.

Turning now to the Lower Silurian series, Prof. Charles S. Prosser, in a table of the actual thickness of the New York Paleozoic rocks,[5] gives

[1] See Second contribution to the studies of the Cambrian faunas of North America, by Charles D. Walcott: Bull. U. S. Geol. Survey, No. 30 (1886), pp. 15-18. This locality was visited by the writer with Director Walcott in August, 1896.

[2] Geology of the Green Mountains in Massachusetts, by Pumpelly, Wolff & Dale: Mon. XXIII, U. S. Geol. Survey, p. 190, 1894.

[3] On the structure of the ridge between the Taconic and Green Mountain ranges in Vermont, by T. Nelson Dale: Fourteenth Ann. Rept. U. S. Geol. Survey, p. 541, 1895.

[4] A recent measurement of the Lower Cambrian quartzite on the Green Mountain range opposite Bennington exceeds 1,500 feet.

[5] The thickness of the Devonian and Silurian rocks of central New York, by Charles S. Prosser: Bull. Geol. Soc. Am., Vol. IV, p. 116, Feb., 1893.

Table of Cambrian and Silurian formations of the slate belt of eastern New York and western Vermont.

LOWER SILURIAN (Sl = ORDOVICIAN).

Area within the slate belt.

Horizon.	Name.	Strata.	Fauna.	Thickness.
				Feet.
Ig......	Hudson grits.....	Gray grit (graywacke) interbedded with black shales or slates.	("Normanskill"), Climacograptus phyllophorus, Diplograptus foliaceus, D. angustifolius, Didymograptus sagitticaulis, Glossograptus ciliatus, Stephanograptus exilis, S. gracilis.	500+
Hw....	Hudson white beds.	Greenish or black, more or less quartzose, shales or slates, weathering white or whitish, with small cherty-looking or quartzite beds, also weathering white. Some brecciated limestone. Intermittent.	....	400 or less.
G......	Hudson shales....	Black or gray shales and slates, sometimes banded black and gray from bedding.	Same as above.........	50+
F......	Calciferous	Very thin-bedded limestone and gray or black shales. Possibly intermittent.	Bryograptus, Callograptus salteri(?), cf. Dendrograptus sp., Dichograptus, Dictyonema flabelliforme.	35+

Area within the slate belt.

Horizon.	Name.	Strata.	Fauna.	Thickness.
				Feet.
Irs......	Hudson red and green slate.	Red and green roofing slate or shale alternating with or replacing one another, with small beds of greenish quartzite, sometimes calcareous. The red with green spots. Replacing part of Ig. Intermittent.	Annelid trails and algæ(?).	100+
Hg	Hudson thin quartzite.	More or less bright green or dull reddish or purplish phyllite, with very thin beds of quartzite. (More frequent toward the schist mass and possibly replacing F, G, and H. More constant than Irs.)	....	200±

Area west of slate belt.

Horizon.	Name.	Strata.	Fauna.	Thickness.
				Feet.
Itl......	Trenton limestone.	Limestone, occurring mostly west of the slate belt, replacing probably I, H, and G, and possibly F, and then representing the Trenton, Chazy, and Calciferous.	Trenton brachiopods, crinoids, and trilobites.	(?)

Area east of slate belt.

Horizon.	Name.	Strata.	Thickness.
			Feet.
Sb......	Berkshire schist..	Sericite, chlorite, and quartz schist, often graphitic at base, frequently speckled with crystals of actinolite. Contains beds of greenish quartzite up to 10 feet and over in thickness, more rarely small beds of quartz conglomerate or of limestone. Equivalent to F, G, H, I, including Lorraine and Utica.	1,200+

LOWER CAMBRIAN.

Horizon.	Name.	Strata.	Fauna.	Thickness.
				Feet.
E[1].....	Ferruginous quartzite and sandstone[1]	Quartzite, usually with spots of limonite; in places, however, a bluish calcareous sandstone (grains of quartz with a calcareous and ferruginous cement) weathering rusty brown. Quartz veins abundant in both. A quartz conglomerate sometimes associated with the quartzite.	....	25-100
D[1].....	Cambrian black shale[1]	Black shale or slate, generally weathering blue black, sometimes pyritiferous, with thin beds of limestone and less frequently limestone breccia..........	Linnarsonia sagittalis var. taconica; Orthis, probably salemensis; Lingula? Lingulella coelata? Lingulella granvillensis; Hyolithes communis; Leperditia dermatoides; Conocoryphe —— sp? Solenopleura, probably tumida; a phyllocarid crustacean, closely related to Ceratiocaris; spicules of Protospongia.[*]	50-250
C[1].....	Black Patch grit[1]	Dark gray grit or sandstone with black shaly patches, sometimes with calcareous nodules..........	Olenellus in both grit and calcareous nodules..........	10-40
B[2].....	Cambrian roofing slates[2]	Roofing slate, grayish green, purple, or mixed green and purple, alternating with beds of calcareous quartzite up to 5 feet and limestone breccia up to 40 feet thick.	Olenellus; Microdiscus lobatus; M. speciosus; M. connexus; Solenopleura, possibly nana; Obolella; Iphidea pannula; Hyolithes communis; Hyolithellus micans; Trails of annelids.	200-240
A[3].....	Olive grit[3]........................	Olive green grit (graywacke), more or less massive, spangled with minute scales of hematite or graphite, sometimes with small quartzite beds, frequently calcareous, generally weathering a pale brick red. Associated with it in places a bed of quartzite 12 to 55 feet thick.	....	50-200
	Total	....	....	335-830

[*] Mr. Walcott found in these upper shales, at a point 2 miles south of North Granville, N. Y., and also near Low Hampton, in Hampton, N. Y., Microdiscus speciosus and lobatus, also Iphidea pannula.
[1] C, D, and E are intermittent. Any one or two of them may be wanting. One of them generally, if not always, between the Ordovician (F) and Lower Olenellus (H and B).
[2] These slates are often wanting in western part. Purple and green slates sometimes measure 100 feet each, but usually alternate in lesser beds.
[3] A is rarely purplish or dark reddish before weathering. There may be some slate beds in this horizon.

these figures for the Lorraine shales (Hudson) and Utica, and for the Trenton:

	Western New York.	West Center.	Central.	Eastern New York.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Lorraine and Utica	598	820	873	*a* 3,500
Trenton	954	842	637	350

a This estimate of 3,500 feet is taken from Ashburner's general section from top of Catskills to bottom of Mohawk Valley: Trans. Am. Inst. Min. Eng., Vol. XVI, p. 910.

Mr. Walcott estimates the thickness of the cherts, shales, green and red Ordovician roofing slates on the east side of the Hudson River at 3,000 feet, and the underlying calcareous sandstone and shale and dark argillaceous shales at 2,000 feet, making 5,000 feet for the Hudson formation.[1] The thickness of the Hudson and Utica slates in middle Pennsylvania, where there is little folding, is given by the Second Geological Survey of Pennsylvania at from 1,000 to 1,600 feet, but is regarded as probably much greater in the Great valley, although measurements there are unsatisfactory.[2]

The estimates for the Ordovician of the slate belt, which must represent the Hudson, Trenton, Chazy, and Calciferous, while far below Mr. Walcott's and Mr. Ashburner's estimates for the Hudson alone, come nearer to figures given for central New York and for middle Pennsylvania. It is quite probable, however, that the upper portion of the Ordovician has been eroded from a large part of the Ordovician areas of the slate belt and this estimate is thus too low.

Allowing 1,400 feet for the Lower Cambrian and 1,000 to 1,200 for the Lower Silurian exposed within the slate belt, it is still within the possibilities that in a region of such moderate relief a mass of beds 2,500 feet thick, thrown into small, close, and mostly overturned folds, would account for such a rock surface as that depicted in that portion of the map which lies west of the Taconic Range.

THE ROCKS IN DETAIL AND THEIR AREAL DISTRIBUTION.

Each member of the Cambrian and Ordovician series will now be described in some detail, beginning with the lowest.

THE OLIVE GRIT.[3]

A greenish, usually olive-colored, very rarely purplish, more or less massive grit, generally somewhat calcareous, and almost always spangled with very minute scales of hematite or graphite. Under the microscope it is seen to consist mainly of more or less angular grains of

[1] The value of the term "Hudson River Group" in geologic nomenclature, by Charles D. Walcott: Bull. Geol. Soc. Am., Vol. I, p. 346-347, Apr., 1890.

[2] J. P. Lesley: Summary final report, Second Geol. Survey Pa., Vol. I, Chap. XLVI, 1892.

[3] Lower Cambrian (Olenellus zone); Horizon A, in table facing p. 178.

quartz, with a considerable number of plagioclase grains, rarely one of microcline, in a cement of sericite with some calcite and small areas of secondary quartz. There are large scales of muscovite and of a chloritic mineral, scarcely dichroic, and under polarized light a bluish green or prussian blue, with little or no change in rotation. More conspicuous and typical of the rock are scales from 0.043 to 0.130 by 0.020 millimeter, frequently bent, pale green, markedly dichroic, and under polarized light olive or slightly bluish green. These scales contain bands of a colorless mineral parallel to their cleavage, which measure 0.0043 in width and polarize in brilliant orange, emerald, or blue. Extinction in both about (if not quite) parallel to cleavage and bands. Finally, there are grains or crystals of a muddy yellow under incident light, probably limonite and that after hematite. The scales of hematite, sometimes graphite, can be made out with a magnifying glass.

This characteristic rock can usually be identified at a distance by the peculiar pale brick-red color of its weathered surface, and, on closer inspection, by the minute spangles and the olive color of the fresh surface. It occurs usually in close proximity to the Cambrian roofing slates (Horizon B), apparently underlying them, and covers large areas of the slate belt. The type locality is on the west side of Lake Bomoseen, one-fourth mile west of the road running north from Hydeville, on the north side of road to Fairhaven. A cliff of it 100 feet high lies three-fourths mile west of the Scotch Hill quarries and 2 miles north of Fairhaven. It may be seen a mile south of Shushan on both sides of the Battenkill; also 2 miles south of Cambridge, on the east side of the valley; again, east of Lake Cossayuna in Argyle, and in the southern part of Hebron, 3 miles west of the Vermont line and south of Chamberlain Mills.

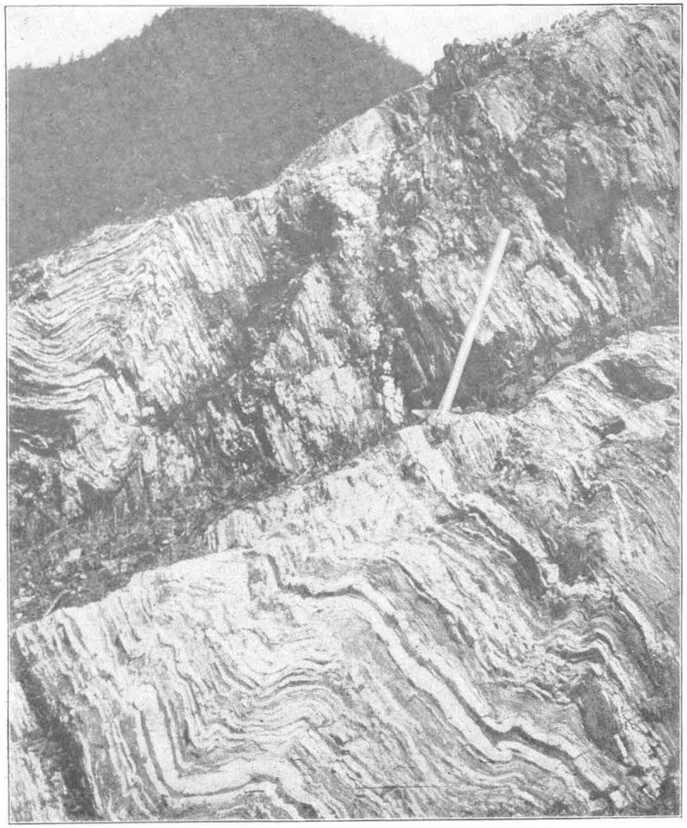
There are indications near the Fairhaven railroad depot of the possible occurrence of a bed of roofing slate within the Olive grits, but the structure at that point is too involved to establish this as a fact. Frequently interbedded with this grit are beds of quartzite an inch or less in thickness. More rarely does it contain massive beds of quartzite from 12 to 55 feet thick. This quartzite is sometimes slightly calcareous and speckled with limonite, probably from the weathering of siderite. It is traversed with quartz veins abounding in small quartz crystals. Rarely a small bed of quartz conglomerate finds a place in it. One of these beds of quartzite can be traced from a point about 2 miles southeast of Cambridge for more than 2 miles in a north-northeast direction. Another occurs a mile northeast of Hebron.

THE CAMBRIAN ROOFING SLATES.[1]

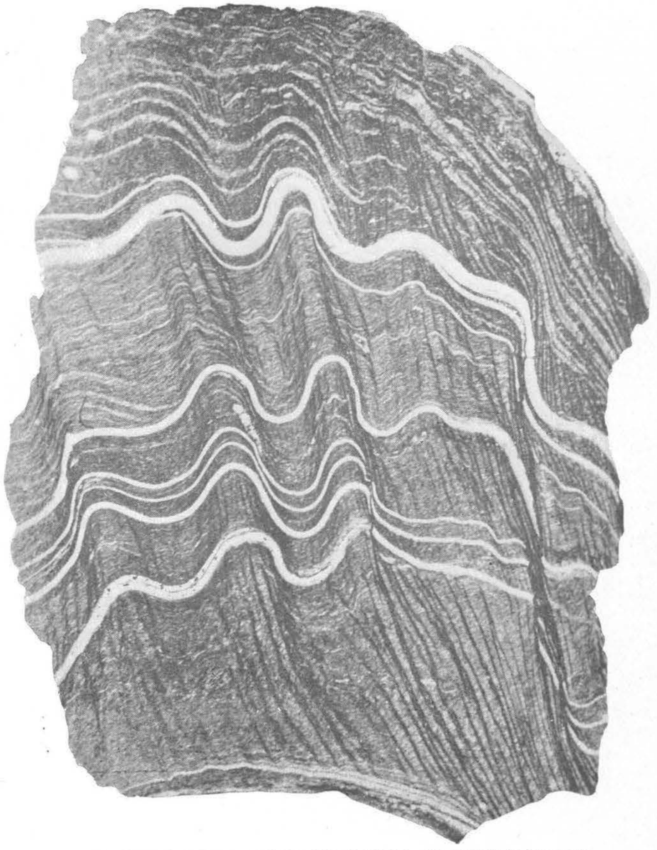
The microscopic features of the slates will be described in detail later.

Greenish gray, purple, and variegated (greenish gray and purple) slates suitable for industrial purposes alternate with each other. The

[1] Olenellus zone; Horizon B, in table facing p. 178.



A, THIN QUARTZITE BEDS OF ORDOVICIAN SERIES.



B. SCHIST FROM TACONIC RANGE, IN THIN SECTION.

quarry diagrams (Pls. XXXIII and XXXIV) show that there is little regularity in these alternations. In the main, however, this horizon seems to consist of from 100 to 140 feet or even 200 feet of greenish and purplish slates, the greenish ones predominating, with from 40 to 50 feet of variegated or mottled overlying, but possibly replacing the purple in places. On the west side of Lake Bomoseen nearly 100 feet of purple are exposed. The purple sometimes contains a few inches of dark reddish slate not unlike the red of the Ordovician. There is some difference in the shade of the different beds of green in the same quarry, some being more greenish, others more grayish. There are also differences in the amount of discoloration produced by weathering in beds of the same locality. This discoloration will be shown to be due to the presence of microscopic rhombs of a carbonate of lime and iron and probably of magnesia. Although some quarries produce only the so-called "unfading green," which has very few of those rhombs, and others only the "fading green," in which they are more abundant, these differences do not appear to belong to strata of different ages, but to occur at different points in strata of the same age. This will be hereafter discussed more fully.

Interbedded with the slates are beds of calcareous quartzite varying from a few inches up to 5 feet in thickness, and likewise of irregular extent. It contains a few grains of plagioclase, more muscovite scales, and is veined with quartz, which crystallizes in cavities. The quartzite sometimes weathers brown; its calcite, therefore, probably containing some siderite.

Associated with the slates are also beds of limestone conglomerate or breccia from a few feet to 40 feet in thickness, carrying the trilobite Olenellus and other fossils characteristic of the Lower Cambrian. One of these beds of limestone breccia is of frequent occurrence in the quarries, overlying the slate. (See quarry diagram P, Pl. XXXIV.)

The slate-bed surfaces are generally covered with annelid trails or impressions of algæ, or both. The purple slates are often ribboned or banded with light green slate beds an inch or more in thickness, or have oval or roundish light green spots, frequently in rows. Similarly the sea-green slates have grayish ribbons crossing them.

THE BLACK PATCH GRIT.[1]

Immediately overlying the roofing slates (Horizon B) and their associated limestone and quartzite, as may be seen at Eddy Hill, near Fairhaven, and on Zion Hill in Hubbardton, is a grayish grit (graywacke) or sandstone. This rock at first sight might easily be mistaken for the Hudson grit (Horizon Ig), but a closer inspection shows that its grains usually have a more roundish outline and, with rare occurrences of plagioclase and zircon, are quartz. It is also usually characterized by black shaly patches. The cement is calcareous and

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[1] Lower Cambrian (Olenellus zone); Horizon C, in table facing p. 178.

sericitic. At Eddy Hill this rock contains calcareous concretions or nodules of a quartz sandstone with calcareous cement, which, as well as the grit, carry fragments of Olenellus. Black pebbles—up to 2 by 1 inch in size—of a clastic rock, consisting of a matrix of dense, dark material, with angular fragments of quartz, plagioclase, muscovite scales, calcite plates, three-spined organic objects, and cellular plates, occur exceptionally in the grit. Such a one was found in Black Creek valley, Hebron, New York. Smaller ones, but without the organic remains, occur at Eddy Hill. At Zion Hill the grit has a very sericitic cement, a chloritic mineral (dichroic and under polarized light dark purple), and some quartzitic areas. At Flint Hill, south of Glen Lake, in Fairhaven, there is a chloritic grit of a peculiar dark, grass-green color, which may belong to this horizon or to Horizon E. The relations at Eddy Hill are shown in Pl. XXIV, *A*; those at Zion Hill in fig. 7.

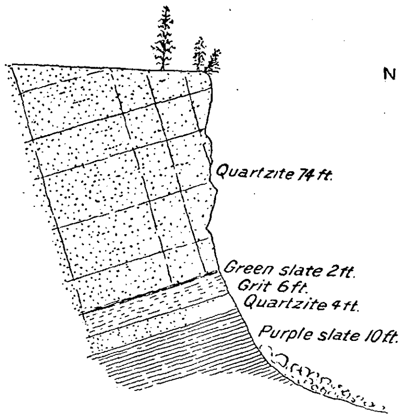


FIG. 7.—Section of Zion Hill, East Hubbardton, Vermont.

The thickness of the Cambrian grit does not appear to exceed 40 feet. The horizon is intermittent, so that the Cambrian black shale (Horizon D) may follow directly upon the roofing slate (Horizon B).

THE CAMBRIAN BLACK SHALE.[1]

Throughout the entire region there are long belts of black or gray shale or slate, which in weathering usually assume a dark bluish tinge. They are rarely somewhat micaceous. These shales and slates occur in proximity to the Ordovician rocks, but never contain any graptolites and rarely any fossils. However, sponge spicules (Protospongia), brachiopods (Lingulella and Linnarssonia), and carapaces of a phyllocarid crustacean have been found in them. These crustacea were found by Mr. Prindle 2 miles southwest of South Granville, near Pinnacle Hill, and also three-fourths of a mile west of North Granville. The shales are not infrequently marked with black, shiny, oval spots one-half by one-fourth inch, possibly imperfect impressions of such carapaces.

At a point 2½ miles south of Castleton Corners these slates have been quarried, and contain fossil algæ. About 3 miles north of Benson some black slates have been prospected, which may also possibly belong here. Thin limestone beds, sometimes brecciated, are often associated with these shales. The following fossils were found either in the limestone or the shales, some of them in both: *Hyolithes communis*, *Linnarssonia sagittalis* var. *taconica*, *Orthis* (probably *salemensis*), a Lingula, *Lingulella granvillensis* and *L. cœlata?*, *Leperditia dermatoides*, a *Conocoryphe* and a *Solenopleura*, probably *tumida*.

[1] Lower Cambrian (Olenellus zone); Horizon D, in table facing p. 178.

COARSELY PLICATED SCHIST OF THE TACONIC RANGE.

The hard, black pyritiferous slate which frequently rests immediately upon the Cambrian roofing-slate group, as at Middle Granville, Scotch Hill in Fairhaven, and at the Eureka quarries in Poultney, alternating with extremely thin beds of fossiliferous quartzose limestone and hard, gray slate, are supposed to belong to this horizon, the Black Patch grit (Horizon C) being absent. (See quarry diagrams, Pl. XXXIV, fig. S, and Pl. XXIV, *B*.)

A belt of the Cambrian black shales occurs one-half mile east of Gorhamtown, in Poultney, and runs northward beyond Castleton toward Hooker Hill. Another, east of the Eureka quarries, can be traced to within a mile south-southeast of Blissville and south to within 2¼ miles of Poultney, its exposure being over 2 miles long. Near its southern end it bears sponge spicules, and 50 feet east of it a small limestone bed yields Olenellus. A similar belt, quite possibly its continuation, was traced by Mr. Prindle from a point a little south of Bomoseen, on Lake Bomoseen, north-northeast for 5 miles to a point 1½ miles north-northwest of Zion Hill, in Hubbardton, and found to recur 2 miles still farther north. This also yields sponge spicules. At a steep hillside near the lake and one-half mile west of Wallace ledge, Mr. Prindle found the following succession, beginning below: Purple slate, 15 feet; green slate, 10 feet; slate and quartzose beds, 8 feet; blackish slate, 17 feet; all dipping about 10° E. Another belt was traced by Mr. Moffit from near Hatch Hill, in East Whitehall, along the west side of the northern half of the isolated Ordovician area, 2½ miles north into Hampton. In line with it, if not in continuation of it, is one beginning 2 miles west-northwest of Fair Haven at the Poultney River and extending 4 miles north-northeast to near the southwest shore of Inman Pond, and reappearing on its east shore with small beds of calcareous quartzose and felspathic grit. At the Poultney River these beds measure from 100 to 200 feet; near Belcher they may reach 250 feet in thickness. In general, they are more persistent than the Black Patch grit (Horizon C) and are easily confounded with the Ordovician shales (Horizon G).

THE FERRUGINOUS QUARTZITE AND SANDSTONE.[1]

At Zion Hill, in Hubbardton, massive beds of quartzite, 74 feet in total thickness, overlie Cambrian green and purple slates as well as a bed of grit. (See fig. 7.) This quartzite recurs 1½ miles south, and again at Barker Hill, 2 miles south. In its upper part it is speckled with brown dots of limonite. At Wallace Ledge, in Castleton (see fig. 8 and Pl. XXI, *B*), a bed of quartzite 20 feet thick overlies green and purple slates, recurring 1¼ and 2 miles south near Bomoseen, and 25–30 feet thick. At Blissville a similar bed, 12 feet thick, is exposed for 350 feet overlying the Cambrian slates. At Flint Hill, near Glen Lake, there are about 50 feet of alternating beds of conglomerate, quartzite,

[1] Lower Cambrian (Olenellus Zone); Horizon E in table facing p. 178.

and dark grass-green, chloritic, calcareous grit with scales of graphite, weathering brownish, overlying green slate. This chloritic grit occurs also at Wallace Ledge and at Blissville in similar relations; also one-half mile east of Bomoseen on the east side of a strip of Cambrian black slate, and, again, 1½ miles north of Bomoseen on a point in the lake. At Flint Hill the conglomerate has a cement of green slate, and is also interbedded with green slate. The pebbles measure up to 2⅝ inches in diameter, and are mostly quartz, but a few are quartzite or an altered grit, consisting of quartz and feldspar (plagioclase, microcline, and orthoclase) grains, the latter partly altered to muscovite. Most of the grains have rims of chlorite and muscovite scales, and some black grains, tourmaline, probably. One grit pebble measured 1 by 2 by one-third inch. There are also pebbles of a clastic black rock.

In the southern and central part of the slate belt, such massive quartzites usually occur between the Cambrian black shales (Horizon D) and the Ordovician black shales (Horizon G). The quartzite is vitreous with brown limonitic specks in the cement, probably from the alteration of a siderite. It then is identical in composition and appearance with the quartzite of Horizon A. In other places, however, it is a bluish calcareous sandstone, the grains being quartz (with a few of plagioclase and microcline) and the cement calcareous and sideritic. The rock is traversed by numerous quartz veins, sometimes very thin. In weathering the calcic carbonate is dissolved away, the siderite ($FeCO_3$) passes into limonite, giving a rusty color, and the rock gradually crumbles back into quartz sand, while the quartz veins remain. Eventually the veins alone remain, forming a network of intersecting quartz blades, showing the various stresses to which the rock was once subjected.

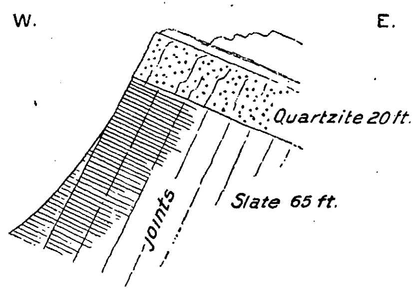
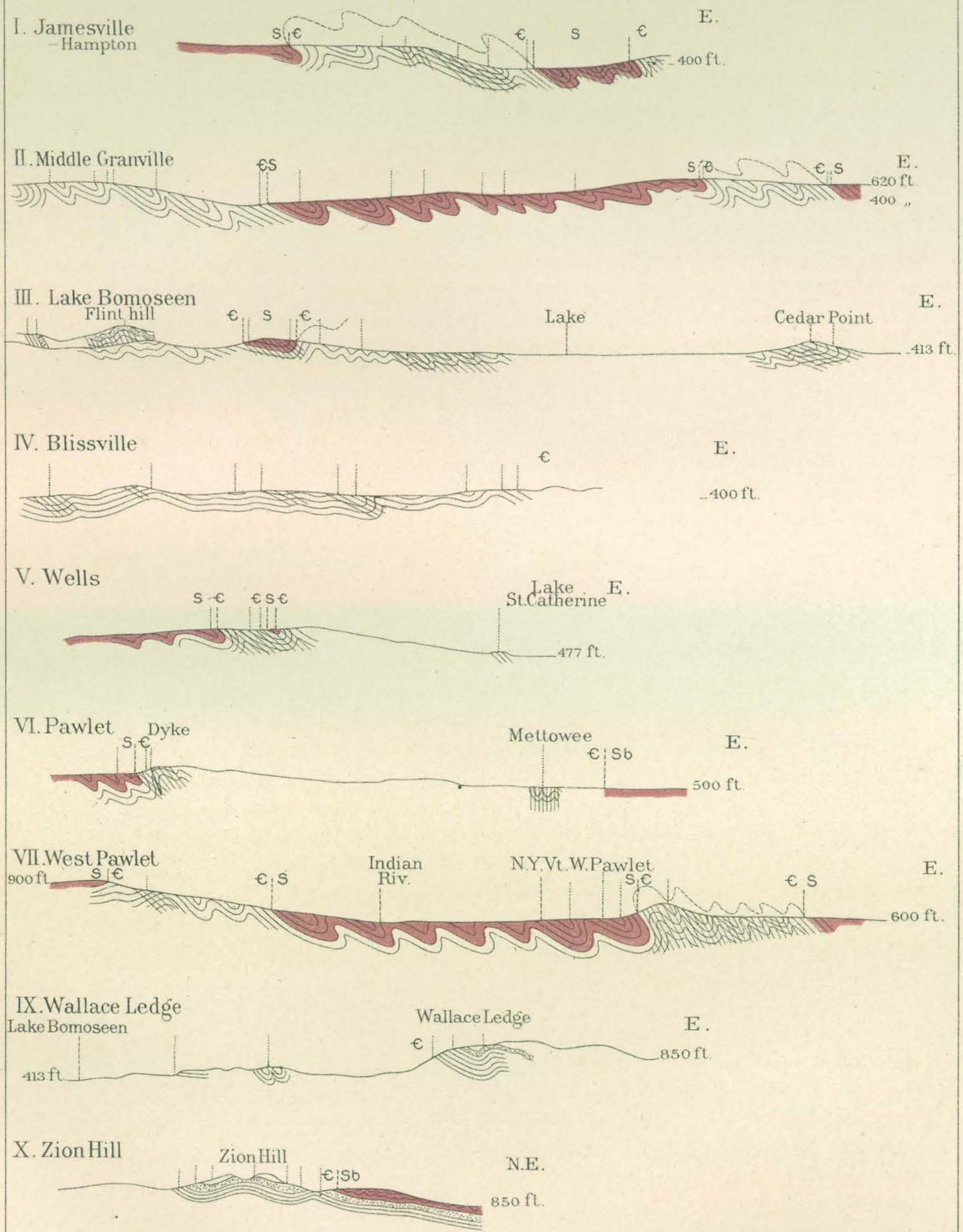


FIG. 8.—Section of Wallace Ledge, Castleton, Vermont.

In this horizon, at a point 2¼ miles north of North Granville and a few hundred feet east of the road going north, Mr. Prindle found a small irregular deposit of dark colored barite associated with calcite.

About 3 miles north of Zion Hill, at a corner in the road to (West) Hubbardton, there is a mass of greenish quartzite of doubtful position, over 100 feet in thickness. At the northern edge of the area shown on the map (Pl. XIII), 3 miles north of Benson, beds of coarse quartzite 20 to 40 feet thick overlie grayish more or less shaly slates. At the top of the southern cliff this quartzite appears to be overlain by 25 to 50 feet of slates. These quartzites may all belong to Horizon E, and correspond to those at Zion Hill, Wallace Ledge and Flint Hill. The quartzite cliffs west of Glen Lake are also placed here.

The Ferruginous quartzite, like the Black Patch grit, is intermittent. Its usual relations to the Ordovician and Cambrian series are shown in figs. 15 and 16, p. 291.



LEGEND

Scale
vertical and horizontal: $\frac{1}{31,250}$

Sections. I-VII. ¼ Mile　IX. 528 ft.　X. 100 ft.

same as Quarry maps Pls. XL and XLI.

Section lines on Quarry maps and General map Pl. XIII.

Vertical dotted lines indicate places where dip was observed; otherwise hypothetical

Vertical dashes indicate boundaries between Cambrian and Silurian, or refer to names.

SECTIONS ACROSS PARTS OF SLATE BELT OF EASTERN NEW YORK AND WESTERN VERMONT

JULIUS BIEN & CO. LITH. N.Y.

THE CALCIFEROUS.[1]

At a number of localities immediately overlying the ferruginous quartzite are certain dark gray calcareous or very quartzose finely bedded shales or black shales, with thin limestone beds. They are easily overlooked on account of their inconspicuous characteristics and their inconsiderable thickness. The extremely fine bedding and the following fauna distinguish them, however, from the rocks of adjacent horizons. Hydrozoa: *Bryograptus*, *Dichograptus*, *Callograptus salteri?* cf. *Dendrograptus sp.*, and *Dictyonema flabelliforme*. Several of these are regarded as probably of Calciferous age, which would place the horizon in the lowest part of the Ordovician. The European species of Bryograptus come from the Upper Cambrian. Dictyonema ranges from the Ordovician into the Devonian. It is uncertain from the observations whether Horizon F is intermittent or everywhere present.

THE HUDSON SHALES.[2]

More easily recognized, and perhaps more generally represented, are black pyritiferous and rusty weathering or grayish shales, sometimes with small beds of black shales, giving the rock a marked banding. The shales may be calcareous, or may in places pass into slate. The fossils are the graptolites of the Normanskill zone, Hudson formation, enumerated under Horizon Ig. Wherever these shales occur in proximity to Cambrian beds they appear conformable to them. The presence of the graptolites is the surest means of distinguishing these shales from the Cambrian black shales, which, when the quartzite (Horizon E) and possibly the Calciferous (Horizon F) are wanting, they may immediately overlie.

THE WHITE BEDS.[3]

The Ordovician series is difficult to follow in the field, owing to irregularities of sedimentation, intricate folding, and frequently poor exposures. Overlying the Hudson shales, but without any sharply marked boundary, is a series of similar black shales or slates interbedded with thin, dark-greenish or black, cherty-looking beds which are often merely more quartzose shales. These shales and quartzose beds both usually weather very light gray or white, so as at a distance to be easily mistaken for limestone or quartzite. In some places, however, the shale is light green and weathers white, while the small beds are quartzite. Brecciated limestone beds containing pebbles of a black, siliceous, slaty rock are also associated with the black shales.

About a mile north of Hampton on the road to Fair Haven there are about 175 feet of a black, resonant, splintery, and slaty rock, weathering white, overlain by about 225 feet of greenish slates with small

[1] Lower Silurian (Ordovician); Horizon F on table facing p. 178.
[2] Ordovician; Horizon G, ibid.
[3] Ordovician; Horizon Hw, ibid.

quartzite beds. The black rock consists mainly of muscovite scales and angular quartz grains, without orientation, in a dark matrix. Under the blowpipe, with cobalt solution, the white surface gives the reaction for kaolinite. The rock was probably originally a feldspathic mud, with quartz fragments and muscovite scales. Some secondary mica may have formed. It may be called a siliceous and feldspathic slate.[1] The same rock occurs also at several other points in the Ordovician areas. The cherty beds under the microscope resolve themselves into quartz fragments and muscovite scales, the former predominating.

At Mount Colfax, in the town of Jackson, N. Y., about a mile south of the triangulation point (1,342 feet), these dark-greenish, white-weathering, and black graptolite shales are traversed by a brecciated and slickensided quartz vein about 8 feet thick, containing a little copper sulphide and probably some native gold, but of no economic importance. The beds strike N. 30° W. and dip southwest in sharp minor folds. Vertical joints strike N. 60° W. The slickensided under surface of the vein dips S. 72° E. at an angle of 20°.

How far the white beds are persistent deposits is uncertain.

THE HUDSON THIN QUARTZITES.[2]

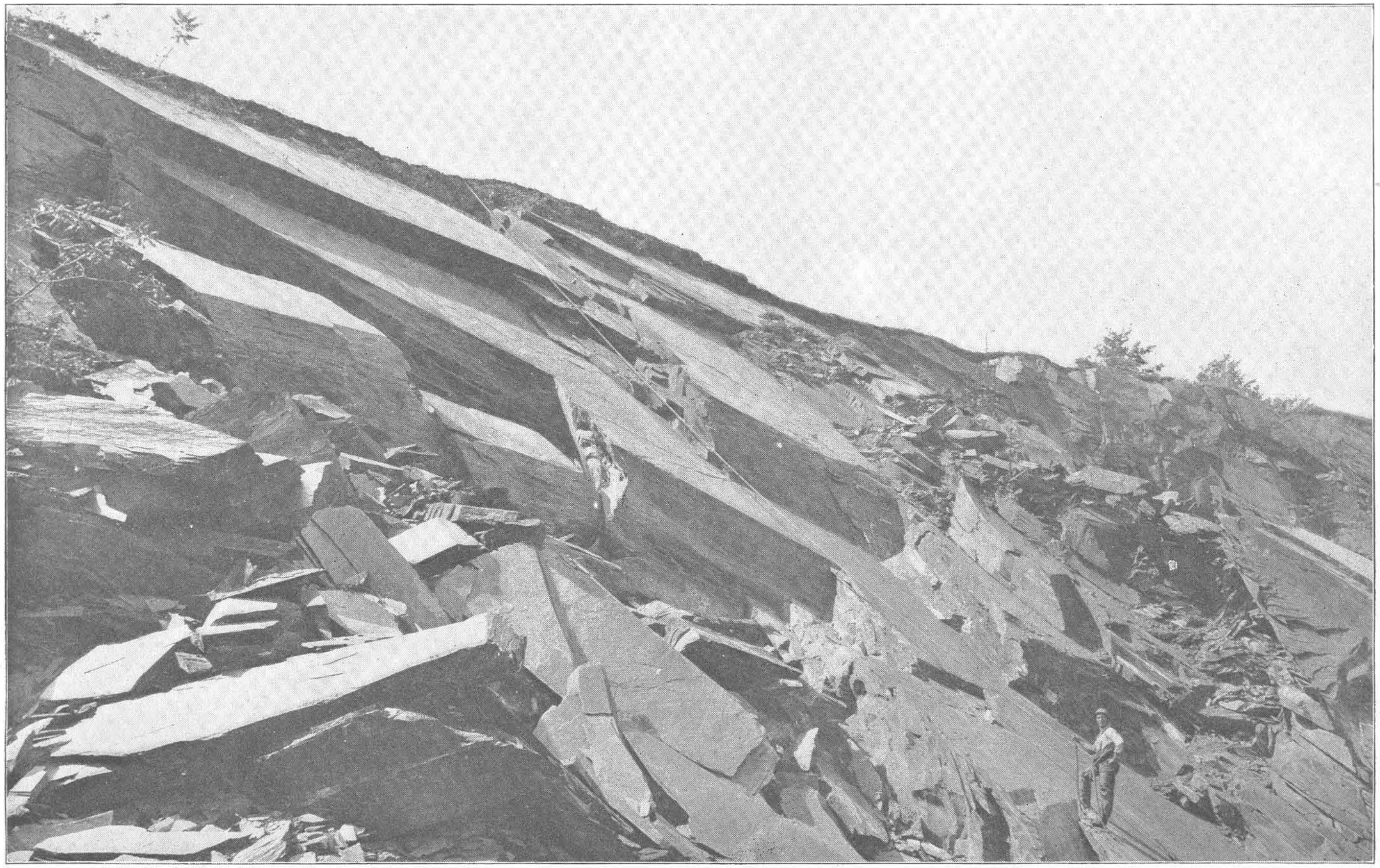
Toward the schist hills of the Taconic range there are more or less bright-green phyllites, with half-inch quartzite beds, alternating with purplish phyllites with similar quartzites. The general character of these beds is shown in a photograph taken near Goose Egg Hill, in White Creek, New York, which is here reproduced as Pl. XIV, *A*.[3] Although no fossils occur to indicate the age of these beds, yet from their underlying the Hudson grit at one point and the frequent association of similar beds with the red slate of the Ordovician belts west of the Taconic range they are supposed to belong here. They may possibly also represent the White beds (Horizon Hw).

Near the red slate the quartzites measure from one-tenth to 1 inch, and the phyllite is of a dull-reddish color. A mile north of the road corner lying midway between Granville and Blossom Corners is an outcrop of this rock 800 feet wide. The beds are sharply plicated. The Hudson grits lie on the west of it and the Cambrian slates on the east. It occurs again at a point 2¼ miles northeast of West Pawlet, also three-fourths mile east southeast from the top of Highgo Hill, near the Bennington County line; also 1 mile northeast of East Poultney, and on Hamilton Hill, near Inman Pond, 3 miles north of Fair Haven, in the small Ordovician area. A determination by Mr. George Steiger, at the chemical laboratory of the Survey, shows that a specimen of the slaty part of this rock, from Rupert Mountain, in Pawlet, contained 6.11

[1] See A. Geikie, Text-Book Geol., 3d ed., p. 154, "Kieselschiefer"—Lydian stone, a mixture of silica, alumina, and carbonaceous material.

[2] Ordovician; Horizon Hq. in table facing p. 178.

[3] Originally published as fig. 82, in Structural details in the Green Mountain region and in eastern New York: Sixteenth Ann. Rept. U. S. Geol. Survey, p. 357, 1896.



CAMBRIAN GREEN SLATE QUARRY, MIDDLE GRANVILLE, NEW YORK.

per cent of Fe_2O_3, or about three-fourths of 1 per cent more hematite than the average of four analyses of the red roofing slates. A thin section of the rock from the same locality shows alternating beds of sericitic white quartzite and of sericite schist, the latter with numerous dots of Fe_2O_3, quartz grains, and some chlorite. The difference between the two sets of beds is that the quartzite has far more SiO_2, far less Fe_2O_3, and less sericite. They correspond to alternations of clayey ferruginous sediments with sandy ones which were very slightly clayey. Each bed measures about one-eighth inch and all are plicated. While one of the quartzite beds is sharply folded, the adjacent bed of phyllite is minutely faulted (slip-cleavage), as is also the next bed of quartzite. The alternations in the material make exact measurements of the amount of displacement by slip-cleavage possible.

A thin section of a similar rock from one-half mile south of North Rupert shows the same general character, but the quartzite contains grains of plagioclase feldspar, and quartz vein matter has been deposited in the transverse openings formed by the slip cleavage. Minor lenses of quartzite occur also in the red beds, and there are fractures diagonal both to the bedding and the slip-cleavage, which are filled with secondary muscovite. Sections of this rock afford beautiful illustrations of the effects of compression and dynamometamorphism on changing sediments.

THE HUDSON GRITS.[1]

The Hudson grit is a rock so marked in its characteristics as to be easily identified. It is coarse, grayish, sandy looking. Fresh fracture surfaces are very dark, and show glistening glassy quartz grains and, very frequently, minute pale-greenish slaty particles. Under the microscope, it consists of angular grains of quartz, orthoclase, plagioclase, and scales of muscovite, probably clastic. The cement contains not a little carbonaceous matter, secondary calcite, and pyrite. In the more easterly Ordovician areas the cement is quite sericitic, and the feldspar is partially sericitized, but in other places, and along the Hudson, in Rensselaer County, the amount of sericite in the cement is small. The marked features are the heterogeneity of the fragments, their irregular size, angular outline, and usually the absence of any arrangement in them. Chlorite is rarely present. On Rupert Mountain, about 3 miles north-northeast of Rupert village, near the Berkshire schist boundary, the grits show a transition to schist, becoming very sericitic, while the schists show sedimentary quartz grains.

A further peculiarity of the Hudson grits is that they contain particles of various fragmental rocks, showing that they were derived from the erosion not only of older granites and gneisses, but of sedimentary rocks of Ordovician or pre-Ordovician age. About 40 thin sections of the Hudson grit from Poultney, Wells, Pawlet, Rupert, in Vermont;

[1] Ordovician; Horizon Ig on table facing p. 178.

and from Salem, Troy and East Greenbush, in New York, were examined, in order to determine the character of these particles of clastic rocks. The results are these: In some of the sections there are areas composed of minute grains, which, although different in character from the rest of the section, yet merge into the cement, and so may be parts of the cement, itself of coarser or finer grain. Such were discarded. Other areas, however, are so sharply defined at the contact with the cement, and the direction of their plication is so different from that of the cement, that they are clearly fragments of an older rock. Four thin sections from the outcrop at West Pawlet railroad depot—one from a point a mile southeast of Poultney, one from a point 100 feet below the dam in the Poestenkill at Troy, and another from a point near the Hudson 3 miles south of Greenbush, in East Greenbush—gave satisfactory evidence of containing fragments of sedimentary rocks. Thirty fragments were examined, ranging in length from .28 to 1.85 millimeters and in width from .128 to .74; that is, from about one-fourth to nearly 2 millimeters in length and one-eighth to three-fourths in width. They consisted of shale, micaceous quartzite, calcareous quartzite, limestone or dolomite, slate, and flint. The most abundant were found to be quartzite, slate, and shale.

The details as to some of these are as follows:

Slide M. III. 72 *a.*—1 mile southeast of Poultney. Grain an aggregate of angular quartz grains, with a few carbonate rhombs and muscovite scales.

Slide D. XV. 805 *a.*—West Pawlet railroad depot. Grain of sericite fibers polarizing as one mineral; quartz grains and chlorite scales = slate. Another grain of angular quartz grains, muscovite scales, plagioclase grains, a coarse foliation = a grit.

Slide D. XV. 805 *e.*—Same locality. Grain of sericite fibers polarizing as one mineral; several quartz grains; a chlorite scale interleaved with muscovite probably. There are six such grains near together. Of these one has its foliation at right angles to that of an adjacent one, and but two of these grains have their foliations exactly parallel.

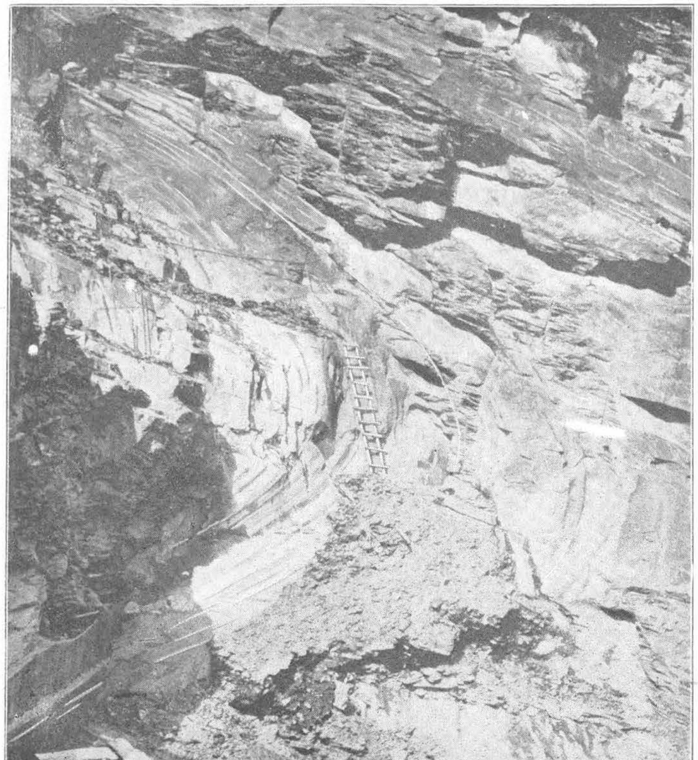
D. XV. 805 *f.*—Same locality. Grain of angular quartz and plagioclase fragments; scales of muscovite; an irregular plate of carbonate. Another grain black, dense, schistose with minute angular quartz grains. Another grain is quartzite.

D. XV. 805. 5.—Same locality. A grain of sericite fibers polarizing as one mineral with quartz grains = a slate.

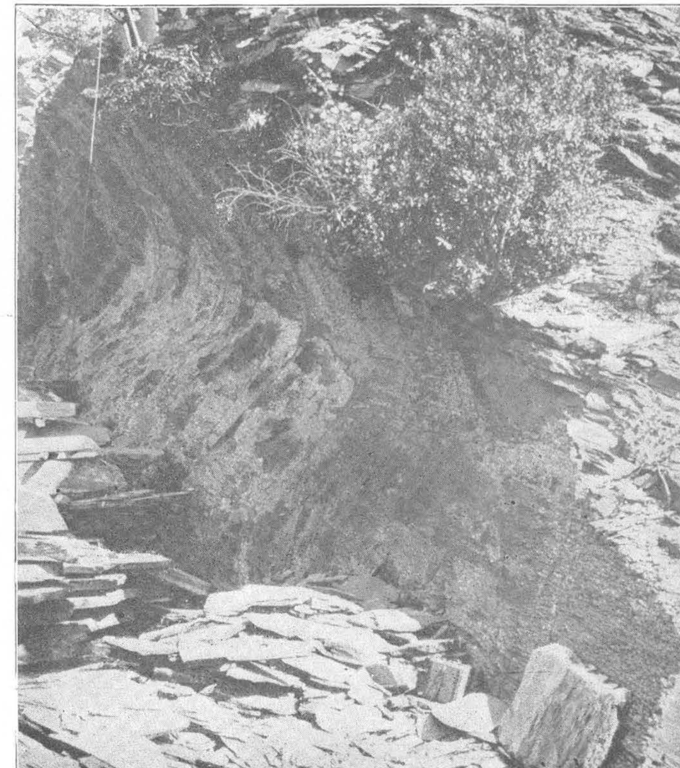
Three other grains of similar character, but with their foliations differently orientated and consequently with different extinctions. A crystal of zircon, fragment of plagioclase, and some carbonate in cement between two of these grains.

P. I. 256. *a.*—100 feet below dam in Poestenkill at Troy. Grain of quartzite. Grain of slate. Grain of limestone containing vein of calcite. Grain of quartz fragments, muscovite scales without orientation, chlorite and rutile needles = a slate in parallel section or a shale. Grain of micaceous quartzite. Grain of stratified carbonate rock with quartz grains = quartzose limestone or dolomite. A grain of slate polarizing as one mineral, with quartz grains, chlorite scales, and tourmaline, section across its cleavage.

The Hudson grits are interbedded or associated with black slates and with graptolite shales. These slates have been quarried at a point 2 miles southeast of Poultney and one-half mile northwest of Lily Pond. They occur also 1½ miles north of East Poultney in a brook north of



A. OVERTURNED SYNCLINE IN SLATE QUARRY AT CEDAR POINT, LAKE BOMOSEEN, VERMONT.



B. INSIDE VIEW OF APEX OF OVERTURNED SYNCLINE AT CEDAR POINT.

Town Hill. The graptolite shales of horizons Ig and G bear the following fauna: *Climacograptus phyllophorus*, *Diplograptus foliaceus* and *angustifolius*, *Didymograptus sagitticalis*, *Glossograptus ciliatus*, *Stephanograptus exilis* and *S. gracilis*, which belong to the Normanskill zone of the Hudson formation.

Outcrops of the Hudson grit occur in close proximity to the Cambrian slates at West Pawlet, at the foot of the quarry dumps; also at Auld & Conger's quarry in Wells, near the Poultney town line. There is a continuous line of Hudson grit ledges from Poultney to West Pawlet on the west side of the Cambrian slate, a distance of 12 miles. Some beds generally intervene between the Cambrian slate beds (Horizon B) and the Hudson grits (Horizon Ig). At the quarries these intervening beds are usually covered by the dumps, so that the Ordovician grits are the next accessible outcrops to the Cambrian slates. As has been stated, Horizons C, D, and E are intermittent. The beds which usually intervene are the greenish shales or slates with small quartzite beds of Horizon Hw or Hq, or some of the shales and slates of Horizon G. In some places all the intervening beds will not exceed 400 or even 200 feet, and may measure still less. At a point 1⅛ miles north-northwest of Chamberlain Mills, Mr. Prindle finds Hudson graptolites in black shales within 15 feet of the Olive grit of the Lower Cambrian, and the black shales within 5 feet of that grit, both rocks dipping east, the Ordovician by an overturn underlying the Cambrian. There is much irregularity in the Ordovician series as well as in the Cambrian.

The black slate area in Benson (B on map) is of uncertain age, no fossils having been found in it thus far, although on its northwestern edge fossils somewhat resembling Ordovician crinoids occur. It hardly differs in appearance from the black slates of Horizon I or from the Ordovician black slates about Roach Pond in Hubbardton, but on the western edge near Root Pond an outcrop of quartzite occurs not unlike the Cambrian quartzite. The slates of the Benson area will be described more fully later.

The Hudson grit occurs in Argyle, west of the Cambrian slate belt, and in many of the Ordovician areas within it. Large outcrops of it occur east of the West Pawlet Cambrian area and again in Rupert, on Rupert Mountain, where the Berkshire schists, the red and green phyllites of Horizon Hq and the Hudson grits all come together.

THE HUDSON RED AND GREEN SLATE.[1]

Economic interest in the Ordovician series is confined chiefly to the red slate. The chemical and microscopic characters of this and the accompanying "bright green" slate will be given later. At several points the Hudson grits appear to be replaced along the strike by the red and green Ordovician slate. Certainly the latter occur sometimes in as close proximity to the Cambrian slates as do the grits. Black graptolite shales sometimes occur very near to and probably underlie

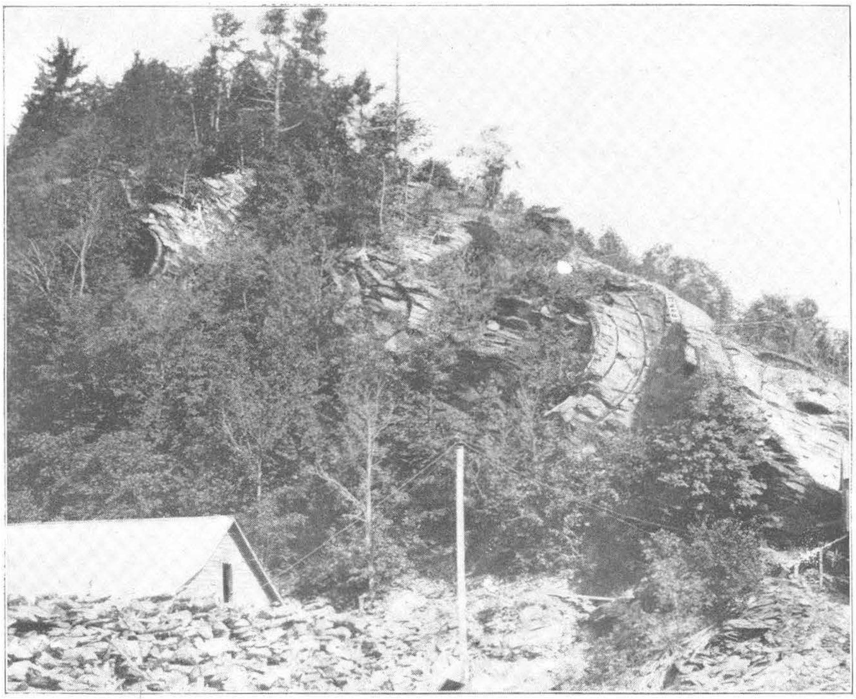
[1] Ordovician; Horizon Irs on table, p. 178.

the red slates. Beds of red and green slate alternate vertically, and also replace each other along the strike, and also pass into shales of the same colors. The structural features of the beds of this horizon are shown in the quarry diagrams given on Pls. XXXIII and XXXIV. The thickness exposed at the quarries reaches 50 and 75 feet, mostly red, with about 25 feet of green overlying, but, subtracting that which is too hard or too soft or badly veined, there are sometimes but 10 feet, rarely more than 25 feet, of good red slate exposed at any one quarry, although it sometimes reaches 42 feet. Owing to the character of the folds and their pitch, as well as the merging of the colors along the strike, it is not easy to ascertain the total thickness of the red and green. A few feet or inches of dark red or purple sometimes occur in the red. Beds of greenish quartzite, sometimes calcareous, and bordered by a purple slate, the whole "ribbon" measuring an inch or two in thickness, are not uncommon (see Pl. XXV, *a*). Also beds one-half inch thick of rhodocrosite (manganese carbonate) with crystalline calcite. (See p. 260 for analysis.) There are also quartz veins in both red and green, sometimes crystallized, and in the red light green spots with or without a purple rim. Both red and green slates are frequently speckled, becoming "knotenschiefer" (see p. 252.) The bedding planes are often covered with glistening annelid trails and with possible impressions of algæ. The red and green slates or their representative shales may occur in any of the ramifying or isolated Ordovician areas indicated on the map between the western limit of the Cambrian and the schist mass of the Taconic range, but no red shales have been found in the long Ordovician strip which passes through West Castleton.

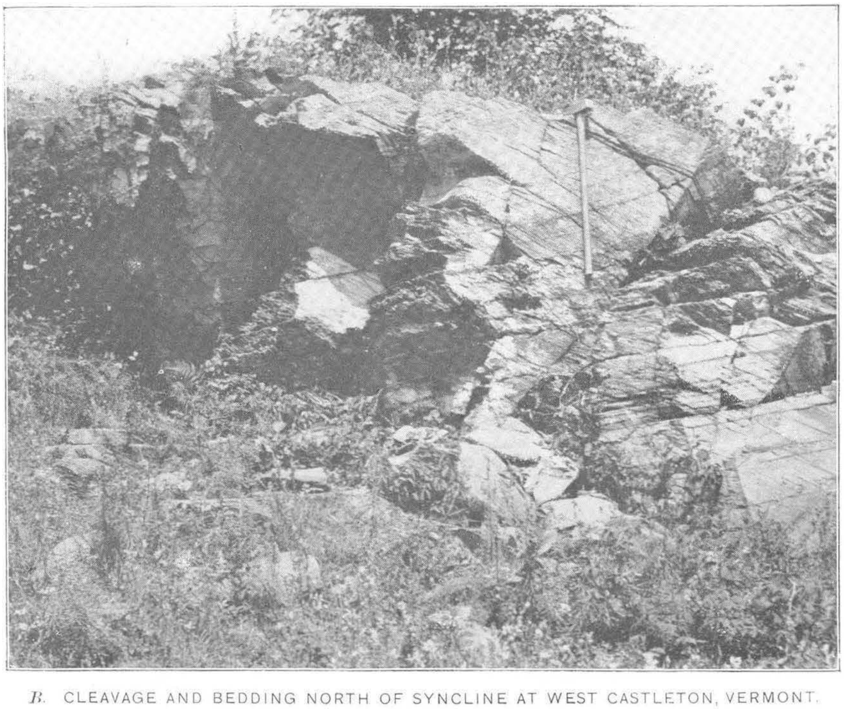
THE TRENTON LIMESTONE.[1]

The Trenton limestone occurs sporadically within the Ordovician areas of the slate belt; also on its western edge in Argyle and in Hartford. There is a continuous series of outcrops of it from West Granville, New York, to the extreme northern edge of the map, bordering the Cambrian on the west, excepting where the black slates of Benson intervene. On the west it reaches the shore of Lake Champlain. There is also another strip of it along the east side of the Benson black slate area, continuing northeasterly to the southwest corner of Sudbury. It occurs also near Black Pond in Hubbardton, toward the southern end of the large Ordovician area. At Carvers Falls in the Poultney River, and at several other points near the Cambrian boundary, it yields Trenton fossils. In some places it was probably deposited contemporaneously with the Hudson grits and shales, or it may underlie portions of them. In others it may represent the entire Lower Silurian series and should then be regarded as Trenton, Chazy, and Calciferous.

[1] Ordovician; Horizon Itl on table, p. 178.



A. OVERTURNED SYNCLINE AT CEDAR POINT, LAKE BOMOSEEN, VERMONT.



B. CLEAVAGE AND BEDDING NORTH OF SYNCLINE AT WEST CASTLETON, VERMONT.

THE BERKSHIRE SCHIST.[1]

The schist mass which lies east of the slate belt and constitutes the Taconic Range has a pretty uniform petrographic character with some important variations. It consists mainly of fibrous muscovite (sericite) more or less minutely plicated, with not a little chlorite, to which it largely owes its usual green color, some quartz, usually of secondary origin, also rutile needles and magnetite octahedra, and sometimes siderite rhombs altered to limonite. It has large lenses and veins of quartz. In places the rock is black and graphitic, and then usually pyritiferous.[2]

The schist is sometimes purplish, owing to the presence of dots of Fe_2O_3. This rock is sometimes used for the manufacture of an inferior brown paint.

In Pittsford, Hubbardton, and Ira, and probably other places, the schist is finely speckled with crystals, which prove to be actinolite, measuring .13–.217 by .008–.043 millimeters, with their main axes in any direction, but with their broad sides, in some localities at least, transverse to both bedding and slip cleavage planes. A bright green pyrophyllite occurs also in thin scales. An analysis of this from a locality on the north side of Herrick Mountain, in Ira, Vermont, made by Mr. George Steiger, at the laboratory of the Survey, yielded:

	Per cent.
SiO_2	68.02
$(AlFe)_2O_3$	24.75
Ignition	3.95
CuO	1 to 2
CaO	Trace.
CO_2	Trace.
Total	96.72

Another feature of the schists is the presence of beds of quartzite, usually greenish, from an inch or two to several feet in thickness, and, more rarely, a conglomerate of small quartz pebbles several feet in thickness, and, rarely, a bed of unfossiliferous limestone. These small quartzite beds occur opposite West Rutland, and thick beds of it are seen between Moose Horn Mountain and Single Hill in Wells, and also on Goose Egg Hill in White Creek, and on Biddies Knob in Pittsford. The minerals of frequent occurrence in the Massachusetts portion of the range—albite, ottrelite, and garnets—are less abundant or do not occur east of the slate belt.

[1] Ordovician; Horizon Sb on table, p. 178.

[2] For the petrography of the schists of the Taconic Range in western Massachusetts and eastern Vermont, see Dr. J. E. Wolff's notes in Monograph U. S. Geol. Survey, Vol. XXIII, Part III, pp. 182-184, 1894. Also Thirteenth Ann. Rept. U. S. Geol. Survey, pp. 303-305, 1894.

While the chemical and mineralogical composition of much of the schist east of the slate belt is almost identical with that of the roofing slates, particularly the green ones, the principal difference lies in its structure. It is almost universally crumpled more or less minutely, and this crumpling is generally accompanied by a transverse slip cleavage, both of which features deprive it of economic value as a slate. Pl. XV, from a photograph taken by Mr. Walcott along Wells Brook, in the strike of Moosehorn Mountain, shows this crumpling on a large scale; Pl. XIV, *B*, shows it on a microscopic scale.

The indications of a transition from the Hudson grits to the Berkshire schists on Rupert Mountain have already been referred to. The areal relations of the schists to the Ordovician of the slate belt indicate that it must be the equivalent of the entire Ordovician there represented, i. e., the Calciferous, Chazy, and Trenton (Hudson), and its thickness, which ranges between 1,000 and 2,000 feet, is probably adequate to this.

STRUCTURAL GEOLOGY.

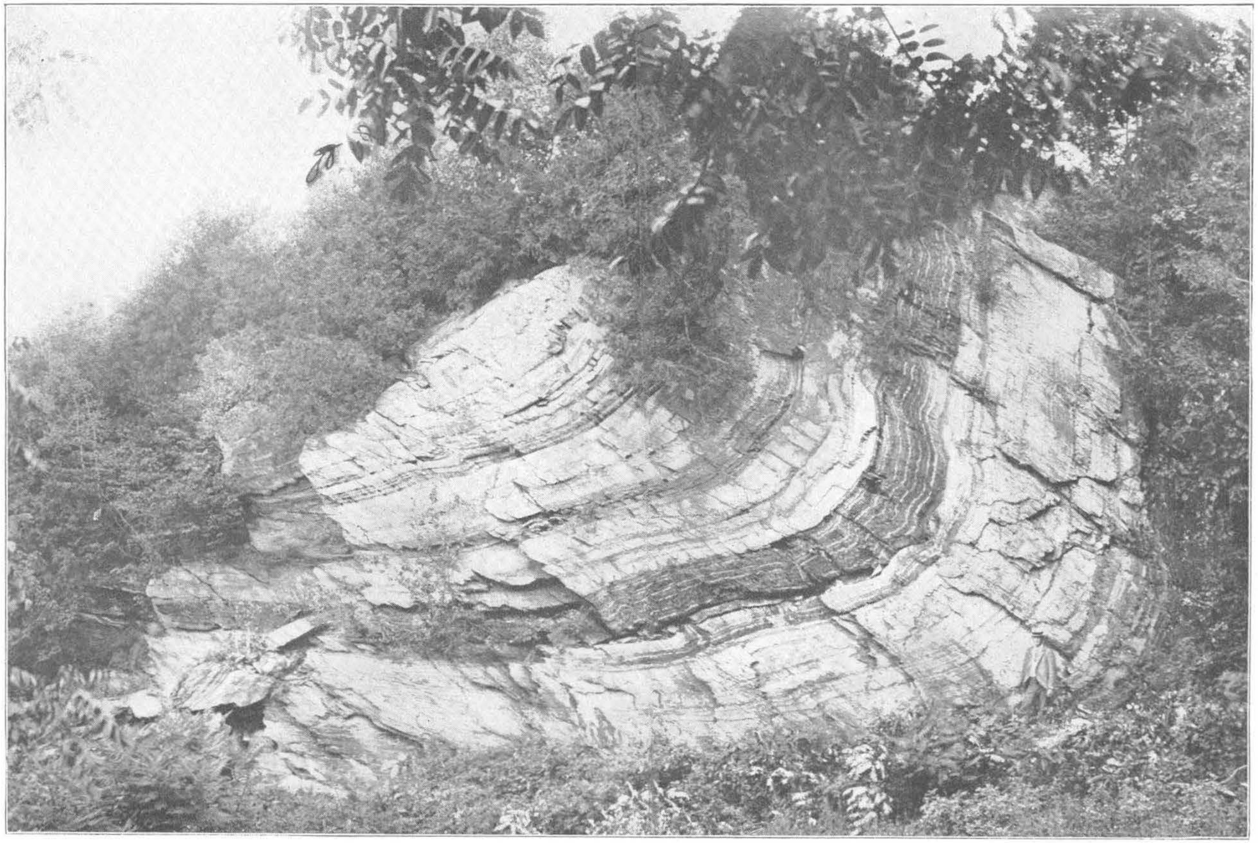
The structural features of the slate belt and of the adjacent part of the schist mass are shown in the ten sections given in Pl. XVI and that in fig. 10, which are drawn at favorable and important points. Those portions of the sections which are well substantiated are indicated by vertical dotted lines. The obstacles to exact measurements and to a satisfactory stratigraphical table militate also against the construction of complete sections. However, the typical features of the region are finely shown at certain points, and these have been utilized in drawing the hypothetical parts of the sections. Symbols showing the structure at a number of the quarries are given on the large scale quarry maps (Pls. XL and XLI), upon which, as well as upon the general map (Pl. XIII), the section lines have been drawn.

THE GEOLOGICAL SECTIONS.

SECTION I.—JAMESVILLE-HAMPTON.

This crosses the Jamesville Cambrian slate belt. The occurrence of the Ordovician red slate on the east of the Jamesville belt is shown at the Matthews quarries, a mile west of Poultney, in Hampton, and on the west at those of the National Red Slate Company, about a mile north-northwest of Raceville, in the town of Granville. About a mile due north of Raceville there is a small opening in red slate in close proximity to the Cambrian. The red slate dips easterly under the Cambrian by overturn. From 500 to 600 feet north-northwest of this the Hudson grits crop out, and a mile north-northwest, on the east side, three-fourths of a mile north of section, Mr. Walcott found Hudson graptolites in easterly dipping shales.

The eastern base of the Jamesville Ridge consists of the Cambrian black slates and shales with small beds of limestone (Horizon D). These also crop out at the bend in road south of section. These slates and shales form the uppermost strata of the ridge, Horizon E being absent, but that outcrop probably belongs to those on the west side of ridge. Arising from beneath Horizon D are the green and purple roofing slates, with 10 feet of limestone with Lower Cambrian fossils. There are 7 or



SYNCLINE OF ORDOVICIAN SLATE AT WEST CASTLETON, VERMONT.

8 old quarries on the hillside. In the largest some 20 feet or more of black and gray slates overlie the green and purple slates which dip 22° E., with a cleavage of 35° E. A low, easterly bedding and a somewhat steeper easterly cleavage (up to 45°) are well shown at several of the quarries. Beds of calcareous quartzite occur. The purple slates now underlie, now overlie, the green. In the main the ridge appears to be an anticline of Horizons B and D, very much overturned to the west, with the red slates (Irs) and the Hudson graptolite shales (G) and the Hudson grits (Ig) on both sides of it. In the section the only well-observed things are the relations of cleavage and bedding on the eastern slope. The overturn at the west where the Ordovician underlies is inferential and the other folds are hypothetical.

SECTION II.—MIDDLE GRANVILLE.

This crosses the Middle Granville "sea green" and red slate quarries. Judging from the dovetailing of the Cambrian and Ordovician a few miles south of Middle Granville, we should expect, immediately west of Middle Granville, first, an anticline, then a syncline. The Jamesville belt crossed by the eastern end of the section would be, as in Section I, anticlinal, and the intervening broad Ordovician belt would be synclinal in structure.

There are about a dozen Cambrian slate quarries north of the village. Pl. XVII is from a photograph taken by Mr. Walcott when these quarries were in operation. Some measurements were taken about these quarries by the writer, but the locality is perplexing. There is a fault, and possibly much folding and faulting. The following succession, however, is clear, beginning above: Black shale and slaty shale (Horizon D), 70-100 feet; limestone with Lower Cambrian fossils, 4 feet; green and purple slate (Horizon B), 50-60 feet. There is an open drainage cut 213 feet long, east of one of the larger quarries, which crosses the black shales and exposes one fault plane. There is a tunnel 180 feet long west of the quarry, with a shaft at the end also in black shales. The men who worked in the tunnel report that it also traversed black shales. West of the shaft is another slate quarry, and southeast of the east end of the open cut still another one. There appear, therefore, to be two masses of black beds and three of roofing slate. Mr. Prindle finds some evidence of an Ordovician area at the top of the hill. It would seem, therefore, possible that between that point and the red slate of the valley on the east we have an anticline consisting of several minor folds, and that the Cambrian green and purple slate occupy the centers of the lesser anticlines and the black shales the sides, as shown in the section. But the structure might be interpreted as consisting of two beds of green and purple slates alternating with two of black shale, or a fault could be supposed between the central body of green slate and the black slate west of it. Several quarries in this line show about 70 feet of the black rock (Horizon D).

Only occasional observations were made in the valley east of the ridge, and these all indicate low easterly dips, and so do the observations at Nixon's and Pritchard's quarries, with slight indications of a westerly dip at one of the latter. The folds are probably all overturned to the west, but their dimensions may vary greatly from those shown in this part of the section. The only data as to the Cambrian ridge at the east end of the section are easterly dips on both its east and west sides, indicating the usual overturn.

SECTION III.—LAKE BOMOSEEN.

This crosses Cedar Point and extends to Glen Lake. At Cedar Point, Lake Bomoseen Slate Company's quarry, there are 127 feet of purple, overlain by 50 of green, and these by 5-10 feet of limestone, but all doubled over into a close syncline with an axial plane almost, if not quite, horizontal and traversed by a cleavage foliation dipping 20° east (see Pls. XVIII, *A*, *B*, XIX, *A*, and Pl. XXXIV, *N*). For that part of the section which lies east of the Ordovician strip, and west of the bend in the section line the data have been taken from the old quarries a mile south (see Pl.

XXXIV, fig. T, and Pl. XVI). The folds are many and small and overturned to the west. At the West Castleton quarries, north and south of this section and east of the Ordovician strip, the slates dip 45° to 50° east, and consist of about 25 feet of purple overlain by 8 feet of green slate, and these by 8 feet of limestone, followed by poor slates and quartzite beds. The relations of Ordovician and Cambrian are not well exposed. The Cambrian slates must either turn steeply to the west or be faulted. At the extreme north end of the Ordovician strip Mr. Prindle made out the following relations (see fig. 9): The Black Cambrian slates (Horizon D) and the Ferruginous quartzite (Horizon E) occurring between the Cambrian limestone and roofing slates (Horizon B), and the Ordovician graptolite shales (Horizon G). About a half mile north of West Castleton the graptolite shales occur 300 feet west of the Cambrian slates with some thin quartzites (Horizon Hw or Hq).

The structure of the Ordovician strip itself is beautifully shown at a ledge by the road side between West Castleton and Glen Lake (see Pl. XX). The rock is a grayish, more or less calcareous shaly or arenaceous slate, banded with black beds from a fraction of an inch to 2 inches in width. On the west side of the syncline the beds dip very slightly east or horizontally. Farther east, at the top, the dip is 55° W. and still farther 90°. The cleavage throughout is about 35° E. The ledge is evidently the center of the syncline and gives the key to the structure of the whole strip, which is 3¼ miles in length, while the fossils leave no doubt as to its age.

A little south of the section and of Glen Lake is a hillock known as Flint Hill (shown in the section) presenting peculiar features. The base of the hill consists of green Cambrian slate and so does the hillock east of it. This slate is capped

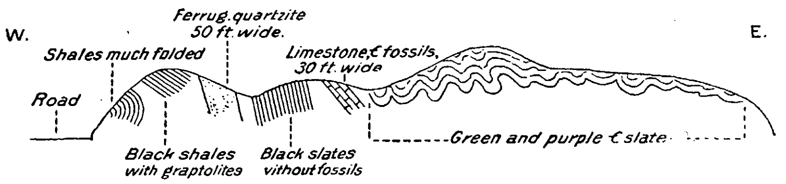
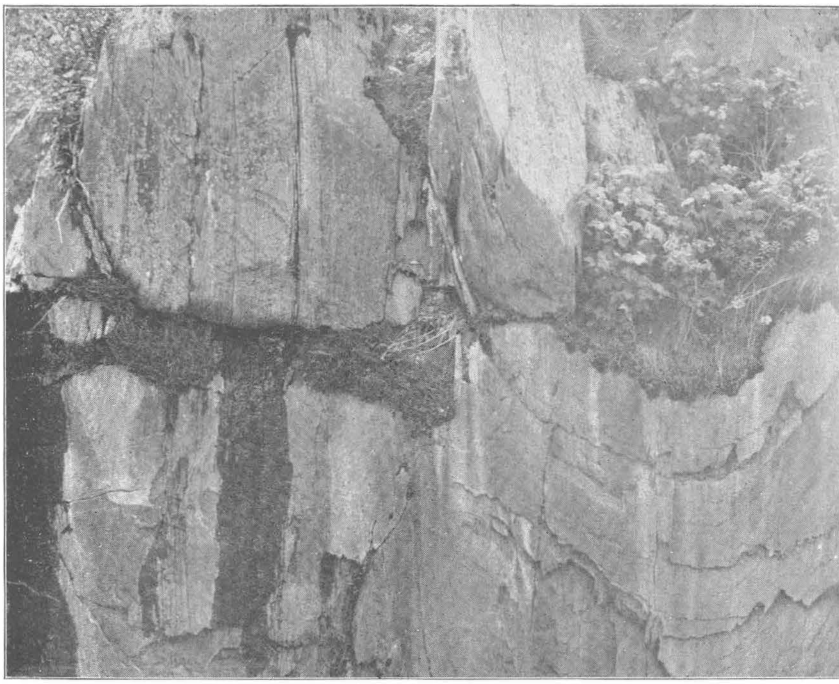


FIG. 9.—Section of Cambrian and Ordovician, West Castleton, Vermont, by L. M. Prindle.

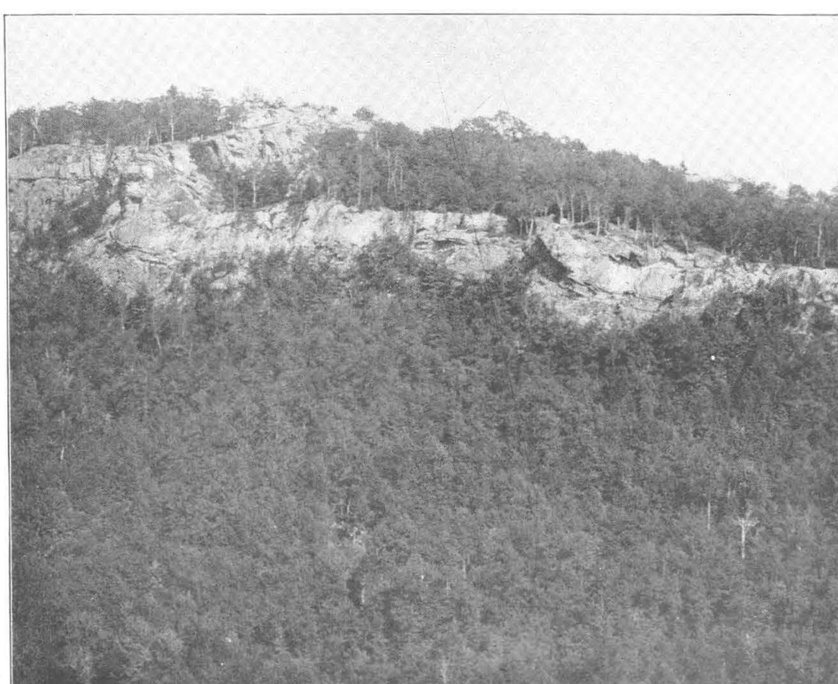
by beds of quartzite and conglomerate with pebbles of quartz and quartzite, and a dark yellowish green grit, 50 feet thick, of anticlinal structure, with a southerly pitch of 10°. The quartzite, the conglomerate, and the slate alternate with each other. In places the slate itself contains pebbles up to 2⅝ inches in diameter. As the quartzite does not recur in the ravines east or west, it may be a minor anticlinal fold in a general syncline, the rest having been eroded; or it may have thinned out east and west. Some 700 feet farther west, however, a quartzite occurs, 65 feet thick, overlying a mass of the Olive grit (Horizon A) 60 feet thick, and dipping east. This may be the quartzite of Horizon A. Northwest of Glen Lake Mr. Prindle explored a cliff of quartzite one-fourth mile long and 50 to 75 feet high and about 50 feet thick, dipping now 90°, now 65° W., then 80° E. Whether this quartzite belongs to Horizon A or should be classed with the Flint Hill quartzite in Horizon E is uncertain.

SECTION IV.—BLISSVILLE.

This crosses several lines of quarries near Blissville in Castleton, Vermont. There are 20 quarries hereabouts, including the old Eagle quarry. The northeasterly line of quarries shows a minimum of about 50 feet of green and variegated slate (strike N. 10° to 15° E., dip 20° to 30° E.) overlain by 20 feet of black slate and shale and thin bedded limestone, followed by a few feet of green slate and a bed of quartzite 10 to 12 feet thick, which is exposed for 350 feet along the strike. The quartzite contains calcareous nodules which weather out, and overlies and, at the south, runs into a few feet of a green grit like that of Flint Hill. The black shales crop out at



A. COMPRESSED VERTICAL FOLDS AT THE GORGE OF THE METTAWEE RIVER.



B. QUARTZITE FOLDS OF WALLACE LEDGE, VERMONT.

several points along the road south, and also on the ridge east of it. These are classed in Horizon D and the quartzite in Horizon E.

Between this line of quarries and the road running south the Olive grits (Horizon A) crop out at several points and extend to the road corner north—all with an easterly dip. The first quarry on the west side of the north and south road shows a very gentle syncline at its south end and the beginning of an anticline at its northeast corner. The next line of quarries west includes the Eagle. The strike here changes to N. 15°–20°–30°–40° W. The dips are 25°–30° E. and SE. The cleavage strikes N. 5° E. and dips 20° E. There are about 70 feet of purple, overlain by 10 feet of green and these by 15 feet of thin-bedded Olenellus limestone. At the most northerly quarry of this line but one the beds are folded and overturned almost as much as at Cedar Point (see fig. O, Pl. XXXIV). The strike of axis of fold is N. 40° W.; cleavage dip, low, east. Small beds of light green, with or without a quartzose limestone in the center, produce bands on the cleavage surface.

At a quarry intermediate between the second and third lines of quarries, and one-fourth of a mile north of this section, the strike changes to N. 75° W., dip 15°–20° S.; cleavage strike, N. 35°-50° E., dip 15° E. The complication is probably due to a southerly pitch.

In the third line of quarries the beds are nearly horizontal. The fourth line, a half mile south of section, shows very low westerly dips and at the extreme west end of the section a gentle syncline is exposed crossed by a cleavage dipping 35° E.

SECTION V.—WELLS.

This starts at the west shore of Lake St. Catherine and crosses the slate ridge west.

The portion of the slate belt most largely worked of late years is the ridge between West Pawlet and Poultney. Away from the quarries it is difficult to obtain satisfactory observations, and within the quarries bedding is generally obscured by cleavage.

Beginning at the lake, purple and green Cambrian slates dip 45° E. Judging from scattering observations along the west side of the ridge, it must be largely composed of roofing slate. From a point about a half mile west of the lake there is a line of quarries and prospect holes extending northwards for 2 miles. The cleavage dip is uniformly east. Farther west the section crosses a strip of red Ordovician slate almost a half a mile long and 180 feet wide at the broadest part, but tapering out both north and south. The dip is 35° E. This is probably a small compressed and overturned syncline. The Ordovician grit is absent here, but some of the small quartzite beds (Hw or Hq) occur between the Cambrian slates and the red slates. All the slates exposed between the strip of red and the road on the west should recur on the east of the red, but in inverse order. At Auld and Conger's quarries there are 170 feet of slate of various qualities, green and variegated, exposed. Strike N. 5° W. dip 35° E., with cleavage dipping 40°–45° E. Dipping toward and under the slate, but with greenish and grayish beds intervening, are the Hudson grits. Strike N. 5° E. dip 40° E. Between the syncline of red slate and the Hudson grits there is probably an anticline, as drawn in the section, and all the slates on the west side of the red ought to recur east of the grits in inverse order. The folds shown in the grit are hypothetical, but the first one west of the slate would naturally be a syncline.

SECTION VI.—PAWLET.

This begins near the Mettowee and crosses the slate ridge. The boundary between Ordovician and Cambrian at the east end of the section is uncertain. In the gorge of the Mettowee green and purple Cambrian slates of no commercial value are finely exposed. At the sawmill (Pl. XXI, *A*) the axial planes of the folds stand erect, and the anticlinal parts of some of the folds have been pinched out. The cleavage is vertical. The eastern side of the ridge for a mile and more south consists of sharply folded phyllites interbedded with quartzite possibly belonging to Horizon A. West of this is a strip three-fourths of a mile wide of unknown character, but, from the situation of two quarries about 2¼ miles south of a point a half mile west of the Mettowee sawmill, and from the direction of the strike of the slate at these quarries, slate probably occurs in the western half of this blank space of the section. The roofing slate quarries from this latitude to West Pawlet lie almost all within a strip one-fourth of a mile wide along the eastern side of the Ordovician grits on the western slope of the ridge. The structure at the quarries is difficult to make out. Bedding, where observed, dips east, as does also the cleavage. From the observed relations of the Cambrian and Ordovician wherever they occur very near each other in this region the Cambrian overlies the latter through an overturn. An anticline should, therefore, occur on the Cambrian side of the boundary and a syncline on the Ordovician side of it. Not far from the Columbia quarry is a dike of camptonite,[1] 5 feet 9 inches wide, running northeast to southwest, dipping 90° or steeply to the northwest. The slate on the east side of the dike strikes north and dips 70° E. and on the west side 55° E. The dike has a rough jointing parallel to its sides and weathers in spherical nodules. The cleavage at the quarries dips about 55° E. West of the quarries are greenish shales and phyllites with small quartzite beds, striking N. 5° E. and dipping 45-50° E., measuring apparently about 125 feet, but possibly less, if close folded. These probably belong in the Ordovician (Hw or Hq). West of these come the Hudson grits (Ig) dipping 65° E.

SECTION VII.—WEST PAWLET.

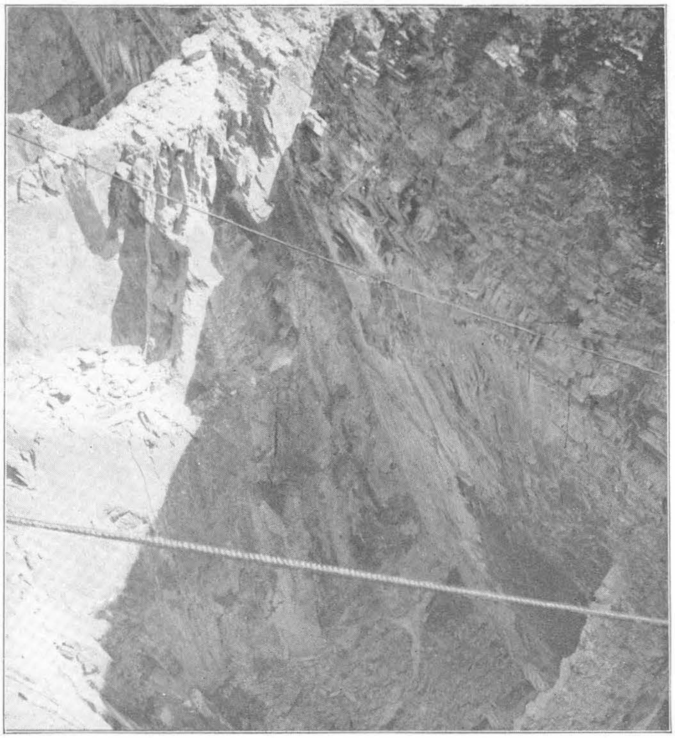
This crosses the West Pawlet quarries and reaches the other Cambrian belt west of Indian River. The West Pawlet belt ends abruptly south of the village, with Hudson grits south, east, and west.

Some of the quarries are over 175 feet in depth (see Pl. XXII, *A*). At the Hughes Quarry No. 7 there is a syncline with an anticline east of it (see fig. C on Pl. XXXIII), and the foreman stated to the writer that another one was found later east of it. The pinching out of the material between the folds observed at the Mettowee gorge (Pl. XXI, *A*) recurs here. At the Rising and Nelson Quarry No. 2 the syncline is finely shown (Pl. XXIII and fig. A on Pl. XXXIII). We have here an isoclinal syncline with its axial plane dipping east with the cleavage. In such a structure the same beds of course occur on either side of the fold in opposite order and also at the bottom, but there in greater thickness. The structure indicated is a syncline with an anticline on either side of it, but, unless faulting occurred, these must be parts of an anticline, and the Hudson grits, which crop out in the village and at the foot of the dumps, should be part of a syncline. The strike of the slates ranges from N. 12° to N. 25° E., and that of the cleavage N. 5° W. to N. 5° E., dip 70°, but in places 40° to 50° E. The thickness exposed, measured across two synclines and one anticline, is about 100 feet. There are some dark-gray or "black" beds on the east side of the syncline which, according to this construction, would belong not on top, but within the roofing slates (Horizon B). The Hudson grits west of the Cambrian slates strike N. 10°-20° E. and dip 55° to 60° E., but at the West Pawlet railroad depot this changes to N. 5° W. and the dip to 80° E.

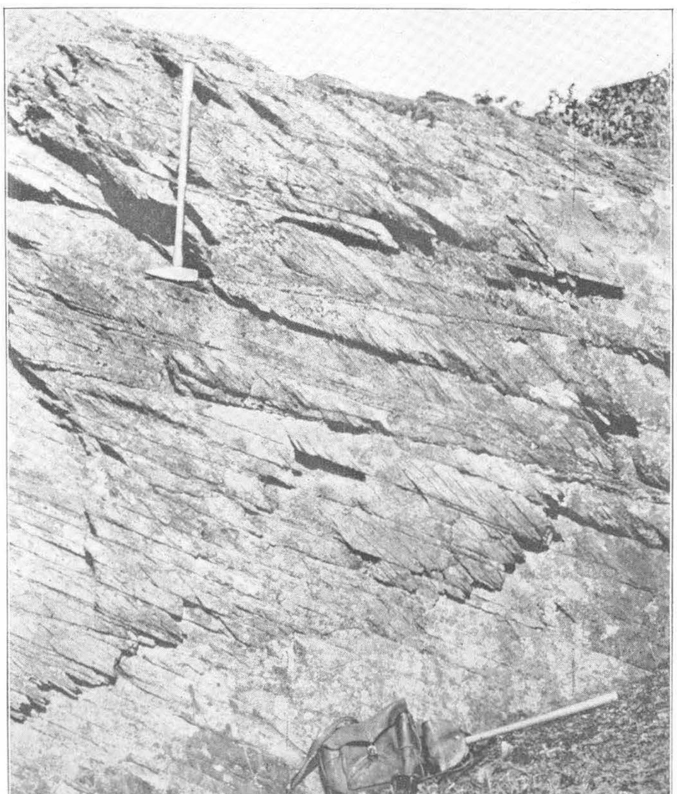
In the Indian River Valley neither the few red slate quarries nor the scattering outcrops afford very satisfactory data. The folds are probably numerous and overturned so as to give only easterly dips. Mr. Walcott has indicated a graptolite locality on the west side of the valley.

The Cambrian ridge at the west has a few old purple slate quarries. Some Cambrian fossils occur in the limestone. Along the eastern side of the ridge the

[1] See petrographic description, p. 225.



A. INTERIOR OF DEEP SLATE QUARRY AT WEST PAWLET, VERMONT.



B. LEDGE OF CAMBRIAN PHYLLITE, WITH BEDDING AND TWO CLEAVAGES, WALLACE LEDGE, VERMONT.

Cambrian shales (Horizon D) occur. About a half mile east of South Granville, near the Ordovician boundary, west of this Cambrian belt, the purple slates dip 40° W., with a cleavage dipping 30° E. and striking N. 15° E., the bedding forming green bands on the cleavage surfaces. The second Cambrian ridge is clearly anticlinal in structure.

The remaining sections have less economic interest.

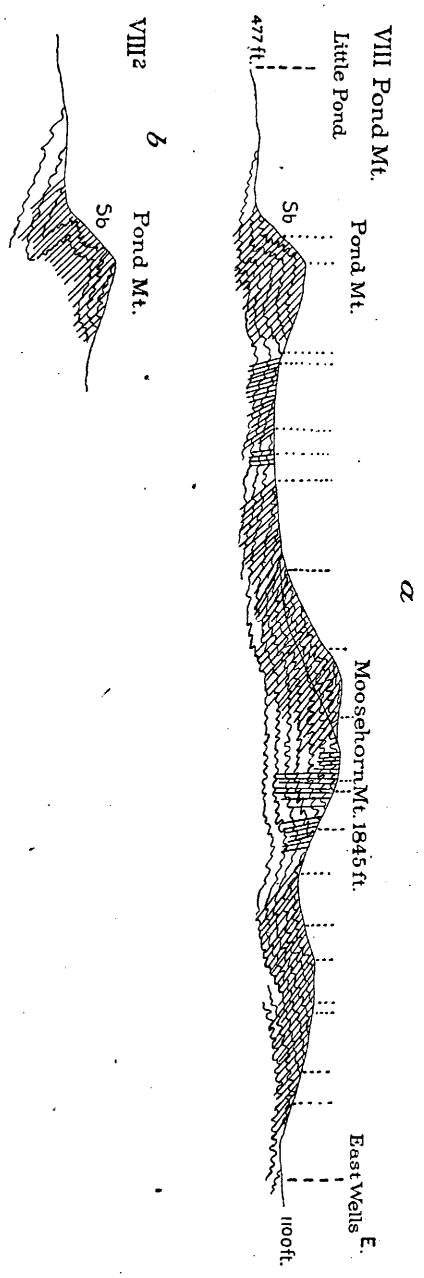


Fig. 10.—*a*, Section of schist hills east of slate belt; *b*, another construction of Pond Mountain.

SECTION VIII.—POND MOUNTAIN.

This begins at East Wells and crosses Moose Mountain and Pond Mountain, ending at Little Pond, the continuation of Lake St. Catherine (see figs. 10, *a* and *b*). The materials for this section were gathered entirely by Miss Bascom, and serve to throw light upon the structure of the schist mass east of the slate belt. Pl. XIV, *B*, represents a microphotograph of a thin section of one of Miss Bascom's specimens. A photograph taken by Mr. Walcott several years ago (Pl. XV) gives a very good idea of the coarser features of the schist. The greater part of the section is well substantiated. The prevailing cleavage is indicated.

Beginning at East Wells is a gentle syncline, the axis of which is a little west of the top of the hill. Then a gentle anticline on the west side of Moose Mountain, with another on its east side and an extremely open syncline between. This agrees with the structure found by the writer in 1891 at Haystack Mountain, which forms part of the same line of hills.[1] Pond Mountain, with its problematic cliff, has an easterly cleavage, which in the distance appears like bedding, and did to the writer in 1891,[2] but Miss Bascom found steep westerly dips in a ravine part way up, and in looking up at the cliffs from below planes parallel to the cliff face can be made out, which are probably the same high westerly bedding planes. Adams regarded the cliffs as due to faulting.[3] At the base the schist dips east, as it does also at the top. Hence the two possible constructions which are shown in figs. *a* and *b*. As the schist of the cliffs is

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, 1894, p. 340, fig. 41.
[2] Ibid., p. 339 and fig. 40.
[3] C. B. Adams's Third Ann. Rept. Geol. Vt., p. 12; Burlington, 1847.

not in an unnatural position with reference to the Cambrian at the west, there is no necessity of assuming a fault, but the boldness of the cliff calls for some explanation. The steep dip of the bedding at Pond Mountain is also in marked contrast to its gentle undulations in the masses east of it. This high westerly dip, together with erosion, working upon it from the west, may account for the cliff, while the general course of the cliffs themselves may be due to that of the anticlinal axis to which it corresponds. Whether this intense folding resulted in any faulting could not be determined.

SECTION IX.—WALLACE LEDGE.

This begins at the east shore of Lake Bomoseen, and crosses Wallace Ledge. At the ridge nearest the shore there are 50 feet of Cambrian black shales (Horizon D) overlying green and purple slates (Horizon B), all dipping very low east. The next hill east consists of the same black shales very much folded. These continue north and south of the section for a considerable distance. There are no outcrops in Sucker Brook valley. Then comes Wallace Ledge (see Pl. XXI, *B* and fig. 8, on p. 184), which consists of a bed of quartzite 20 feet thick overlying a mass of green Cambrian slate 65 feet and more in thickness. The folds in the quartzite are striking features in the landscape and show well the character of the folding in this part of the slate belt. There is a little slate overlying the quartzite and then 4 to 5 feet of dark yellowish green grit similar to that at Flint Hill (Section III). The underlying mass of slate dips about 25° E. The quartzite folds pitch 20° S. and on one side strike N. 30°–50° W.[1] At the top of the hill a little northeast the structure is greatly involved. The quartzite may belong to Horizon E.

SECTION X.—ZION HILL.

This goes from East Hubbardton across Zion Hill. Zion Hill presents abrupt cliffs from 50 to 100 feet high, with talus below, on the east, west, and north sides. Fig. 7, on p. 182, gives the details of the northern face. The strike on the north side is N. 70°–80° E. and the dip is 20° S.; on the northwest corner N. 25° E., and dip 35° E., and on the northeast corner N. 40° W. and dip high west. The general structure thus indicated is a syncline with a southerly pitch. The series represented includes the upper part of the Cambrian roofing slate (Horizon B), possibly the Black Patch grit (Horizon C), and the Ferruginous quartzite (Horizon E). On the east side of the hill is a ravine following the axis of a minor anticline; and here the same beds recur, dipping both east and west. At several points on the southeastern spur of the hill the dark grass-green grit previously noted at Flint Hill (Section III), Blissville (Section IV), and at Wallace Ledge (Section IX) crops out. Whether this represents the Black Patch grit (Horizon C) of the western and southern Parts of the slate belt, or is a distinct bed belonging to Horizon E, is uncertain. This may possibly apply also to the bed of grit on the north face of Zion Hill, which is also somewhat chloritic and nowhere black. There are indications of a minor fold between the divergent spurs. The upper part of these spurs is covered with drift where the section crosses. On the west side of the hill are certain purplish schists with small lenticular chlorite nodules, dipping toward the hill. Similar schists occur half a mile east of East Hubbardton, along the foot of the Taconic Range. In the map both of these have been classed as Ordovician. The eastern part of the section is hypothetical.

Why the quartzite should terminate so abruptly on the north is not clear. Large masses of quartzite occur a few miles north. Were the cliff facing south it might be explained as the lee side of a glaciated mass. The intermittent character of the coarse sediments in the region may account for it. If the boundaries are correctly drawn, the hill ought to pitch north under the Ordovician. It is possible that we have to do here with a case of transverse faulting, like that on Dorset Mountain,[2] but on a small scale.

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[1] The glacial striæ run S. to S. 10° E.

[2] On the structure of the ridge between the Taconic and Green Mountain ranges, in Vermont, by T. Nelson Dale: Fourteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 543–546, and Pl. LXVIII, Secs. J, K.

SYNCLINE AT WEST PAWLET, VERMONT.

GENERAL STRUCTURAL FEATURES.

From the foregoing sections, necessarily more or less incomplete, the general structural characteristics of the belt can be grasped. The strata of the schist mass on the east, closely plicated and cleft with vertical or easterly dipping slip cleavage, lie in broad undulations, but are crowded over at the west into a somewhat sharp anticline (see Section VIII). The structure of the Cambrian slate mass, which usually adjoins the Ordovician schist, is illustrated in Sections VI and VII. There are close folds, more or less overturned to the west, with easterly dipping slaty cleavage obscuring the bedding. The folds are so close and the cleavage is so pronounced that the cores of adjoining synclines and anticlines are brought very near together, or the anticlinal portions of several adjacent folds do not appear. In the northern part of the Cambrian area quartzite beds are more abundant within the roofing slates than in the southern. Although the entire mass of slate and quartzite is in places thrown into folds so greatly overturned that their axial planes are nearly horizontal, yet the slate itself is less distorted in the direction of the cleavage than in the southern area, and the cleavage itself is also less perfect in the northern than in the southern. Series of such various folds form compound anticlines, and these minor Cambrian anticlinoria alternate with Ordovician synclinoria conformably overlying Cambrian ones. As the Ordovician areas consist of shales, slates, grits, and small quartzite beds, the beds being more heterogeneous, slaty cleavage is less prevalent, but the folds are also overturned toward the west (see Sections I, II, V, VI, VII, Pl. XVI).

A north-northwesterly strike appears about Blissville and again at Cedar Point in the Cambrian (see map, Pl. XLI). Large beds of quartzite overlie the roofing slate and are typical of this portion (Sections III, IX, X).

At the J. J. Jones quarry, 3 miles north of Castleton, this change in the strike can be observed. At the south end of the quarry the beds strike north and dip 35° E., but for a stretch of 100 feet from the north end of quarry the strike is N. 20°–25° W. and dip 30° E. Again, at a saw mill in the North Britain valley, 1½ miles north of Castleton River, some badly fading and twisted slates strike N. 30°–40° W. and dip 40° W., while the cleavage strike is north to N. 5° W. and dip 40°–60° E.

Wherever the beds of either Cambrian or Ordovician are very shaly the folding is much more intricate than shown in any of the sections. Usually in such places the stratigraphy can hardly be made out.

STRUCTURAL DETAILS.

In the following paragraphs the more important structural details of the slate belt are illustrated and discussed. Those on "cleavage banding" and on the dikes are of purely scientific interest.

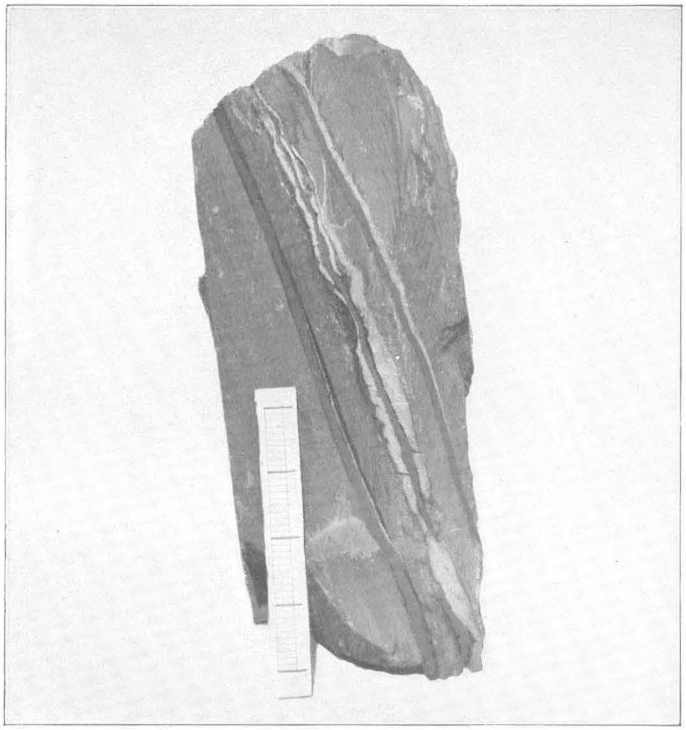
BEDDING.

Ordinary planes of bedding may be defined as those which were approximately parallel to the surface of the water in which the sediment was formed. If the sediment changes in character, then a horizontal bed of different material results. If, deposition being interrupted, annelids creep over the bottom or algæ decompose there, and the same kind of sedimentation be afterwards resumed, then two horizontal beds of the same material will result, separated by a plane covered with trails and impressions. Some bedding planes may be the result of contraction in drying, others possibly the effect of compression. Whatever explanation may be offered for bedding, the bed is the starting point in a slate quarry, for the direction of the bed indicates (cleavage, etc., being equal) where the same quality of slate is likely to recur.

Plate XXIV, *A*, shows a ledge of the Cambrian green roofing slate with a cleavage dipping 20° east (strike N. 15° W.); joints striking N. 30° E. and dipping 45° east. The upper part is a quartz sandstone or grit (Horizon C) with calcareous concretions containing Lower Cambrian trilobites. The direction of the axial planes of the calcareous bodies and the direction of the line of contact between the slate and sandstone show the direction of the bedding to be horizontal.

Plate XXIV, *B*, representing a specimen from the Scotch Hill quarries at Fair Haven shows four beds one-eighth to one-fourth inch thick, alternating with four beds of hard gray slate, all diagonal to the cleavage, which is parallel to the sides of the specimen. One of the small beds is a black slate, three others are gray quartzose limestone on one side, with black slate on the other. These black surfaces are covered with bifurcating fossil impressions. The difference in the mineral composition of the small beds and the position of the fossils show these bands to be beds. In many of the quarries, and in all the varieties of slate, these fossil impressions cover large surfaces and often afford the only, but perfectly reliable, indication of bedding. In some of the purple slates the fossil impressions are green, or become so in weathering. In some of the "sea green" slates they are dark gray and flaky, or spotted, and measure a half inch in width. The impression has given rise to some chemical change in the slate or has been accompanied by a slight deposition of carbonaceous matter. This and their frequent bifurcation would seem to be an argument for their being due to plants rather than trails, although annelids do line their borings with organic matter. Others, again, are quite serpentine in outline and a half inch wide, and may well be due to annelid trails.

Plate XXV, *A*, from a photograph of a piece of red slate from the old quarries of the Fair Haven Red Slate Company, in the southeast corner of Whitehall, shows a bed an inch thick crossing the cleavage diagonally, and, therefore, spreading out to double that width on the cleavage surface. In the center of the "ribbon" is a bed, one-fourth inch thick, of greenish limestone, and on either side of the ribbon is a very thin rim



A. CONTACT OF CAMBRIAN SLATE AND SANDSTONE.

B. GRAY SLATE WITH BLACK SLATE AND LIMESTONE BEDS DIAGONAL TO CLEAVAGE.

of green slate; the rest of it is purple. Under the microscope the composition of these little beds is this: The central green consists of calcite and siderite rhombs; some of the siderite is altered to limonite. There are large quartz grains, muscovite scales without parallel orientation, and occasional plagioclase grains. The purple consists chiefly of muscovite and chlorite scales, both lying in two directions at right angles to one another; irregular dots of hematite, some carbonate rhombs, quartz grains, and rarely a grain of plagioclase. The thin green strips on the sides contain less hematite than the purple, and a large number of the muscovite and chlorite scales lie parallel to the bedding and transverse to the cleavage. The red slate itself is like the purple, but with far more hematite and probably less chlorite. The iron obscures the other minerals. In this specimen the central bed of quartzose limestone is probably due to change of sediment. Whether the varying amounts of ferric oxide in the purple and green, as compared with the red, can be explained by chemical reactions or are due to changes in sedimentation will be discussed in connection with the spotted slates.

Sometimes the quartzose "ribbons" are parallel to the cleavage, as in a specimen from the Nixon Red Slate Company's quarry at Middle Granville, with a dark-green noncalcareous bed.[1]

The purple Cambrian slate in such quarries as Cedar Point (see Pls. XVIII, *A*, *B*, XIX, *A*, and fig. N on Pl. XXXIV), and Parry and Carter's, in Poultney, west of the north end of Lake St. Catherine, and in the old quarry shown in fig. O on Pl. XXXIV, forming the syncline in Section IV, Pl. XVI, frequently has such beds of green slate with or without a central calcareous band crossing the cleavage. The sidewalks of several villages in Washington County are flagged with slabs of such purple green-ribboned slate. The ribbon indicates the course of the bedding. These ribbons sometimes run into rows or planes of spots of various sizes, usually more or less oval or circular in cross section. Where a series of such spots are in line its course is that of the bedding.

These small beds are often plicated, as in figs. Q, R, on Pl. XXXIV, and fig. H, on Pl. XXVI, and faulted besides, as in Pl. XXV, *B*. Fig. D, Pl. XXXIII, shows the relations of this plicated bed to the cleavage and jointing, and fig. E, Pl. XXVI, is a microscopic drawing of a thin section of it. The bed here consists of calcite and vein quartz, the original calcareous sediment having been crystallized and segregation vein quartz deposited. The diagram shows the faulting of the bed, the bending of the cleavage foliation, and the secondary slip-cleavage caused by the dislocation.

The plication of such small beds of quartzose limestone is sometimes extreme (figs. A, B, H, Pl. XXVI)[2]. The folding in this case is con-

[1] U. S. Nat. Mus., Spec. D. XV, 270 f.
[2] U. S. Nat. Mus., Spec. D. XIV, 301 d, 1895.

fined to the hard beds, while in the more plastic material of the slate on either side pressure resulted in slaty cleavage.[1]

Fig. F, Pl. XXVI, represents a plicated bed of quartz and one of calcite separating beds of purple and green slate. Under the microscope both quartz and calcite beds are bordered with chlorite scales on the outside, and separated by such scales; there is also some pyrite along the edges. The cleavage of the slate is at right angles to the course of the bedding, but slightly deflected near the plicated beds. In several places the slaty material has been drawn partly into the bed.

A thin section of a small plicated bed of quartzite in the purple slate of the Cedar Point slate quarry shows the following: The bed consists mainly of quartzite, but this contains grains of plagioclase, rhombs of carbonate, probably calcite, and scales of muscovite. Toward the slate there are coarse fibers of muscovite. The slate merges into the quartzite, sending out long streamers of sericite, which penetrate between the grains of quartz and calcite. The slate contains large scales of chlorite within the meshes of sericite, which scales lie at right angles to the cleavage, i. e., parallel to the course of the bed. It also contains grains of quartz. The fibrous character of the slate is apparent at the border of the quartzite bed. The significance of such a bed is that sandy material was deposited for a brief interval during the deposition of the finer material which produced the slate; there were grains of quartz and of feldspar, and probably scales of mica, together with calcareous mud. Under the compression and the chemical changes which accompanied it the quartz grains were cemented into quartzite, the calcareous mud was crystallized, and the bed was plicated and became entangled with the slaty material. The slaty material itself was also somewhat plicated, and a secondary cleavage (slip cleavage) was produced in it.

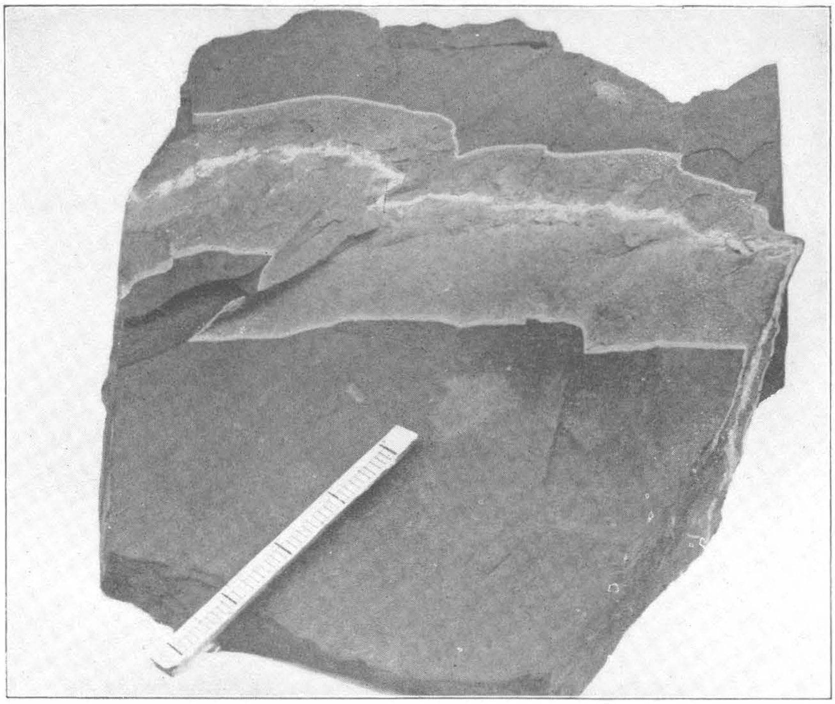
Pl. XXVII, *A*, from the Ordovician syncline at West Castleton, also illustrates this plication of quartzite beds and the overturning of the folds. Pl. XXVII, *B*, from the Cambrian slate quarries a mile south, and fig. T on Pl. XXXIV, taken from the same quarries, show these features on a larger scale. Finally, Wallace Ledge, Pl. XXI, *B*, already described, is but the same thing on a still greater scale. The last geological report of Vermont calls attention to this characteristic of the region.[2] Exceptionally the quartzite beds seem to have been pushed out of their normal parallelism, even without folding or faulting.

A case of brecciation on a somewhat large scale is shown in fig. G, Pl. XXVI, taken near fig. T, Pl. XXXIV.

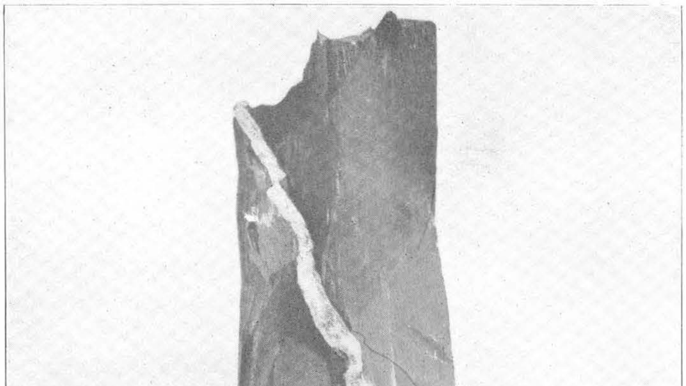
Frequently, however, the small beds of different composition are very minute, or else the bed surface is simply a parting whose meanderings must be carefully followed in order to distinguish it from

[1] See C. H. Hitchcock, Second Ann. Rept. Geol. Maine, 1862, p. 285, fig. 45, where a bed of strongly plicated limestone lies between unplicated beds of slate. See also the classic figure of H. C. Sorby given in his paper On the origin of slaty cleavage: Edinb. New Phil. Jour., Vol. LV, July, 1853, pp. 139, 140, which was reproduced by Tyndall in his Roy. Inst. Lecture, and also by Phillips in his British Assoc. Report on cleavage.

[2] Op. cit., Vol. I, p. 359, fig. 225.



A. RED SLATE WITH BED OF LIMESTONE AND GREEN SLATE DIAGONAL TO CLEAVAGE.



B. PLICATED AND FAULTED CALCAREOUS BED IN GREEN SLATE

PLATE XXVI.

PLATE XXVI.

PLICATED AND FAULTED BEDS IN SLATE.

(*A*) Drawing of extremely plicated bed of quartzose limestone or calcareous quartzite in Cambrian slate at Fair Haven, Vermont. Natural size. The slate on both sides of the bed for a half inch is green; beyond that, purplish.

(*B*) Drawing of extremely plicated bed of quartzose limestone or calcareous quartzite in Cambrian slate at Fair Haven, Vermont. Reduced one-half.

(*C*) Faulted quartzite bed in slate at Meadow Slate Company's quarry, Fair Haven, Vermont. Normal fault.

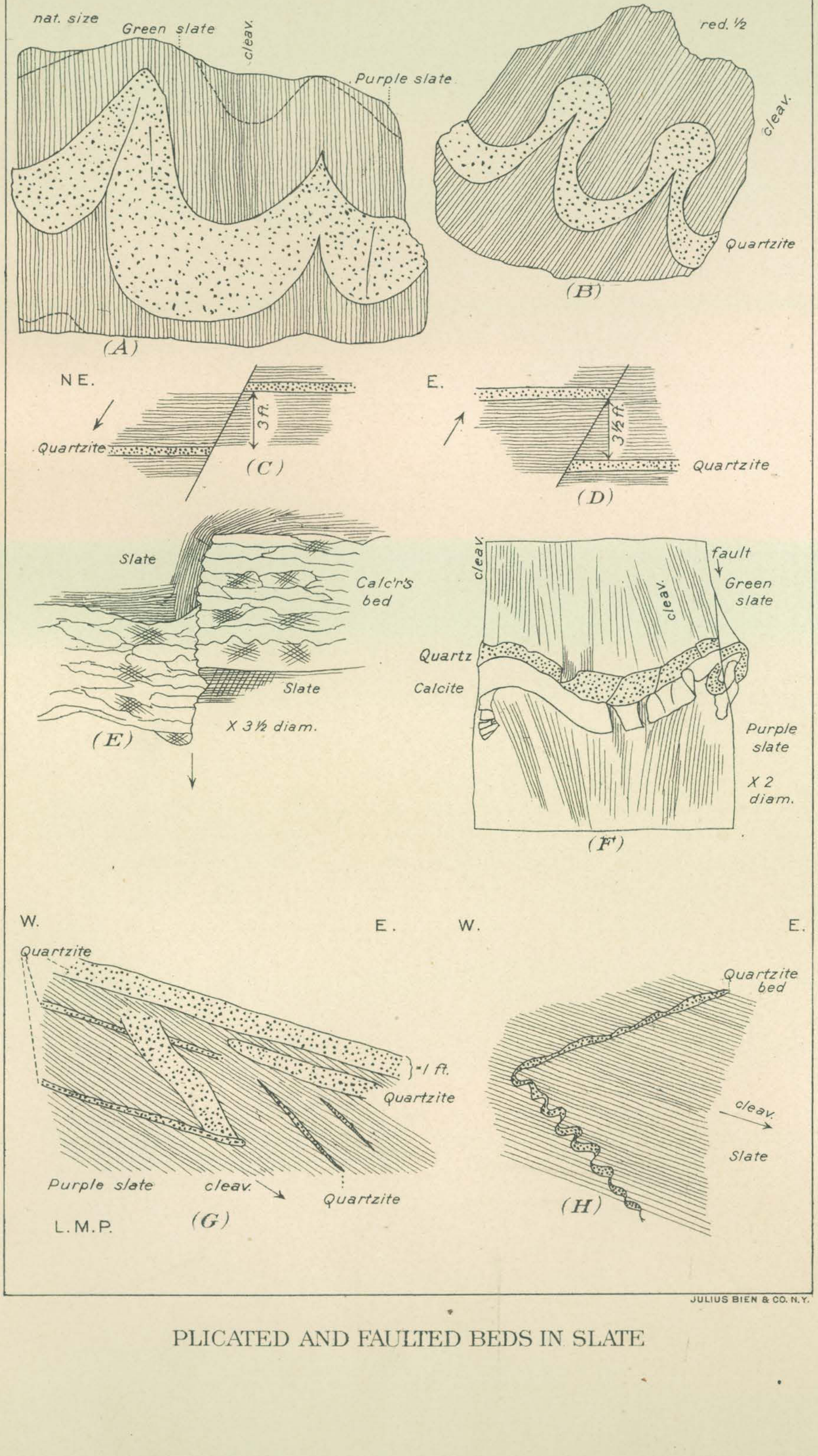
(*D*) Faulted quartzite bed in slate at Eureka quarry, Poultney, Vermont. Reversed fault.

(*E*) Microscopic drawing of thin section of faulted calcareous bed at Pawlet, Vermont, given in Pl. XXV, *B*, showing adjustment of cleavage to faulting and production of secondary cleavage. Enlargement, 3½ diameters.

(*F*) Drawing of thin section of plicated and faulted beds of calcite and quartz separating beds of purple and green Cambrian slate at Blissville, Castleton, Vermont. Enlargement, 2 diameters. Both calcite and quartz beds are bordered on both sides with chlorite scales.

(*G*) Drawing of dislocated beds of quartzite in purple Cambrian slate at old quarry, about one mile south of West Castleton, Vermont. A fragment of a bed of quartzite has been turned about into the cleavage foliation and across smaller beds of quartzite. By L. M. Prindle.

(*H*) Drawing of plicated and folded quartzite in Cambrian slate at Fair Haven, Vermont. Height, 40 feet. Minor plications somewhat enlarged.



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PLICATED AND FAULTED BEDS IN SLATE

fractures of various kinds, as at the West Pawlet syncline, Pl. XXIII, and at West Castleton, Pl. XIX, *B*; or the bedding may be indicated by the weathering out of calcareous matter from the slate itself, some beds containing more of it than others, as at the syncline at West Castleton, Pl. XX. The rock here is a shaly slate consisting of alternating light and dark gray bands, i. e., beds of muscovite and chlorite scales, grains of quartz, spherules of pyrite, and some carbonate, but there is more carbonate in the gray bands than in the black ones, which contain more carbonaceous matter. Now and then there is a minute bed consisting largely of calcite. This explains why the beds are so clearly and yet so delicately brought out on the joint face. The original sediments had varying amounts of calcareous material in them. The carbon dioxide brought down from the atmosphere by the rain has, as it were, carried away the more calcareous parts, leaving the less calcareous ones in relief. (See also Pl. XXXII, *B*.)

In many of the quarries change of color alone is an indication of the passage from one bed to another. This change may be gradual or abrupt. But color is not an infallible guide, as the red slate sometimes passes into the green along the same bed, and there is no reason why the Cambrian purple should not likewise pass into the green of the same formation.

In cases where there are no fossil impressions or intervening beds of very different material or partings or slight changes in the composition of the slate itself, producing changes of color or different degees of erodibility, the course of the bedding can sometimes be made out in a thin section cut transverse to the cleavage when examined under the microscope. There may be an occasional arrangement of the particles parallel to the original bedding or an extremely minute bed of other material, or lines of different particles may cross the cleavage foliation. Fig. C on Pl. XXVIII illustrates cases of this kind.

CLEAVAGE.

In most slate regions cleavage is not coincident with bedding. Some of its relations to bedding in this region are illustrated in the synclines of West Pawlet (Pl. XXIII), Cedar Point (Pls. XVIII, *A*, and XIX, *A*), and West Castleton (Pl. XX), and in Pls. XXXIII and XXXIV, and also in the symbols on the quarry maps (Pls. XL and XLI). So much has been written on the causes of slaty cleavage that a reference to the literature of the subject is sufficient.

Perhaps slaty cleavage may be defined simply as a rearrangement of the particles of a deposit by pressure and a simultaneous arrangement of any new crystalline particles formed during that pressure. This arrangement of old and new particles is related to the directions of pressure and of resistance.

All the older authorities on slaty cleavage usually define the direction of pressure as being at 90° to the cleavage. This definition of the direction of pressure has been disputed. At my request Dr. Becker has put his views on this subject into a few sentences, which are here given:

Slaty cleavage is produced when a solid but plastic mass, firmly supported on one side, experiences a pressure on the opposite side which is not perpendicular to the supporting surface. The resulting cleavage has a direction intermediate between that of the applied force and the fixed support. The cleavage itself makes with the deforming force an angle which may vary between a very small value and one equaling or even exceeding 45°. The firm support of the deformed rock required by the theory may be afforded either by a purely material resistance or by any combination of forces which prevents the mass from rotating as a whole while undergoing deformation. Lateral pressures not equal in all directions appear to be of minor importance so long as they do not interfere with the condition that the angle between the resultant force and the fixed support shall differ sensibly from 90°. The origin of the cleavage as conceived in this theory is incipient "solid flow," which is a different thing from liquid flow. The production of cleavage should usually be accompanied by the formation of master joints at angles to the cleavage approaching 90°, and the direction of the pressure is perpendicular to the intersection of the cleavage with such joints, intersecting (but not exactly bisecting) the obtuse angle. The grain of the slate should be parallel to this intersection. In general there should be an elongation in the direction of the grain and a contraction in the plane of cleavage at right angles to the grain.

On the other hand, Professor Van Hise expresses his view in these words:

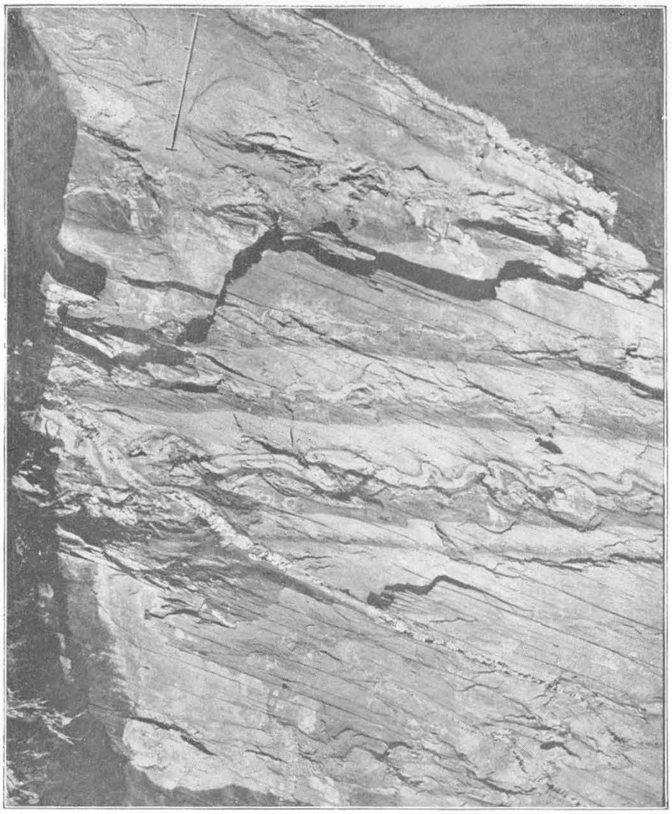
During the formation of slaty cleavage the structure at any moment is developing at right angles to the greatest pressure; the final position of cleavage may not be at right angles to the greatest final pressure.[1]

No case of horizontal cleavage has been found in the slate belt. In some instances it dips as low as 20° (thus at Cedar Point), and sometimes the bedding is horizontal, but then the cleavage dips 20°. It is quite possible, and indeed probable, as will be shown beyond, that the slate has been affected by movements secondary to that which produced the cleavage, but hardly probable that the present inclinations of cleavage are mostly due to them.

The cleavage here dips uniformly east when inclined from the vertical, and the folds, when overturned, are overturned to the west, so that their axial planes also dip east. The easterly inclination of the axial planes of the folds and the easterly dip of the cleavage are probably both traceable to the same cause.

The microscopic structure of the slaty cleavage is shown in Pls. XXXV-XXXIX. The cleavage varies in regularity, as may be seen in comparing Pl. XXXVI, *A*, with Pl. XXXVII, *A*. The finer cleavage prevails in the southern part of the Cambrian belts, the coarser north of the latitude of a point 2 or 3 miles north of Poultney.

[1] See Bibliography, pp. 168, 172, papers by Dr. Becker and Professor Van Hise. See also Review of Van Hise's Principles of pre-Cambrian geology, by Bailey Willis, Jour. Geol., Vol. VI (May-June, 1898), pp. 426-427.



A. SMALL QUARTZITE BED IN OVERTURNED FOLDS IN ORDOVICIAN SLATE.

B. OVERTURNED FOLD OF QUARTZITE IN CAMBRIAN SLATE.

PLATE XXVIII.

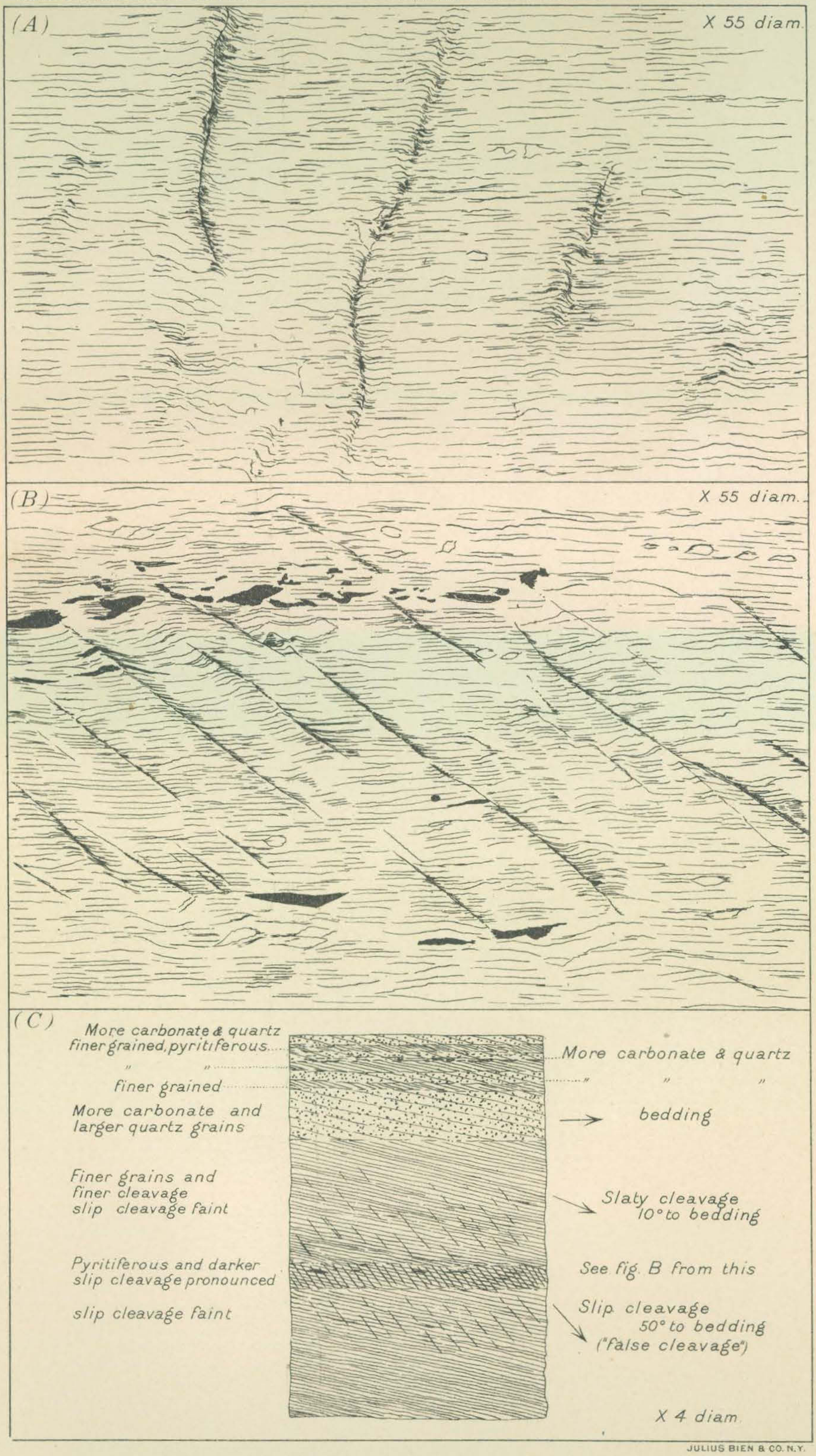
PLATE XXVIII.

THIN SECTIONS SHOWING FALSE CLEAVAGE.

(*A*) Microscopic view of a thin section of purple Cambrian roofing slate from an old quarry three-fourths of a mile south of Fair Haven, Vermont, showing slip or "false" cleavage. Section transverse to both cleavages. Enlargement, 55 diameters.

(*B*) Microscopic view of a thin section of green Cambrian roofing slate from the Huckleberry Hill quarry, 2 miles southeast of West Pawlet, Vermont, showing slip or "false" cleavage. Section transverse to both cleavages. Enlargement, 55 diameters. The black spots are pyrite. This figure represents a small part of the dark band shown in fig. C.

(*C*) Microscopic view of the same thin section, entire, showing alternation of fine and coarse beds, some of which are pyritiferous, and only in one of which is the false cleavage pronounced. Enlargement, 4 diameters.



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SLIP-CLEAVAGE AFTER SLATY-CLEAVAGE
(false-cleavage)

Effect of frost on cleavage.—As all slate quarrymen know, repeated freezing and thawing is disastrous to the cleavability of roofing slates. The material must be split fresh from the quarry. In order to ascertain, if possible, what difference in microscopic structure freezing and thawing produced this experiment was tried: A specimen was obtained early in the winter fresh from the quarry and unfrozen, and was kept moist in a moderate temperature until severe weather set in.. It was then broken into two equal parts, one of which was kept moist indoors, the other exposed on the sill of a north window for a week, during which the temperature went down to 10° below zero F. This part was then thawed out over a furnace register. Both frozen and unfrozen pieces were after some accidental delay sliced and examined microscopically. The whole texture of the frozen slate was found to be perceptibly closer than that of the unfrozen. The test would have been more satisfactory had the thin sections been made at once.

False cleavage.—What quarrymen call "false cleavage" is what is scientifically known as close-joint cleavage, strain-slip cleavage, or ausweichungs-cleavage, or, more simply, slip cleavage, or Professor Van Hise's fissility. In the case of slate, this slip cleavage may show itself either where slaty cleavage alone is visible or in the bedding also, as in figs. A and C, on Pl. XXVIII. Therefore, after the setting up of slaty cleavage, a secondary cleavage—slip cleavage, consisting of a minute faulting of the cleavage planes—may occur as the result of stress. There is a readjustment of the cleavage planes with reference to the new pressure instead of a rearrangement of all the particles, as in the primary slaty cleavage. Fig. A, on Pl. XXVIII, represents a slice from a quarry a half mile south of Fair Haven, which quarry proved a failure because the slate broke along these planes of slip cleavage. The presence of "false cleavage" can be detected microscopically from a piece a half an inch square, or even smaller, as certainly as by experiment with a piece of commercial size. Pl. XXII, *B*, represents a Cambrian rock of no commercial value, in which two cleavage foliations cross the bedding.[1]

GRAIN.

What is called grain by the quarrymen, longrain in France, is a more or less obscure striation of the cleavage surface in a direction at right angles to the plane of cleavage, but not necessarily parallel to its strike. In this belt the grain is not infrequently parallel to a system of east and west joints which form the lateral walls of the quarry, or it may intersect these more or less acutely. The slate blocks are broken along the grain to reduce them to workable proportions. As the direction of the grain is one of weakness, it is usual to cut roofing slates with their long sides parallel to the grain. In some of the quarries, however, there is hardly any grain whatever.

[1] See further on the subject of several cleavage foliations, Mon. U. S. Geol. Survey, Vol. XXIII, p. 152, fig. 52. Thirteenth Ann. Rept. U. S. Geol. Survey, p. 322, fig. 30; Sixteenth Ann. Rept. U. S. Geol. Survey, p. 565, fig. 93, and p. 566, fig. 94.

Fresh specimens were obtained from the quarries with the direction of the grain marked on them by the foremen. Thin sections were then prepared both parallel and at right angles to the grain. Contrary to expectation, these sections at right angles to one another and across the cleavage resembled one another very closely. This difference, however, did appear: In sections across the grain many of the flakes of chlorite and some of muscovite lay transverse to the cleavage. This chlorite is probably of secondary origin. Instructive in this connection are the experiments of Jannetaz in reproducing the grain as well as the cleavage by artificial means. He found that the grain arose in the direction of the pressure which produced the cleavage.[1]

JOINTS.

Sedgwick termed the three commoner kinds of joints occurring in slate regions *strike joints* (joints parallel to the strike), *dip joints* (joints parallel to the direction of the dip), and *diagonal joints* (joints diagonal to strike and dip), terms which ought to be ever kept in use.[2] The most conspicuous joints in this region are the dip joints, which strike from N. 65° W. to N. 90° W. and dip 90° or a few degrees from it. Next in importance are the strike joints, which strike from N. 5° W. to N. 20° E. and dip usually from 45° to 75° E., but sometimes from 30° to 70° W., still more rarely 90°. Horizontal joints ("bottom joints") are very rare. The directions of some of these systems of joints at several of the quarries are shown on the quarry maps by special symbols (Pls. XL and XLI). Their relation to the cleavage is shown in some of the quarry diagrams (Pls. XXXIII and XXXIV), and all the compass observations of joint planes at the quarries are given in the table on pp. 218–221. Some of the strike joints, called slants and slips by the quarrymen, are often slickensided by motion and friction of the faces.

Mr. Prindle found a system of diagonal joints striking N. 35° to 40° E. so prevalent near dikes that their presence alone enabled him to prognosticate both the proximity and course of a dike. At a dike in Hebron, besides the set parallel to the dike there is another diagonal to it. The writer made the following observation at a dike in purple slate near Lake Bomoseen: Course of dike N. 80° W., joints in slate near dike N. 80° W. and N. 2° E., dip 90°; joints in dike N. 75° W., dip 90°, also N. 15° E., dip high west. The diagonal joints noted at the quarries strike from N. 35° to 55° E., dipping from 50° SE. to 90°, with another system at right angles, striking N. 45° to 50° W. and dipping NE. or SE.—or 90°. Rogers described this relation of joints to dikes, and it had also, he states, been previously noted in England.[3]

[1] See Jannetaz, Mémoire sur les clivages des roches (schistosité, longrain), et sur leur reproduction: Bull. Soc. Géol. France, 3d Ser., Vol. XII, p. 211, 1883-84. This subject is treated more fully later in this paper.

[2] A Synopsis of the Classification of the British Paleozoic Rocks, by Adam Sedgwick, London, 1885, p. xxxv.

[3] H. D. Rogers, Geology of Pennsylvania, Vol. II, Part II, p. 912, fig. 718, joints in red shale parallel to dike; also fig. 719, joints in argillaceous sandstone; 1858.

PLATE XXIX.

PLATE XXIX.

ZONES OF SHEARING ("HOGBACKS").

(*A*) Diagram of thin section of "sea-green" Cambrian slate from Williams and Edwards' quarry in Wells, Vermont. Enlarged 2 diameters. Section across the cleavage and an incipient "hogback," showing the two bends in opposite directions and developed in but two places into fractures. Secondary fractures at 15° to cleavage cross the zone. A calcareous strip, possibly a trace of bedding, crosses the cleavage at 45°. All the fractures filled with calcite.

(*B*), (*C*), (*D*) Microscopic drawings from above thin section, enlarged 40 diameters, showing in reversed position the outlines of several of the vertical and diagonal fractures within and at edge of zone.

(*E*) Diagram from specimen of "hogback," from E. E. Lloyd's sea-green slate quarry, Poultney, Vermont.

(*F*) Slate from within a fully developed "hogback," showing outline of fracture. Same location as *E*.

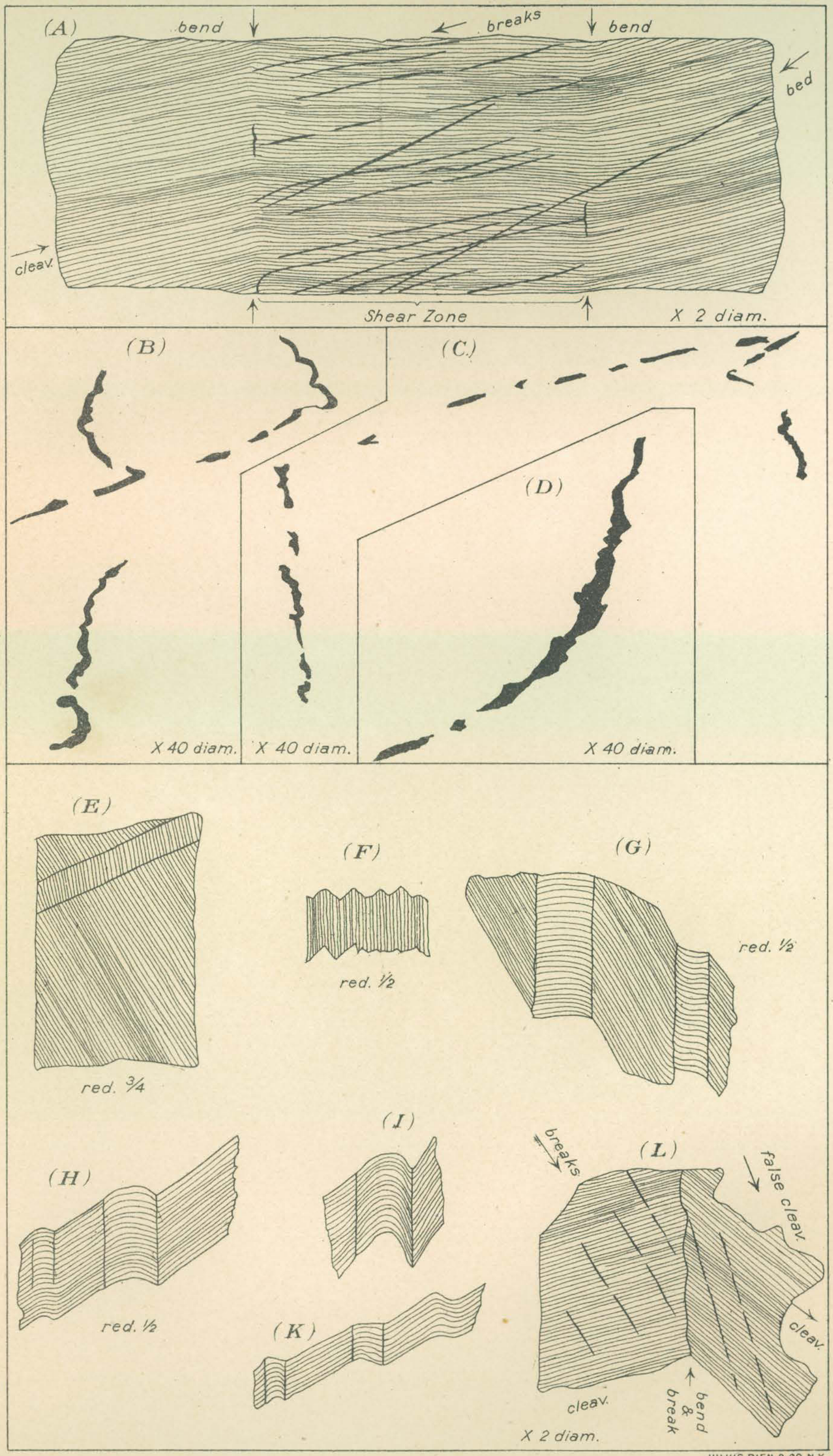
(*G*) Same location as above slate, showing two "hogbacks."

(*H*) Diagram from specimen of Cambrian slate from Eddy Hill, Fair Haven, Vermont, showing development of "hogbacks." Secondary quartz occurs along the fractures. Reduced one-half.

(*I*) Shear zone in Silurian schist 1½ miles east of Rupert, Vermont.

(*K*) Diagram from top of the Pattern, in Pawlet, Vermont.

(*L*) Diagram from thin section of Cambrian slate from Eddy Hill, Fair Haven, Vermont, enlarged two diameters, showing one of the main fractures of a "hogback" with diagonal fractures which are filled with quartz, and beside it slip-cleavage.



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SHEAR-ZONES
(Hog backs)

FAULTS.

Within the slate belt proper there may be faults of some magnitude, but none have been observed. At several of the quarries faults are exposed with a throw of but a few feet. (See Pl. XXVI, figs. C and D.) One of these is a normal fault, the part overlying the fault plane having slidden down; the other is a reverse fault, the similar part having been forced up. A microscopic section across the reverse fault shows the sharp bending of the beds at the fault plane, and the deposition of a thickness of one-sixteenth of an inch of vein matter in bands along that plane. This matter consists of chlorite, calcite, and quartz.

Some of the slate flagstones in the village of Granville, the exact source of which could not be ascertained, are full of small faults, which come out finely in the rain, and show how much secondary compression there must have been at that locality.

Faulting may occur within a slate mass in two directions at right angles to one another.[1]

"HOGBACKS" (SHEAR-ZONES).

This term is used by coal miners to describe a sharp rise in the floor of a coal seam. The propriety of its application in slate quarries is not so obvious. It is used there to designate peculiar bends or fractures, which consist of two angular bends in opposite directions and near each other, traversing a mass of slate. These flexures may and often do merge into fractures, and the slate between the two planes of fracture is broken up into small fragments. The two bends or fractures may be anywhere from one-sixteenth of an inch to 4 feet apart. At one of the old Middle Granville Cambrian quarries, a slate surface shows within a space of 4 inches four hogbacks varying from one-sixteenth to one-fourth inch in width. Another has six in a space of 6 inches. As hogbacks generally traverse the cleavage diagonally, the blocks of slate adjacent to them come out in triangular form, and thus occasion much waste. The strike of some of the hogbacks is parallel to that of several of the dikes, and both may have been formed under the same stress. Figs. E, G, I, on Pl. XXXIII, and figs. L, U and V, on Pl. XXXIV, show the relations of hogbacks at several quarries. Fig. A, on Pl. XXIX, shows the microscopic structure of the hogback of fig. V, Pl. XXXIV. The section was made where the bends had not as yet developed into complete fractures. The entire width of the hogback is nine-tenths of an inch. Between the two sides is a system of cracks crossing the cleavage at an angle of 15°; another system crosses the cleavage at 25° and extends beyond the side. This may be the original bedding. Both of these systems of cracks are filled with secondary calcite. Another set, likewise filled with it, crosses the cleavage here and there about at right

[1] See a case of this in the Hudson slates, of Rensselaer County, Thirteenth Ann. Rept. U. S. Geol. Survey, 1894, Pl. CI, p. 320, fig. 26. Also, in this connection, A faulted slate slab, by J. J. H. Teall: Geol. Mag., Dec. III, Vol. I, Pl. I., London, 1884.

angles, but in zigzag (see figs. B, C, D, Pl. XXIX). These, farther on in the quarry, become continuous fractures. The secondary fractures within the zone probably result eventually in breaking up the slate, as it occurs usually in fragments within a fully developed hogback. The observations at this quarry were: strike of bed N.±, dip 30° E.; strike of cleavage N.±, dip 42° to 45° E.; strike of hogback N. 35° to 40° E., dip 65° NW. In this case the strike of the hogback corresponds to that of the diagonal joints of the region and of a number of the dikes. Figs. E to L, on Pl. XXIX, illustrate the development of a hogback still further. In fig. L the diagonal fractures are filled with quartz, and a slip-cleavage (false cleavage) also occurs. Other observations of hogbacks are given on the quarry tables, pp. 218–221. These show a set striking north and dipping 45° to 77° E.; another striking N. 55° W., and dipping northeast, and exceptionally one dipping nearly south. References to the literature of the subject are given on p. 288.

CLEAVAGE BANDS.

This subject has been recently dwelt upon by the writer.[1] Its interest is purely scientific.

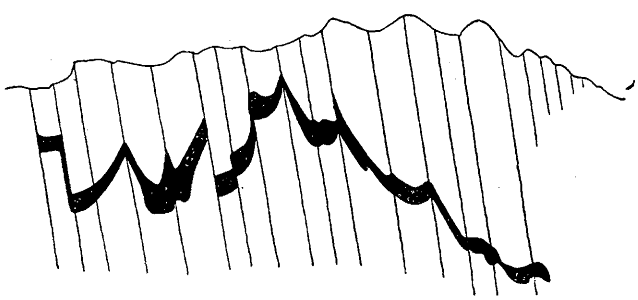
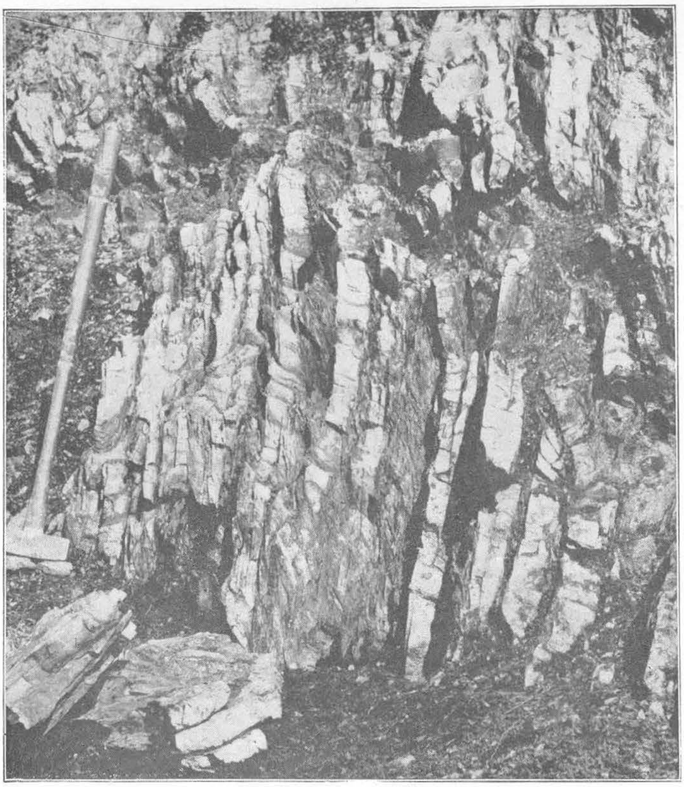


Fig. 11.—Cleavage banding showing slippage of bands.

Pl. XXX, *A* and *B*, are from photographs taken at a locality in Rupert, Vermont, found by Mr. L. M. Prindle, and already partly described. Cleavage banding is of frequent occurrence in the slate belt and in the schist mass east of it, although not always as well shown as at this point. It resembles the hogback structure just described, but presents further stages. In Pl. XXX, *A*, the rock is divided into alternate bands of hard, uncleft quartzose shale and of bands of very finely cleft shale. The bedding zigzags across both bands. The material of both bands was originally identical. The present differences are the result of a difference in the amount of motion—i. e., of slip-cleavage—along alternating strips of rock and of the consequent difference in resistance to erosion. There is also a difference in color, some infiltration of limonite having taken place along the more highly cleft bands. The structure

[1] Sixteenth Ann. Rept. U. S. Geol. Survey, pp. 561–564, 1896. In that paper no distinction was drawn between shear zones and cleavage bands. The cleavage bands in their first stage probably resemble a shear zone.



A.

B.

CLEAVAGE BANDING IN ORDOVICIAN SLATES IN RUPERT, VERMONT.

in Pl. XXX, *B*, is similar, but the finely cleft bands are thinner. Fig. 11 shows the same structure in purple slate, probably Cambrian, in Gorhamtown, Poultney. Small beds of green slate indicate the course of the stratification, and show the amount of slippage suffered by the bands. In the Poultney River, about a mile east of East Poultney, certain hard, bright green and purple slates near the schist mass show the cleavage banding well. In breaking up such a rock the denser uncleft parts come out in slab-like blocks, the larger surfaces of which lie transverse to the bedding.

Dr. Becker[1] explains this structure by the alternate interference and coincidence of waves of vibration produced by shock. When the waves of vibration coming from opposite directions coincide, cleavage fractures—i. e., planes of slip cleavage—will be numerous. In the ledge figured in Pl. XXX, *A*, there are 360 such planes to the inch in the cleft bands, but where the vibrations interfere the cleavage fractures will be few and the material unchanged. The hard bands in the same ledge show as many fractures, but they are discontinuous and merely incipient.

Professor Van Hise regards such structures simply as the result of the concentration or sparseness of slip cleavage.[2]

A thin section recently made from the same Ordovician shale in Rupert shows eight slip-cleavage planes to a millimeter in the cleft band, but none in the hard band. The rock consists of quartz fragments and muscovite and chlorite scales. In the hard band these are not arranged. The rock is simply a shale; but sericite has developed in the cleft bands, and the rock has there become a schist.

In a piece of sericite schist from the mass east of Rupert the rock consists of alternating strips with and without slip-cleavage, those without being wider. The slip-cleavage planes meander about and run into each other, though having a general parallelism. The plication is much more intense and irregular in the cleft strips and also appears to be more sericitic there.

It seems probable that the shear zones (hogbacks) represent but a variation of the process involved in the cleavage bands. The force bent and crushed the slate in the bands instead of producing very numerous planes of slip-cleavage within them.

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[1] Finite homogeneous strain, flow, and rupture of rocks: Bull. Geol. Soc. Am., Vol. IV, Jan., 1895. On page 16 he says: "Thus there seems sufficient reason to believe that a pressure very rapidly applied, producing primary ruptures attended by shock, will be immediately followed by secondary ruptures in the same direction as the others at intervals dependent upon the wave length of the impulse. In much the same way a high explosive shatters a rock far more than black powder. A phenomenon of which no explanation has been offered in this paper is that of thick slates and of those flags which are to be considered as very thick slates. These, though cleavable in a certain thinness, are not capable of further splitting. Such rocks indicate a flow which is not uniformly distributed through the mass, but on the contrary passes through maxima at intervals corresponding to the thickness of a slate or flag. It is possible that at the inception of strain such masses were in a state of tremor so intense that the interference of waves determined surfaces along which flow began. These surfaces would be weakened by the flow, and further strain would be distributed among them rather than over the intervening solid sheets. Effects of a similar kind are produced on a pile of sheets of paper, such as 'library slips,' resting on an inclined cloth-covered table which is jarred by rapid blows."

[2] Op. cit., Sixteenth Ann. Rept. U. S. Geol. Survey, pp. 662–664, 1896.

VEINS.

The quartz veins or "flints," as the quarrymen call them, are a striking feature of the slate, as well as a cause of perplexity in quarrying. They appear at the most unexpected points, frequently ramify very irregularly and disappear as suddenly. Pl. XXXI, *A* and *B*, from the old quarries at Jamesville, are good types of such veins of segregation. In some cases there is a rough parallelism in them, as in Pl. XXXI, *B*. In both of these localities they cross both bedding and cleavage, their general dip being roughly at right angles to that of the cleavage, and their strike probably not very different from that of cleavage and bedding. Pl. XXXII, *A*, represents a small slab of purple Cambrian slate from Hampton, in which there are twelve parallel veins, one-fourth inch thick in a space of 20 inches.[1] This illustrates what may be seen at some of the quarries on a scale a hundred times larger. At Benson, in the black slate, small banded veins of fibrous calcite form a series of gashes "en échelon." Pl. XXXII, *B*, representing between 4 and 5 square feet of the joint face of the West Castleton syncline, shows the unequally weathered surface of the plicated calcareous shaly slate. Numerous minute quartz veins parallel to the cleavage foliation of the syncline stand out in relief, crossing the minor plications of the bedding.

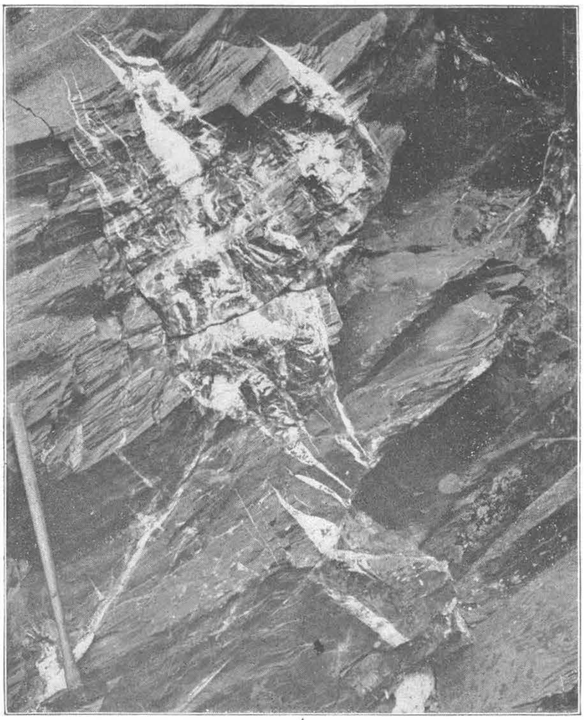
In the cases adduced there is some relation between the foliations of the slate and the course of the veins, but veins do occur which appear to be quite lawless, crossing in every direction, anastomosing, and intersecting one another, and sometimes inclosing fragments of the adjacent slate and constituting the cement of a brecciated area. That the veins are the result of various secondary stresses, producing openings of more or less irregularity, is manifest. Where the stress ceased to operate the vein tapers out; where the stresses were complex the veins are so.

The material which filled the openings thus made is chiefly quartz, usually "milky" in color and often finely crystallized in small cavities. With the quartz are often associated chlorite and calcite, and possibly dolomite. The chlorite occurs in hexagonal scales, in vermicular aggregations, or in tortuous columns. Some of the smaller veins are banded, presenting alternations of quartz and fibrous calcite, or of quartz and rhombs of calcite. The quartz contains cavities measuring from 0.002 to 0.005 millimeter in diameter, partly filled with fluid. Galenite in small particles was found in veins at the Jamesville quarries. As stated above, certain small, gash-like veins are filled with fibrous calcite. The fibers or prisms lie transverse to the course of the vein. Daubrée regards such veins as due to stretching[2]. That the material of the veins described, of whatever sort, must have come from the adjacent slate itself is evident, and also that it was deposited in solution.[3]

[1] See Nat. Mus. Spec. D. XIV, 365, XX.

[2] Daubrée, Géologie expérimentale, p. 144, fig. 166.

[3] Lesley endeavored to popularize the subject of quartz veins in his Summary, Final report second Geol. Surv. Pa., Vol. I, pp. 566-568, 1892.



A.

B.

QUARTZ VEINS OF SEGREGATION IN CAMBRIAN SLATE, JAMESVILLE, NEW YORK.

Artificial fractures.—A minor feature in roofing slates is the peculiar curvature of the fractures across the cleavage produced by blasting with gunpowder. These curves are so different from those obtained in any fractures in the slate due to shearing compression, shock, stretching, or any other geological strain as to attract attention.

NODULES.

In some of the quarries very hard nodules, a few inches in diameter and of lenticular form, occur along the bedding planes. They consist of a quartzite nucleus containing much calcite and large scales of muscovite surrounded by slaty layers with calcite, quartz, and muscovite scales. Pyrite is disseminated throughout both nucleus and outer zone. Such nodules are evidently of sedimentary origin.

QUARRY DIAGRAMS.

Diagrams representing the structure at a number of quarries are given on Pls. XXXIII and XXXIV. The following table contains most of the observations taken at the quarries, and all that are of special interest.

The data are not as complete as might be desired, owing generally to the practical difficulties in the way of obtaining them. Where bedding is given but not cleavage, the cleavage is very nearly if not quite the same as the bedding. The usual dip joints may be assumed when not given. Approximations are indicated by the signs plus (+), minus (—), more or less (±). The quadrangles designate the topographic sheets of the United States Geological Survey. This list includes only quarries where two or more structural observations were taken. The numbers in the first column will be found on the map, Pl. XIII.

Slate quarry

Quarry number.	Geologic horizon.	Bedding.		Cleavage.		Strike joints.		Dip joints.		Diagonal joints.	
		Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.
1	[1]C, B	N. 50° E.	30° E.	....	....	N. +	30° W.	N. 70° W	90°	....	....
2	C, B	N. 15° E.	40° E.	N. 10° W.	30° E.	N. 10° E. N. 10° E.	90° 45° E.	E.-W.	90°	....	....
3	C, B	N. +	30° E.	....	....	N. +	70° E.	N. 70° W.	90°	....	....
4	C, B	N. 15° E.	30° E.	....	....	N. 15° E.	50° E.	....	....	....	....
5	C, B	N. 30° E.	40° E.	N. +	15° E.	N. 15° E.	65° W.	....	....	N. 45° W.	90°
6	C, B	(?)	(?)	N. 5° E.	80° W 80° E	....	....	E.-W.	90°	....	....
7	C, B	N. 20° E.	35° E.	....	....	N. 25° E. N. +	45° W. 45° E.	N. 75° W.	90°	....	....
8	C, B	N. +	E. low.	N. 15° E.	80° E.	....	....	E.-W.	90°	....	....
9	S, Irs	N. 23° E.	30° E.	....	....	N. +	80° E.	....	....	....	....
10	C, B	N. +	30° E.	N.	42° E.	N. 5° W.	40° E.	....	....	....	....
11	C, B	N. 5° E.	40° E.	N.	40° E.	N. 15° E. N.	65° E. 45° W.	N. 75° W.	90°	....	....
12	C, B	N. 20° E.	(?)	N.	40°-70° E.	N. 15° E. N. 10° E.	62° E. 30° W.	N. 75° E.	90°	....	....
13	C, B	N. +	E. low.	N.	40° E.	N. 5° E.	65° E.	E.-W.	90°	....	....
14	C, B	N. 25° E.	25° E.	N. 15° E.	50° E.	N. 7° E N. 25° E.	50° E. 45° W.	....	....	....	....
15	C, B	N. +	37° E.	N. 15° E.	55° E.	....	....	....	....	....	....
16	C, B	N. +	30° E. ±	N. +	50° E. ±	N. +	E. high.	....	....	....	....
17	C, B	N. +	20° ± E.	N. +	40° ± E.	N. + N. +	90° 30° W.	....	....	....	....
18	C, B	....	50° E.?	N.	37° E.	N. 12° W.	60° E.	E.-W. E.-W.	55° W. 90°	....	....
19	C, B	....	....	N.	35° E.	N. 10° E. N.	55° E. 40° E.	N. 82° E	90°	....	....
20	C, B	N. +	30° E.	N. 10° W.	50° E.	N.	60° W.	E.-W.	90°	....	....
21	C, B	N. +	17° E.	N. 5° W.	42° E.	....	....	E.-W.	90°	....	....
22	C, B	(?)	(?)	N. 20° W.	40° E.	N. 5° W.	55° W.	N. 80° E.	90°	....	....
22.1	C, B	N. 5° W.	35° E.	N.	40° E.	....	....	N. 75° E.	90°	....	....
23	C, B	N. 25° W.	30° E.	N. 25° W.	32° E.	N. N. +	75° E. 45° ± W.	....	....	....	....
24	C, B	(?)	(?)	N. 17° W.	40° E.	N. 10° W.	50° E.	N. 65° E.	90°	....	....
25	C, B	(?)	(?)	N. 25° E.	65° E.	....	....	....	....	....	....
26	C, B	N.	—45° E.	N. 15° E.	45° E.	N. +	42° W.	....	....	N. 50° W.	70° SE.
27	C, B	N. +	20° E.	N. 12° E.	40° E.	....	....	N. 70° W.	70° ESE	....	....
28	C, B	N.	25° E.	N. 15° E.	37° E.	....	....	....	....	....	....
29	C, B	N. +	20° E.	N. +	27° E.	....	....	....	....	....	....
30	C, B	N. +	22° E.	N. +	35° E.	....	....	....	....	....	....
31	C, B	(?)	(?)	N. 10° W.	45° E.	N.	75° E.	E.-W.	90°	....	....
32	C, B	N. +	15° E.	N. 5° E.	30° E.	....	....	N. 70° E.	85° N.	....	....
33	S, Irs	N.	30° ± E.	....	....	....	....	....	....	N. 30° E.	70° W.
34	S, Irs	N.	45° E.	....	....	....	....	N. 65° W.	90°	....	....
35	S, Irs	N. +	15° E.	N. 15° E.	20° E.	....	....	....	....	....	....
36	S, Irs	N. 20° W.	E.-W.	N. 5° E.	30° E.	N. +	55° E.	E.-W.	90°	....	....
37	S, Irs	N. 12° W.	35° E.	N. 12° W.	35° E.	....	....	....	....	....	....
38	S, Irs	N. 10° W.	25° E.	N. 5° W.	30° E.	N. 10° W.	25° E.	N. 75° W.	90°	....	....
39	S, Irs	N. 5° E.	50° E.	N. 5° W.	45° E.	....	....	....	....	....	....
40	S, Irs	N.	35° E.	N.	40° E.	....	....	....	....	....	....
41	S, Irs	N.	30° E.	N.	40° E.	N. 15° W.	50° E.	N. 77° E.	90°	....	....
42	C, B	N. 22° W.	30° E.	N. 3° W.	35° E.	N.	40° W. 90°	N. 65° W. N. 82° W.	90° 90°	....	....
43	C, B	N. 10° W.	Fold.	N. 10° E.	20° E.	....	....	....	....	....	....

a Almost horizontal.

[1] Cambrian.

observations.

Grain strike.	"Hogbacks."		Faults.		Field No.	Collector of datum.	Quadrangle.	Part of slate belt.
	Strike.	Dip.	Strike.	Dip.				
					364	D	Cambridge	Southern.
					365	D	do	Do.
					366	D	do	Do.
					236	D	do	Do.
					196	D	do	Do.
					280	D	do	Do.
					356	D	do	Do.
					279	D	do	Do.
					435	D	do	Do.
	N. 37° E.	65° NW.			219	D	Pawlet	East Central.
(Bottom joints.)					225	D	do	Do.
					227	D	do	Do.
					231	D	do	Do.
					241	D	do	Do.
	{E.-W. NE.}	{S. high NW.}			254	D	do	Do.
	NE. or N.	{40° NW. or W.}			255	D	do	Do.
					256	D	do	Do.
					259	D	do	Do.
					260	D	do	Do.
Feeble.	N.	50° E.			367	D	do	Do.
N. 45° E.	NE. ±	57° NW.			368	D	do	Do.
					431	D	do	Do.
N. 80° W.	N. 45° E.	70° NW.			35	D	do	Do.
					265	D	Fort Ann	Do.
					268	D	do	Do.
					286	D	do	Do.
					695	D	do	Do.
					696	D	do	Do.
					697	D	do	Do.
					700	D	do	Do.
					701	D	do	Do.
	N. 10° W.	45° E.			717	D	do	Do.
					1050	P	do	West Central.
					1106	P	do	Do.
					1080	P	do	East Central.
			N.+	45° E.	704	P	do	Do.
					269	D	do	Do.
					270	D	do	Do.
					201	D	do	Do.
					284	D	do	West Central.
	N. 7° E.	77° E.			397	D	do	East Central.
					398	D	do	West Central.
N. 55° W.					617	D	Castleton	East Northern.
					622	D	do	Do.

Slate quarry

Quarry number.	Geologic horizon.	Bedding.		Cleavage.		Strike joints.		Dip joints.		Diagonal joints.	
		Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.
44	C, B	N. 7° W.	45° E.	N.	30° E.	N. 18° E.	45°+	E.-W.	90°	....	....
45	C, B	N. +	35°–65° E.	N. 7° W.	50° to 65° E.	N.	90°	E.-W.	90°	....	....
46	C, B	N. 15° E.	60° E.	N. 15° E.	60° E.	....	....	....	....	....	....
47	C, B	N. 55° E.	20° E.	N. 30° E.	25° E.	N. 20° E.	60° E.	....	....	....	....
48	C, B	N. 25° E.	20° E.	N. 7° E.	25° E.	N. 25° E.	45° E.	N. 80° W.	80° N.	N. 30° E. N. 40° E.	45° E. 50° SE.
49	C, B	(*a*)	....	N. 25° W.	20° E.	....	....	E.-W.	90°	N. 35° E.	60° SE.
50	C, B	N.	20° E.	N. 27° E.	30° E.	N. 5° W.	30° E.	N. 65° W.	90°	....	....
51	C, B	....	0°	N. +	17° E.	....	....	....	....	....	....
52	C, B	....	0°	N. 25° E.	15° E.	....	....	N. 70° E.	90°	....	....
53	C, B	N. 40° W.	Fold.	N. 15° E.	E. low.	....	....	....	....	....	....
54	C, B	N. 17° W.	30° E.	N. 5° E.	20° E.	....	....	....	....	....	....
55	C, B	N. 15° W.	30° E.	N. 15° E.	20° E.	....	....	....	....	....	....
56	C, B	N. 75° W.	17° S.	N. 42° E.	15° E.	N. 22° E.	60° E.	....	....	....	....
57	C, B	N. +	7° W.	N. +	17° E.	....	....	....	....	....	....
58	C, B	N. +	15° W.	N. 10° E.	17° E.	....	....	....	....	....	....
59	C, B	....	Fold.	N. +	35° E.	N. +	45° E.	....	....	....	....
60	C, B	N. +	17° E.	N. 10° W.	27° E.	....	....	E.-W.	90°	N. 35° E.	60° SE.
61	C, B	N. 27° W.	5° E.	N. 27° E.	15° E.	N. 17° E. N. 5° E.	90° 90°	N. 67° W.	90°	....	....
62	C, B	N. +	Var.	N. 15° W.	20° E.	N. 15° E.	90°	N. 85° W.	90°	NW. ± N. 55° E.	65° NE. 90°
63	C, B	N. 15° E.	Var.	N. 7° W.	15° to 30° E.	....	....	....	....	....	....
64	S, Irs	N. 15° W.	22° E.	N.	25° E.	....	....	....	....	....	....
65	Benson, S?	N. +	17° E.	N. 5° E.	30° E.	N. 20° E.	50° E.	N. 75° W.	90°	....	....
66	S, Irs	N. 30° W.	20° E.	N. 15° W.	25° E.	....	....	N. 80° W.	90°	....	....

a Almost horizontal.

observations—Continued.

Grain strike.	"Hogbacks."		Faults.		Field No.	Collector of datum.	Quadrangle.	Part of slate belt.
	Strike.	Dip.	Strike.	Dip.				
....	....	....	....	....	645	D	Castleton	East Northern.
....	....	....	....	....	658	D	.....do.........	Do.
....	....	....	....	....	672	D	.....do.........	Do.
....	....	....	....	....	199	P	.....do.........	Do.
N. 60° W.	N. 55° E. N. 40° E.	87° NW. 80° NW.	N. 80° E.	35° S.	314	D	.....do.........	Do.
....	....	....	....	....	335	D	.....do.........	Do.
....	....	....	....	....	221	M	.....do.........	Do.
....	....	....	....	....	337	D	.....do.........	Do.
....	....	....	Along cleavage ...		338	D	.....do.........	Do.
....	....	....	....	....	339	D	.....do.........	Do.
....	....	....	....	....	659	D	.....do.........	Do.
....	....	....	....	....	759	D	.....do.........	Do.
....	....	....	....	....	760	D	.....do.........	Do.
....	....	....	....	....	340	D	.....do.........	Do.
....	....	....	....	....	341	D	.....do.........	Do.
....	....	....	....	....	342	D	.....do.........	Do.
(*b*)	....	....	....	....	321	D	Whitehall.....	West Northern.
....	....	....	....	....	296	D	.....do.........	Do.
N. 35° W.	....	....	....	....	294	D	.....do.........	Do.
....	....	....	....	....	301	D	.....do.........	Do.
....	....	....	....	....	357	D	.....do.........	Do.
....	....	....	....	....	305	D & P	.....do.........	Do.
....	N. 55° W.	70° NE.	....	....	373	D	.....do.........	Do.

b "False" cleavage strikes N.

DIKES.

Kemp and Marsters described two dikes within the slate belt, one west of Fair Haven, in the town of Hampton, New York, the other near South Granville.[1] In their second paper they called attention to the numerous dikes of the Lake Champlain region, and predicted that many more would be found. The general map, Pl. XIII, shows the correctness of that prediction. Three of the twenty-two dikes were found by Miss Bascom in the schist mass east of Lake St. Catherine; most of the others were found by Mr. Prindle or Mr. Moffit. All the dike specimens were submitted to Miss Bascom for determination. Her descriptions of five typical microscopic sections are given beyond (p. 223).

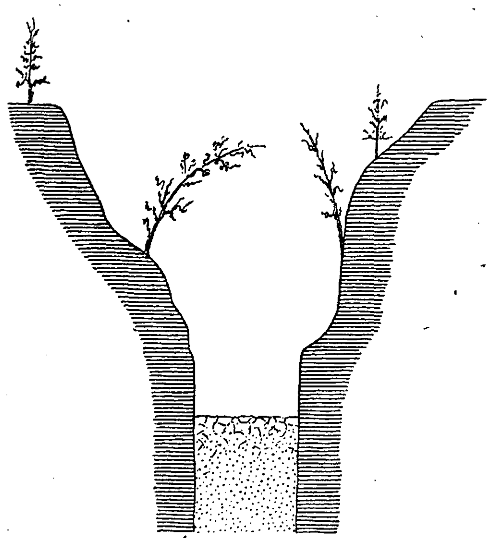


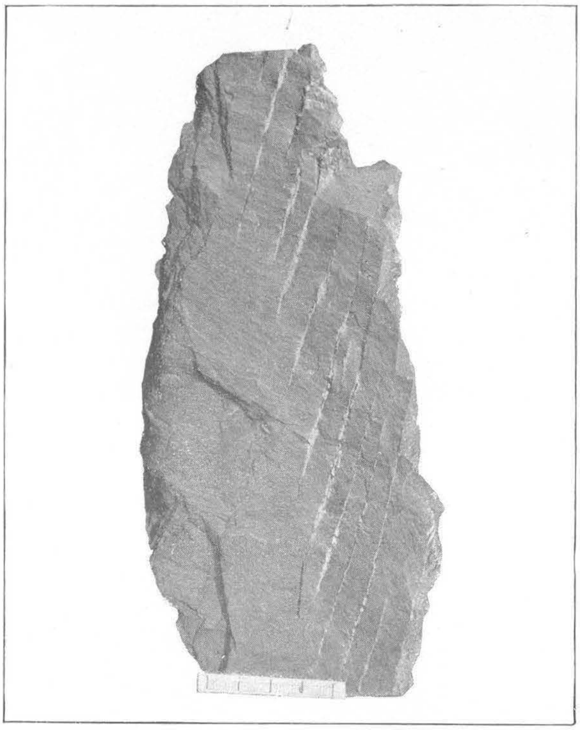
FIG. 12.—Dike of augite-camptonite in Cambrian slate.

Although these dikes are of interest to petrographers mainly on account of their mineralogical composition, the courses of the dikes have important bearings on the structural geology of the region. The correspondence of the course of many of them to that of the diagonal joints in the slate has already been pointed out, and the significance of this will be dwelt upon later (p. 271). The relation of the dikes to the various systems of joints could be brought out on a map on which the strikes of both were fully given.

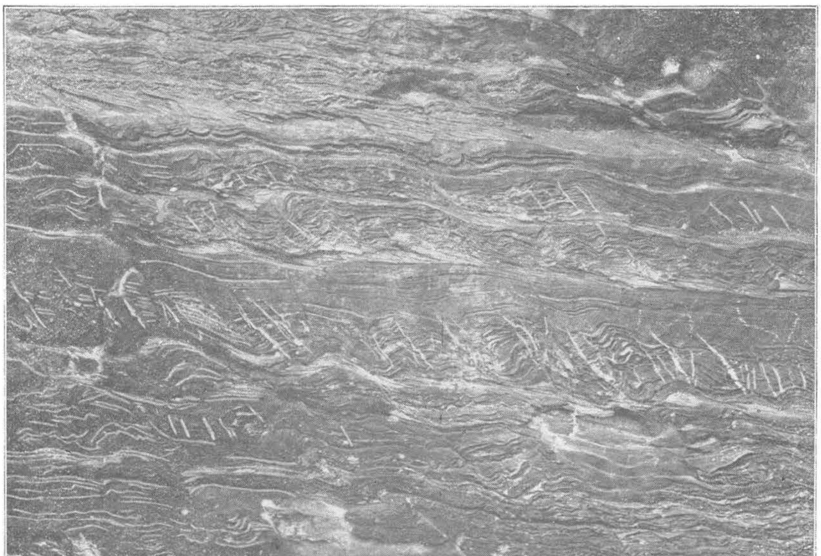
The dikes well exposed for the greatest distance are the two of augite-camptonite which appear to cross Lake Bomoseen, one from Glen Lake and the other from the eastern part of Benson. That beginning near Glen Lake is $2\frac{3}{4}$ miles long and usually about 20 feet wide, but at its eastern limit measures 42 feet. It crosses both Cambrian and Ordovician beds. The northern one is $3\frac{1}{4}$ miles long, 12 to 30 feet wide, and traverses only the Cambrian. A dike beginning near Belcher, in Hebron, New York, is exposed off and on in the Cambrian for 4 miles, and may be continuous with that in the Ordovician at South Granville. If so, it would measure 7 miles. One of the more interesting dikes forms the bed of Lewis Brook in Gorhamtown, Poultney, Vermont, extending east and west for over 600 feet, and measures

[1] On certain camptonite dikes near Whitehall, Washington County, New York, Kemp and Marsters: Am. Geol., Aug., 1889, p. 97.

The trap dikes of the Lake Champlain region, Kemp and Marsters: Bull. U. S. Geol. Survey No. 107, pp. 15, 31, 39, 53, 54; 1893.



A. PARALLEL QUARTZ VEINS IN CAMBRIAN SLATE, HAMPTON, NEW YORK.



B. QUARTZ VEINS IN CLEAVAGE PLANES OF SYNCLINE AT WEST CASTLETON, VERMONT.

35 to 40 feet in width. It is an augite-camptonite approaching a diabase. The adjacent rock is the purple and green slate of Horizon B, with a cleavage striking N. 10° E. and dipping 68° E. Owing to its peculiar mode of weathering in blocks the eruptive has been eroded more rapidly than the softer slate and now forms the bottom of a miniature canyon 50 to 100 feet deep, through which the brook ripples and which is overarched with foliage (see fig. 12). The edge of the dike is fine grained, and at its contact with the slate has a white rim one-eighth inch thick. The course of this dike is identical with that of many of the dip joints in the quarries.

The courses of the longer dikes are shown on the map, Pl. XIII. All the courses observed are as follows: N. 15° E., N. 17° E., N. 20° E., N. 27° to 28° E., N. 30° E., N. 37° E., N. 40° E., N. 45° E., N. 47° E., N. 50° E., N. 57° E., N. 65° E., N. 70° E., E. to W., N. 50° W., N. 60° W., N. 70° to 72° W. None run north and south. Those ranging from N. 15° to 20° E. run with the dominant strike of the folds and much of the cleavage and bedding south of the Castleton cut. Those running N. 35° to 57° E. correspond to the diagonal joints and to many of the shear zones (hog-backs), while those with a northwest course correspond to another system of diagonal joints at right angles to the former, while the east and west and N. 70° W. and N. 70° E. courses agree with the strike of the dip joints.

The dikes cross indifferently the Cambrian and Ordovician slates, etc., as well as the Ordovician schists of the Taconic Range.

The dike rocks.—The following report on the dike rocks of the slate belt is by Miss F. Bascom:

This examination has been of a purely petrographical character, unassisted by chemical analyses of the rocks. Under such petrographical study they prove to be augite-camptonites (34 specimens), camptonites (14), and analcitites (7). Nine of these possess a structure approaching the diabasic, yet because of their close association with and gradation into typical camptonites and augite-camptonites they are classed with them. Twenty slides show analcite to be present. In four of these the analcite is confined to the amygdules, where its character was determined both on chemical and optical grounds. In these cases it is without question of secondary origin. In sixteen slides analcite is also present as a constituent of the groundmass. In these cases it becomes a most difficult matter to decide whether it is of secondary or of primary origin. It occupies the interstices of the groundmass, but is an important constituent only in proximity to the amygdules which are of the same mineral constitution. Here analcite saturates the groundmass. It is always allotriomorphic and usually fresh, contrasting in this respect with the more or less altered primary constituents. It occurs in association with calcite and in exactly similar modes. These characteristics are indications of a secondary origin. If the analcite is secondary, its presence does not deserve recognition in the rock name, and where it was concluded that only secondary analcite was present no account was taken of it. There are, however, occurrences of a somewhat distinctly primary character. The analcite is still allotriomorphic, but more or less altered to other zeolites. It contains as inclusions apatite, augite, hornblende, or feldspar, and around its margin the analcite has pushed away the smaller grains of these minerals. This might indicate not only the presence of a crystallizing force, but one that was active in the original consolidation of the rock.

An examination of some slides of the monchiquites of the adjacent regions,[1] kindly loaned by Professor Kemp, led to the conclusion that some of the monchiquites, at least, were analcite basalts. Again, the recent important determination by Pirsson[2] of the primary analcite in rocks of this class also suggested a possibility which would otherwise have been overlooked. In seven instances the analcite showed these somewhat dubious indications of a primary origin, and the dikes in which this analcite occurs are listed as analcitite, no olivine being present.[3]

Four hand specimens[4] show yellowish brown, bronzy phenocrysts, from 3 to 7 millimeters in length. These phenocrysts do not appear in the slides. Upon chemical examination they seemed to be a mixture of limonite and serpentine. They probably represent the decomposition product of olivine phenocrysts.

Special descriptions are appended of the following:

An augite-camptonite from Mount St. Catherine in Wells, Vermont.

A camptonite from Pawlet, Vermont.

A diabasic camptonite from Hubbardton, Vermont.

Two analcitites from Hebron and Hampton, New York.

These descriptions have, at Mr. Dale's suggestion, been made somewhat more explanatory than is necessary for professional petrographers.

Augite-camptonite (B. I, 784*a*–784*c*), Mount St. Catherine, Wells, Vermont.—This rock, as seen in the hand specimens, is of a dark greenish-gray color, weathering to a rusty brown. Lustrous black crystals (phenocrysts) ½ to 1½ centimeters in length, of augite and hornblende, are embedded in a groundmass which is medium to fine grained, and in which slender lath-shaped feldspars can be distinguished. The rock is more or less amygdaloidal, with both flesh-colored dolomitic amygdules and amygdules of an opaque white calcite.

The thin sections disclose a rock made up entirely of freely developed crystals of two distinct periods of consolidation (panidiomorphic and porphyritic). The primary mineral constituents are in order of abundance—feldspar, amphibole, pyroxene, magnetite, ilmenite, olivine, and apatite. The secondary constituents are delessite, calcite, dolomite, leucoxene, pyrite, and serpentine.

The feldspar is a plagioclase occurring in broadly lath-shaped twinned crystals of the secondary period of consolidation. Occasionally a zonal structure is to be seen and twinning after the pericline as well as the albite law. A series of extinction angles on P (001) range from 24° to 36°. This indication of a basic plagioclase (between bytownite and anorthite) is borne out by the decomposition product of the feldspar.

The amphibole is always freely crystallized (idiomorphic) and occurs both in large crystals (phenocrysts) and as a constituent of the groundmass. It is a rich brown amphibole of the barkevicite type. The pleochroism is strong, $\mathfrak{c}$ and $\mathfrak{b}$=deep brown and $\mathfrak{a}$=yellow. The extinction is 15° to 16° on ∞ P (110). The forms present are O P (001), ∞ P $\bar{\infty}$ (100), ∞ P (110), ∞ P $\breve{\infty}$ (010), P (111). Twinning parallel to ∞ P $\bar{\infty}$ (100) occurs. The cleavage is marked. A zonal structure is sometimes present. The crystals of the groundmass appear as slender lath-shaped longitudinal sections, with or without terminal faces, and as hexagonal cross sections.

The pyroxene is also freely crystallized and almost always combined with crystals of the first consolidation. It is a violet-colored, titaniferous, normal augite. The forms most frequently present are ∞ P (110) and ∞ P $\breve{\infty}$ (010). The sections show a marked cleavage, a slight tendency to zonal structure, and a slight pleochroism.

Magnetite is abundantly distributed throughout the slides in small cubes. There are beautiful corroded crystals of ilmenite of a triangular or hexagonal form. Minute needles of apatite are inconspicuously distributed.

[1] Kemp and Marsters, op. cit.

[2] The monchiquite or analcite group of igneous rocks, by L. V. Pirsson: Jour. Geol., Vol. IV, No. 6, pp. 679–690, 1896.

[3] See An analcite basalt from Colorado, by Whitman Cross, Jour. Geol., Vol. V (Oct.-Nov., 1897), p. 684, published since completion of this manuscript.

[4] P. IV, 129*a*, 138*a*, 139*a*, 204*a*.

The vesicles are filled with brilliantly polarizing calcite and lined with radiating aggregates of delessite.

Delessite and calcite are also the predominating decomposition products of the silicates and fill the interstices of the groundmass. The large crystals of augite are in some places altered to a yellow serpentine-like delessite. Sometimes the alteration is complete, but frequently it is confined to the peripheries and cleavage cracks. This alteration is accompanied by minute globulites of an insolvable faintly polarizing by-product, which may be epidote. A single crystal altered completely to serpentine and calcite suggests by its contour and irregular cracks that it may have been an olivine. The dike at South Granville described by Kemp and Marsters shows considerable freely crystallized olivine completely altered to serpentine, iron oxides, and pyrite.

When dolomite is present in the vesicles it is recognized by the curvature of the surfaces of the rhombs.

Camptonite (B. I, 829*a*), east of Middle Mount, Pawlet, Vermont.—A greenish-gray medium-grained rock, without large crystals and with very few vesicles.

The thin section discloses freely developed crystallization and mineral ingredients differing from those of the augite-camptonite only in the absence of augite. The conspicuous constituent is a pinkish-brown hornblende which occurs in prismatic and basal sections. The latter are hexagonal and show the prism (∞P) and clinopinacoid ($\infty P \grave{\infty}$) in about equal development. The cleavage is marked and the pleochroism conspicuous; $\mathfrak{a}$ = pale yellow, $\mathfrak{c}$ and $\mathfrak{b}$ = pinkish brown. The hornblende shows alteration into a yellow serpentine-like delessite and some crystals are completely replaced by this chlorite. This and calcite are also the decomposition products of the feldspar, which is a basic plagioclase and occurs in the characteristic twinned lath-shaped crystals. Magnetite is abundant and some ilmenite is present. In the absence of augite the rock is considered a typical camptonite.

Diabasic camptonite (M. III, 193*a*), 2 miles north of Zion Hill, in Hubbardton, Vermont.—A medium to fine-grained green rock without large crystals and obscurely vesicular.

The thin section shows the primary and free crystallization of the feldspar (ophitic structure). The constituents are feldspar, hornblende, magnetite, and ilmenite, with abundant chlorite and calcite as decomposition products. The hornblende is quite subordinate to the feldspar in amount and is only in part freely crystallized, or not at all so, (hypidiomorphic or allotriomorphic.) It is green and extensively altered to a green delessite, which also fills the vesicles and the interstices of the feldspars.

The rock is very feldspathic. The feldspar is a plagioclase in lath-shaped crystals, and that it is of a basic variety is shown by the abundant calcite as a decomposition product.

Magnetite and ilmenite are both present, the former sometimes bordered with biotite, the latter in skeleton forms.

This rock is rather a diabasic phase of a camptonite than a true diabase, from which type it is distinguished by the absence of pyroxene and the presence of presumably original hornblende.

Analcitite (P. III, 836*b*), 2 miles southwest of Hebron village, Washington County, New York.—The rock is dark greenish gray, medium-grained, without large crystals, but crowded with small spherical white vesicles.

The section shows violet-colored augite and brown basaltic hornblende in freely developed (idiomorphic) crystals, distributed throughout the groundmass in about equal proportions and more or less altered to a yellowish-green chlorite (delessite). Augite sometimes forms the core of the hornblende crystals.

The lath-shaped feldspars polarize in aggregates, giving with a low power a somewhat mottled appearance to the groundmass. This is due to the replacement of the feldspar by secondary quartz. The uniaxial character of the replacing mineral admits of easy determination in converging light. Most of the feldspar throughout the section is replaced in this way, while its crystal outline is perfectly retained.

The interstices of the groundmass are filled with analcite or with delessite. The former also fills the vesicles. Analcite also occupies considerable areas of the groundmass, when it contains as inclusions the other constituents of the rock, and excludes from its boundaries the more minute crystals of augite and hornblende. It also shows some alteration to other zeolites. Because of these characteristics the possibility of a primary origin is recognized. Chlorite is a decomposition product of the feldspar and appears as brightly polarizing blades and grains in the replacing quartz. Apatite is a constituent of the groundmass.

Analcitite (P. III, 1066 *a* and *b*), southwest part of Hampton, Washington County, New York.—This is also a greenish-gray medium-grained rock, without large crystals, but conspicuously vesicular. In one of the hand specimens the vesicles are for the most part analcite, in the other they are longer, less regular, and calcitic. The rock also shows irregular areas of a lighter color than the rest. This is due to the predominance of a pinkish-white feldspar and the absence of all ferromagnesian constituents except slender crystals of biotite. These areas have been interpreted as included fragments rather than as acid segregations, because of their sharply defined boundaries and the character of their mineral constituents, which is in every case the same and quite unlike that of the containing rock.

The thin sections show augite and hornblende with their characteristic features. Cores of augite are not infrequently contained in the hornblende. The alteration product is again a chlorite, yellowish green in 1066*a*, and a more normal green in 1066*b*, the difference being probably due to the iron content. The yellow alteration product of the amphibole and pyroxene was determined to be delessite rather than serpentine, which it closely resembles, on the ground of its divergent fibrous structure, low double refraction, pleochroism, extinction parallel to the axes of the fibers, and the nonemergence of a bisectrix in a plane normal to the axes of the fibers. A confused aggregate of more or less saussuritized, lath-shaped feldspar constitutes the larger part of the groundmass. Apatite crystals in longitudinal and basal sections are abundant.

The main interest of this specimen, as of the preceding, lies in the presence of analcite, saturating the groundmass and filling the vesicles. Like the chlorite, analcite occupies the interstices of the groundmass. It also occurs in a few more considerable areas. While its presence in the vesicles and its association with calcite and chlorite are assurances of its occurrence as a secondary constituent, the fact is also recognized that it may occur in the same rock as a primary constituent.

CHEMICAL AND MINERALOGICAL COMPOSITION OF THE SLATES.

A complete chemical analysis of each of the principal varieties of slate has been prepared by Dr. W. F. Hillebrand, of the division of chemistry, U. S. Geological Survey, for this report.

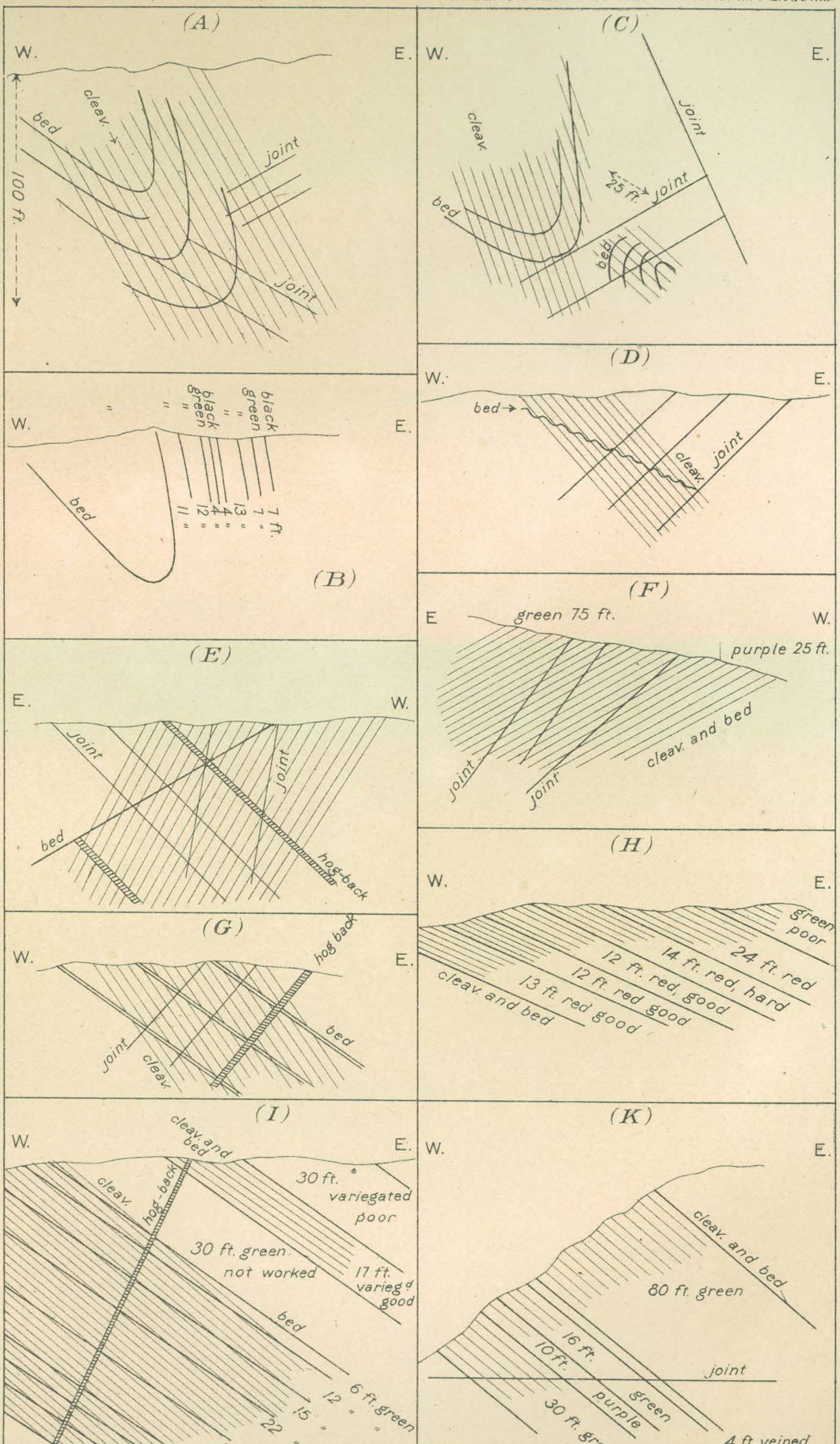
In addition to the 64 thin sections of slate loaned by the U. S. National Museum, the writer has examined some 150 new ones, made either from specimens collected at the quarries by himself or in a few cases from specimens selected under his direction by the owner or foreman of a quarry. Twenty-five of the more difficult slides have been referred to Dr. J. P. Iddings for criticism of the determinations. After familiarizing himself with the petrographic literature of slates and obtaining such acquaintance with their microscopic features as the careful examination of over 200 well-made thin sections affords, and having obtained the critical aid of Dr. Iddings, the writer believes that the microscopic

PLATE XXXIII.

PLATE XXXIII.

STRUCTURAL DIAGRAMS OF SLATE QUARRIES.

(*A*) Rising & Nelson's "sea-green" quarry No. 2, West Pawlet, Vermont.
(*B*) Rising & Nelson's "sea-green" quarry No. 2, West Pawlet, Vermont, with measurements.
(*C*) Hughes's "sea-green" quarry No. 7, West Pawlet, Vermont.
(*D*) Robert R. Roberts's "sea-green" quarry, Pawlet, Vermont.
(*E*) Hughes's western quarry, "sea-green," Pawlet, Vermont.
(*F*) McCarty's sea-green and purple quarry, Poultney, Vermont.
(*G*) Schmidt & Williams's "sea-green" quarry, Pawlet, Vermont.
(*H*) Empire slate quarry (red), Granville, New York.
(*I*) Auld & Conger's quarry ("sea-green" and variegated), Wells, Vermont.
(*K*) Griffith & Nathaniel's quarry (sea-green and purple), Poultney, Vermont.



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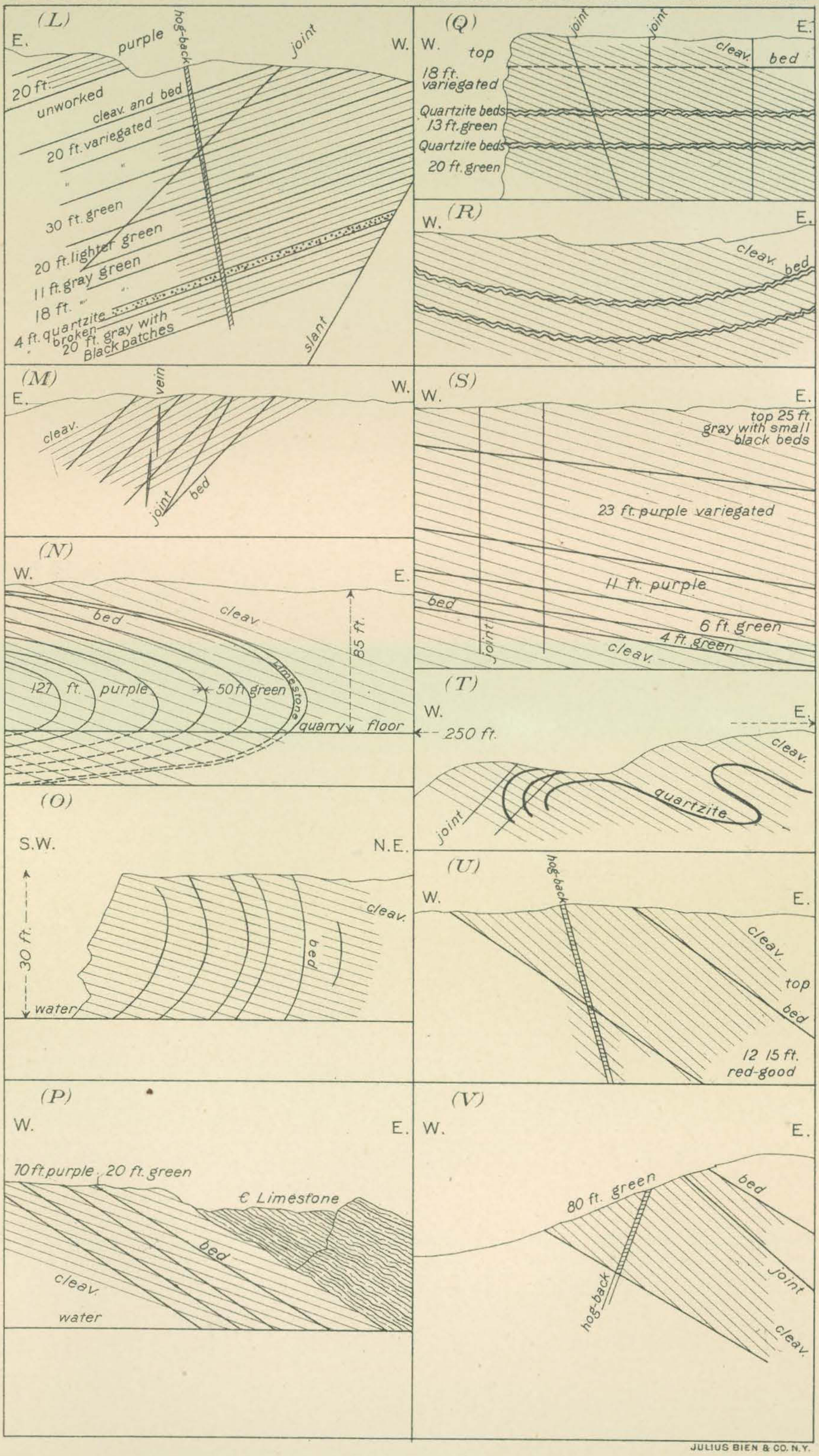
SLATE QUARRY DIAGRAMS

PLATE XXXIV.

PLATE XXXIV.

STRUCTURAL DIAGRAMS OF SLATE QUARRIES.

(*L*) Eureka slate quarries ("unfading green" and variegated), Poultney, Vermont.
(*M*) Valley Slate Company ("unfading green"), Poultney, Vermont.
(*N*) Lake Bomoseen Slate Company (mill stock, purple and green), Cedar Point, Castleton, Vermont.
(*O*) Old quarry (purple with green ribbons), near Blissville, Castleton, Vermont.
(*P*) Old quarry near and north of Eagle Quarry, purple with green ribbons, Blissville, Castleton, Vermont.
(*Q*) Meadow Slate Company's quarry (mill stock, variegated and green), Fair Haven, Vermont. Calcareous quartzite beds 4 to 12 inches thick and 18 inches apart.
(*R*) Meadow Slate Company's quarry, Fair Haven, Vermont, at north end.
(*S*) Scotch Hill Slate Quarry Company's quarry (mill stock, purple, variegated, and green), Fair Haven, Vermont. Dark beds are said to underlie the green.
(*T*) Old quarry (purple), 1 mile south of West Castleton, Vermont.
(*U*) National Red Slate Company's quarry, southwest of Jamesville, in Granville, New York.
(*V*) Williams and Edward's quarry ("sea-green"), Wells, Vermont.



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SLATE QUARRY DIAGRAMS

descriptions which follow the analyses will be found in the main correct. The examination of roofing slates is beset with difficulties. The matting of the scales, the lack of crystal outlines in most of the particles, and their extremely minute size prevent the application of many of the usual tests; but by the repeated examination of a large number of such thin sections many features which at first escape observation stand out quite clearly.

The colored lithographs made from microscopic paintings of carefully selected typical areas of thin sections of slate will serve to reenforce the descriptions, and, which is here of more importance, will illustrate for economic purposes the differences of texture and composition which underlie differences in quality and color. (See Pls. XXXV to XXXIX.) Five representations of each slate are given.

(1) A section, magnified 155 diameters, across the cleavage, seen in ordinary light to show the character of the cleavage.

(2) The same area under polarized light, with the same enlargement, but set with the cleavage lines parallel to the plane of polarization of the polarizer in order to bring out the minerals.

(3) The same, but with the cleavage lines set at 45° to that plane to bring out different minerals.

(4) A section parallel to the cleavage, magnified 155 diameters under polarized light, to bring out different sections of the minerals.

(5) A section parallel to the cleavage, magnified 530 diameters in ordinary light, to bring out the slate needles.

Each of the principal commercial varieties of roofing slate from this region will now be described, its chemical analysis being first given, then its microscopic analysis.

The specific-gravity determinations were made at the Thompson Physical Laboratory of Williams College, by the "bucket method." In each case all air was first removed by boiling in distilled water. The determinations show the true density of the rock at 16° C. compared with water at 4° C.

THE "SEA-GREEN" ROOFING SLATE.[1]

CHEMICAL ANALYSES.

Constituents.	Specimens.[1]			
	A.	B.	C.	D.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2 (silica)	67.76	62.37	59.84	65.29
TiO_2 (rutile; titanium dioxide)	.71	.74	.74	....
Al_2O_3 (alumina)	14.12	15.43	15.02	....
Fe_2O_3 (ferric oxide)	.81	1.34	1.23	....
FeO (ferrous oxide)	4.71	5.34	4.73	....
MnO (manganese oxide)	.10	.22	.34	....
NiO, CoO, (nickelous and cobaltous oxide)	Trace ?	Trace.	Trace.	....
CaO (lime)	.63	.77	2.20	....
BaO (baryta)	.04	.07	.09	....
MgO (magnesia)	2.38	3.14	3.41	....
K_2O (potassa)	3.52	4.20	4.48	....
Na_2O (soda)	1.39	1.14	1.12	....
Li_2O (lithia)	Strong trace.	Trace.	Strong trace.	....
H_2O (water below 110° C.)	.23	.34	.41	....
H_2O (water above 110° C.)	2.98	3.71	3.44	....
P_2O_5 (phosphoric oxide)	.07	.06	.09	....
CO_2 (carbon dioxide)	.40	.87	2.98	....
FeS_2 (pyrite)	.22	.06	.05	....
SO_3 (sulphuric oxide)	Trace.	Trace.	Trace.	....
C (carbon)	None.	Strong trace.	Trace.	....
Fl (fluorine)	....	....	.11	....
Total	100.07	99.80	100.28	....
S (total sulphur above)	.12	.032	.024	....

A (=D. XIV, 1895, 230 a), Rising & Nelson's quarry No. 2, West Pawlet, Vermont; 13-foot bed. B (= D. XIV, 1895, 225 f), Griffith & Nathaniel's quarry, 9 miles north of A, South Poultney, Vermont. C (=D. XIV, 1895, 256 e), Wm. H. Hughes's quarry No. 10 (Brownell), 2 miles north of A, Pawlet, Vermont. D (=D. XIV, 1895, 35, l), Auld & Conger's quarry, 8 miles north of A, in Wells, Vermont; 22-foot bed. Determination of silica only. These are all from the West Pawlet and South Poultney belt.

Specific gravity: C, 2.7910; D, 2.7627.

[1] Lower Cambrian, Horizon B, Olenellus zone.

PLATE XXXV.

PLATE XXXV.

THIN SECTIONS OF "SEA GREEN" SLATE.

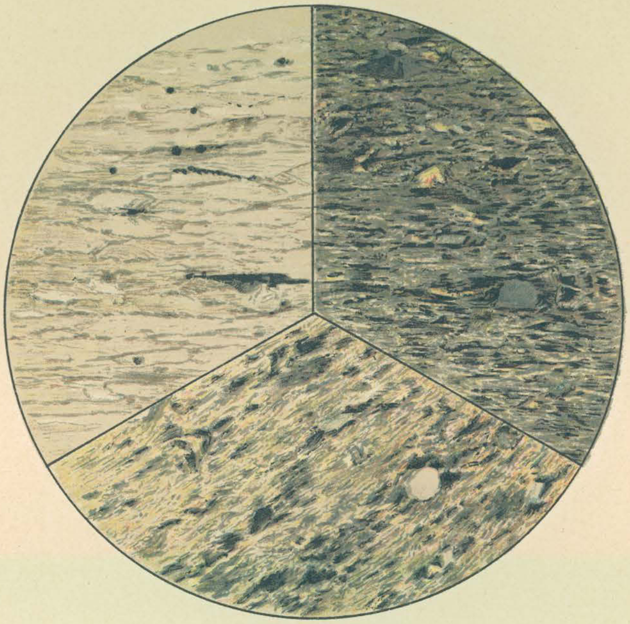
A (left part). Thin section of "sea green" roofing slate from West Pawlet, Vermont, cut at right angles to the cleavage, enlarged 155 diameters in ordinary light, showing the quality of the cleavage. The opaque spherules and streaks are pyrite.

A (right part). Same as above, but under polarized light. The bluish-gray areas are quartz fragments, the bright yellow are muscovite scales, the larger, light particles are carbonate.

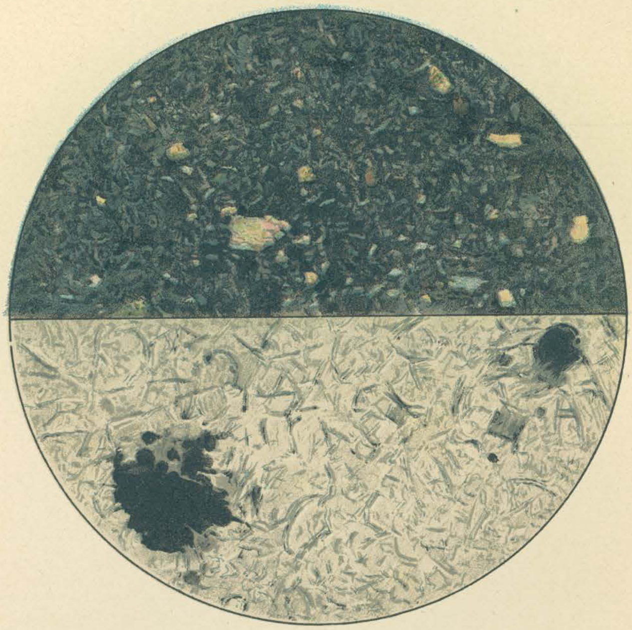
A (lower part). Same as above, but turned 45°, showing the matrix of muscovite polarizing together; also quartz fragments.

B (upper half). Thin section of "sea green" roofing slate from South Poultney, Vermont, cut parallel to the cleavage, enlarged 155 diameters in polarized light, showing bright-colored rhombs and irregular plates of carbonate, fragments of quartz (bluish gray), slender scales of muscovite in a dark matrix mainly of micaceous material.

B (lower half). Same as above, but enlarged 530 diameters in ordinary light, showing the "slate needles" (rutile crystals), opaque masses of pyrite, and a rhomb of carbonate.



(A.)



(B.)

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THIN SECTIONS OF "SEA GREEN" SLATE.

PLATE XXXVI.

PLATE XXXVI.

THIN SECTIONS OF "UNFADING GREEN" SLATE.

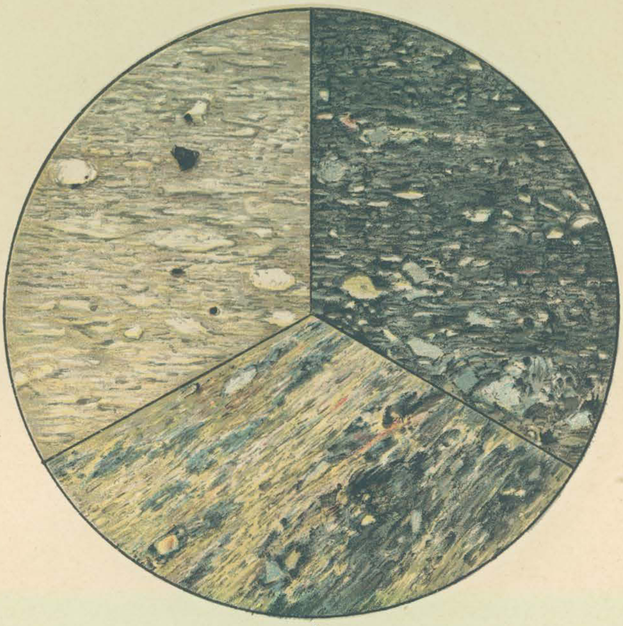
A (left part). Thin section of "unfading green" roofing slate from Poultney, Vermont, cut at right angles to the cleavage, enlarged 155 diameters in ordinary light, showing the character of the cleavage, transparent quartz grains, etc., and opaque grains.

A (right part). Same as above, but not of same area and under polarized light, showing the quartz grains (bluish gray) and one carbonate plate near center of circle and numerous scales of muscovite (yellow).

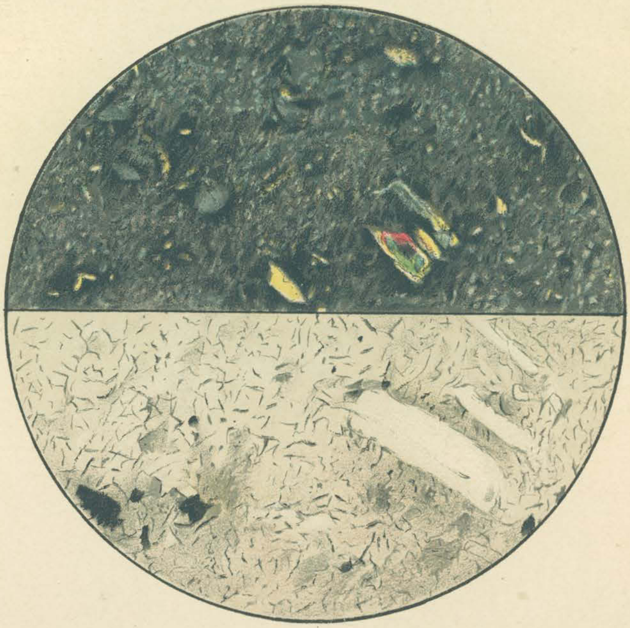
A (lower part). Same as above, but still another part of same slide with cleavage turned 45° to plane of polarization of polarizer, showing the muscovite of the matrix, grains of quartz, and muscovite scales. The usual somewhat irregular character of the cleavage is better shown in the right and lower parts.

B (upper part). Thin section of "unfading green" roofing slate from Poultney, Vermont, cut parallel to the cleavage, enlarged 155 diameters in polarized light, showing quartz grains (gray) and muscovite scales (bright colored) in a dark matrix mainly of micaceous material.

B (lower part). Same as above, but enlarged 530 diameters in ordinary light, showing the "slate needles" (rutile crystals) and opaque pyrite? and transparent muscovite plates.



(A.)



(B.)

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THIN SECTIONS OF "UNFADING GREEN" SLATE.

PLATE XXXVII.

PLATE XXXVII.

THIN SECTIONS OF PURPLE SLATE.

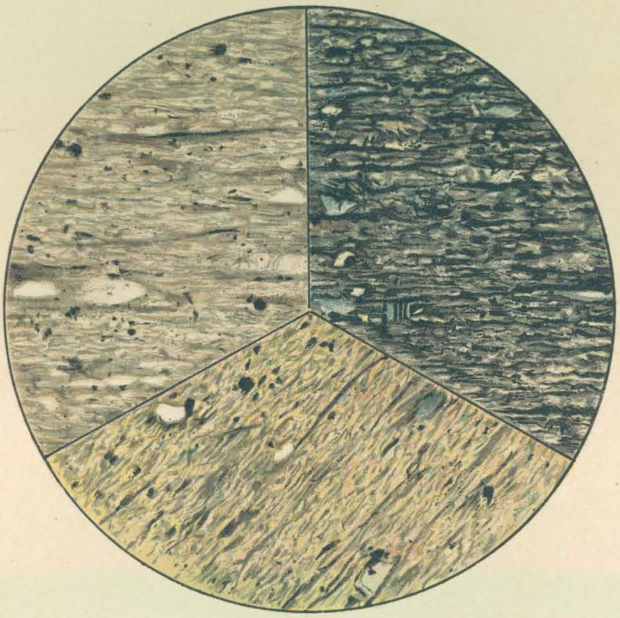
A (left part). Thin section of purple roofing slate from South Poultney, Vermont, cut at right angles to the cleavage, enlarged 155 diameters, in ordinary light, showing the character of the cleavage. The transparent gains are quartz and feldspar. The black dots are pyrite and hematite.

A (right part). Same as above but under polarized light, showing the quartz grains (gray), plagioclase feldspar (banded gray and black). The light-yellowish particles are muscovite scales and carbonate plates.

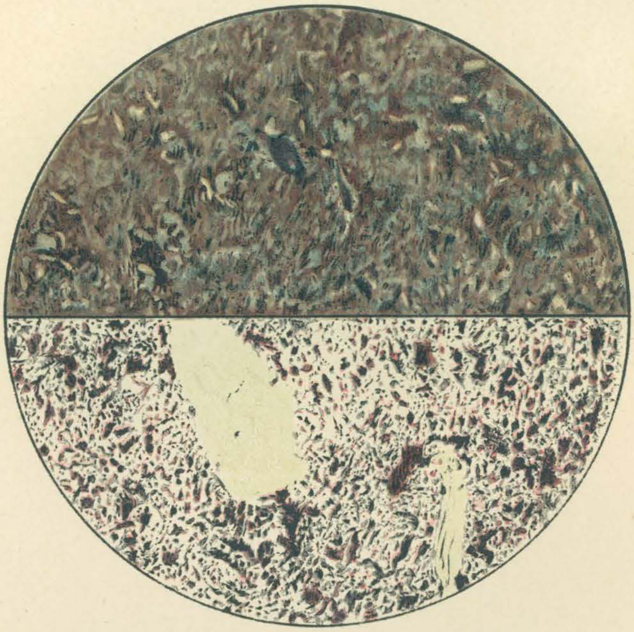
A (lower part). Same as above, but turned 45°, showing the brilliant muscovite matrix polarizing together, the quartz grains (white and gray), the pyrite and hematite dots.

B (upper part). Thin section of purple roofing slate from Pawlet, Vermont, cut parallel to the cleavage, enlarged 155 diameters in polarized light, showing quartz fragments (gray), a chlorite scale (plum color) near center, muscovite scales (yellow).

B (lower part). Same as above, but enlarged 530 diameters, in ordinary light, showing the hematite dots (dark and light red) and large chlorite scales.



(A.)



(B.)

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THIN SECTIONS OF "PURPLE" SLATE.

PLATE XXXVIII.

PLATE XXXVIII.

THIN SECTIONS OF RED AND BLACK SLATE.

A (left part). Thin section of red roofing slate from Washington County, New York, cut at right angles to the cleavage, enlarged 155 diameters in ordinary light, showing the quality of the cleavage. The large white fragments are quartz, the black dot is pyrite.

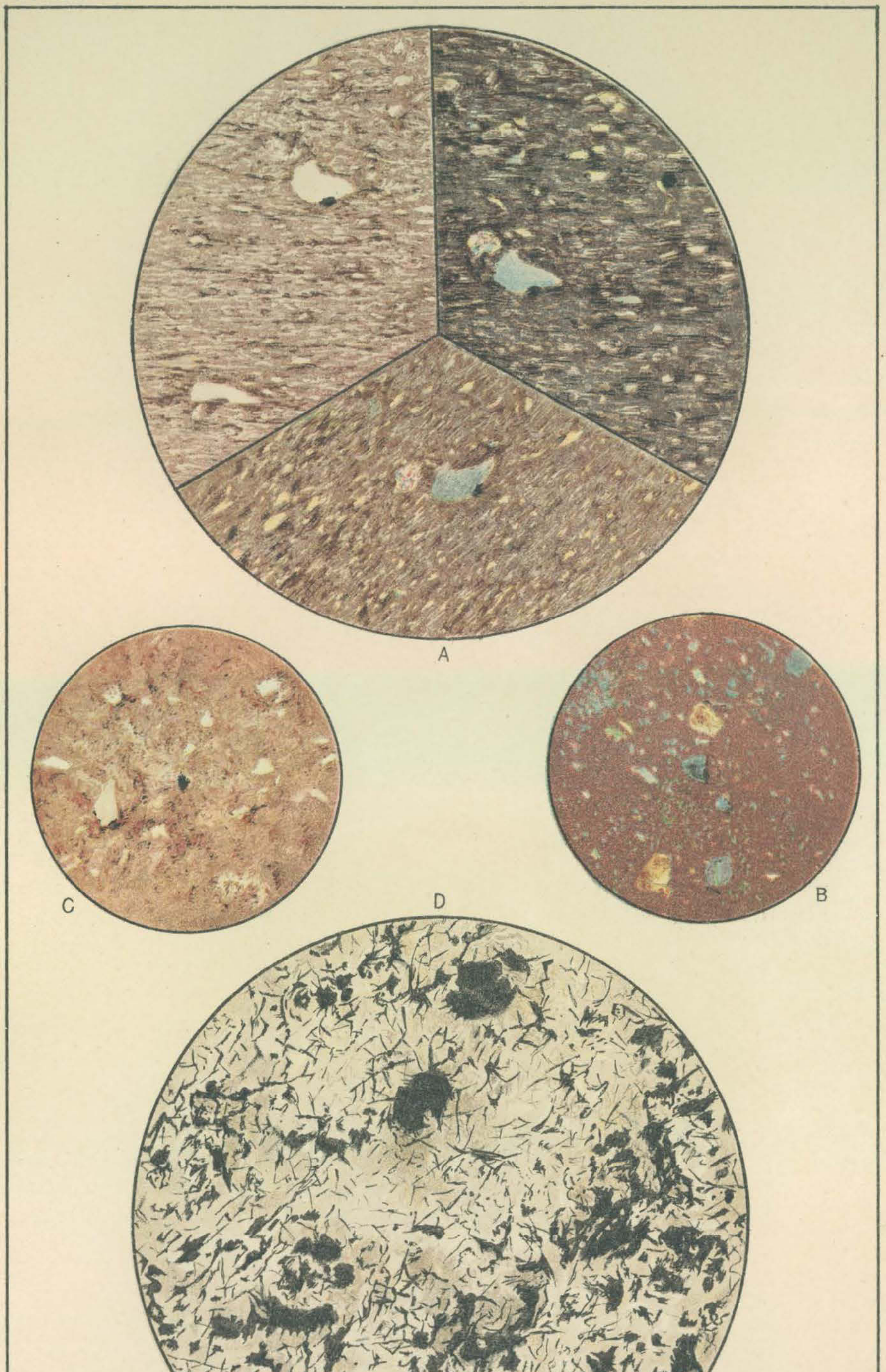
A (right part). Same as above, but in polarized light. The bluish-gray fragments are quartz, the pale-cream carbonate, a brilliant scale is muscovite, the matrix hematite, the black dots pyrite.

A (lower part). Same as above, but turned 45°. Some of the muscovite shows more clearly.

B. Thin section of red roofing slate from Washington County, New York, cut parallel to the cleavage and enlarged 155 diameters in polarized light. The dark and light purplish spots are quartz fragments; the purplish particle with green streak is chlorite and muscovite; the large yellowish spots are carbonate plates; the slender pale yellow are muscovite; the red matrix is hematite.

C. Thin section of red roofing slate from Washington County, New York, cut parallel to the cleavage, enlarged 155 diameters in ordinary light. The light areas are mostly quartz and carbonate, rarely chlorite, with some very minute muscovite scales. The matrix is hematite.

D. Thin section of black roofing slate from Hoosic, Rensselær County, New York, cut parallel to the cleavage, enlarged 530 diameters in ordinary light, showing the slate "needles" (rutile crystals), carbonaceous particles, and spherules or crystals of pyrite.



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THIN SECTIONS OF RED AND BLACK SLATE.

PLATE XXXIX.

PLATE XXXIX.

THIN SECTIONS OF BLACK SLATE.

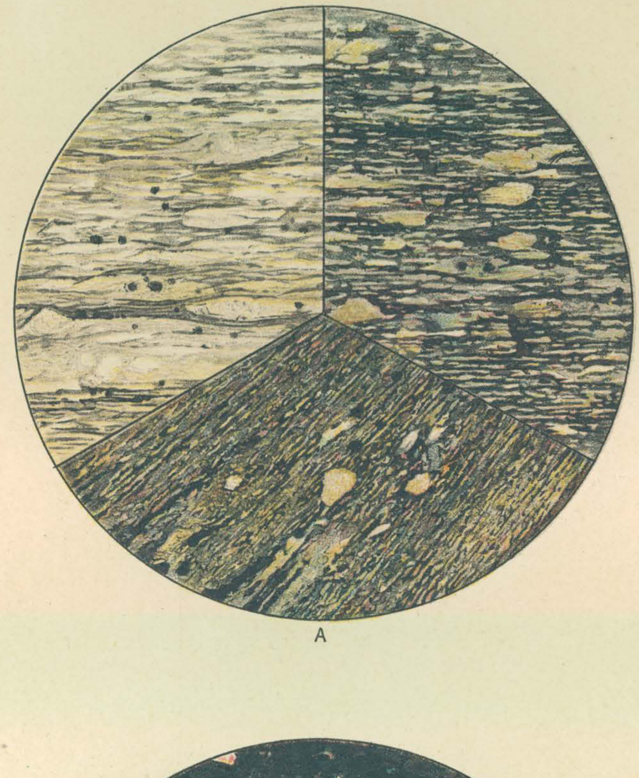
A (left part). Thin section of black roofing slate from Benson, Rutland County, Vermont, cut at right angles to the cleavage, enlarged 155 diameters in ordinary light, and showing the character of the cleavage and the spherules of pyrite. The light areas are quartz and carbonate.

A (right part). Same as above, but under polarized light. The cream-colored areas are carbonate, light gray quartz; the brown dots pyrite.

A (lower part). Same as above, but turned 45°, showing the matrix of muscovite and also some of the carbonate and quartz and pyrite.

B (upper part). Thin section of black roofing slate from Benson, Rutland County, Vermont, cut parallel to the cleavage, enlarged 155 diameters in polarized light, showing quartz grains (purplish gray) and carbonate (cream color) in a dark matrix of micaceous and carbonaceous material.

B (lower part). Same as above, but enlarged 530 diameters in ordinary light, showing opaque spherules (pyrite) and smaller carbonaceous particles in a transparent micaceous matrix.



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THIN SECTIONS OF BLACK SLATE.

MICROSCOPIC ANALYSIS.

The so-called "sea green" slate, when freshly quarried, varies from a light gray to a slightly greenish gray. In some beds it is crossed by ribbons (beds) of a dark gray. The fresh cleavage surface has a more or less waxy luster. After a few years of exposure to the atmosphere the color assumes more or less of a yellowish-brown tinge. Cold dilute hydrochloric acid applied to the edge produces a slight effervescence. Pl. XXXV, figs. A, B, represent thin sections of this slate. Fig. A represents the same slate as Analysis A.

Sections transverse to the cleavage show, in ordinary light, a very fine and regular cleavage, sometimes crossed by obscure traces of bedding, angular transparent grains, green (dichroic) scales, minute opaque spherules covered with crystal points, and from 0.003 to 0.02 mm. in diameter, which, under incident light, glisten like pyrite, some irregular opaque grains, dull yellowish under incident light, and of doubtful character, and, finally, a few lenses of transparent mineral grains. In some transverse sections a few "slate needles" (rutile, TiO_2) are visible.

The most noticeable feature of transverse sections under polarized light is that in rotation they become, so far as the matrix is concerned, alternately dark and light, behaving like a single mineral. The slate consists mainly of brilliant interlacing but more or less parallel fiber-like scales of mica (muscovite-sericite), which produce the effect of a mass of gold embroidery. These fiber-like scales of mica surround and inclose more or less angular grains of quartz, with their longer axes parallel to the cleavage. Such grains measure from 0.052 to 0.347 mm. in length by 0.0043 to 0.035 mm. in width. Their usual dimensions are 0.035 by 0.013 mm. Perhaps less abundant than the quartz, although this proportion varies greatly, are carbonate rhombs and plates.

Scales of a chlorite like that already referred to in the Olive grit (Horizon A) occur interleaved with muscovite or talc. The scales under polarized light vary from a prussian or plum blue to a violet or olive, while the delicate bands polarize in brilliant hues. The entire scales measure up to 0.130 mm. In sections made at right angles to the grain and transverse to the cleavage these scales frequently lie at a very high angle or a right angle to the cleavage. The mineral called "a chlorite" in these descriptive notes has the following characteristics: Under incident light the scales are dark and stand out distinctly from the matrix, as do also any large scales of muscovite. In ordinary light the scales are dichroic (pale green and slightly greenish yellow), and frequently have delicate white bands parallel to their cleavage. Under polarized light such scales become bright lavender (violet) or a prussian blue or an olive, and extinguish parallel to the cleavage, while the white bands polarize in the brilliant colors characteristic of talc and muscovite. These scales occur both in the slate and the Olive grits. Other green dichroic scales, however, cut parallel to their cleavage are under polarized light almost isotropic. Still other pale-green scales, not perceptibly dichroic, remain dark or banded with prussian blue throughout one revolution. A coating of an undoubted chlorite from a slickensided surface in purple slate in Castleton, when scraped off and examined under the microscope, showed the dichroism distinctly, and under polarized light remained green in a complete revolution. It gelatinized in boiling sulphuric acid. Attempts to dissolve the "chlorite" scales of the thin sections of slates in hot sulphuric acid were not successful, possibly owing to wrong manipulation. The double refraction of the bands of muscovite was, however, more conspicuous after than before the application of the acid. The usual appearance of the mineral in the slate sections is the first described above. The sections are transverse to the foliation of the mineral, and the differences in colors may then be due to differences in the thickness of the sections or to a slight obliquity of the scale within the slate.

There are also muscovite scales, often bent, possibly fragmental like the quartz, occasional fragments of feldspar (lime-soda-feldspar) up to 0.043 by 0.052 mm. and, more rarely, small fragments of zircon. Apatite was not detected, although, judging from the analyses, it may occur. The lenses of transparent grains prove under polarized light to consist of cryptocrystalline quartz.

Sections parallel to the cleavage in ordinary light show a pale brownish indefinite groundmass with irregular transparent fragments and rhombs. Some of the rhombs have a colorless, some a black, nucleus, which does not seem to be pyrite. Pyrite occurs as before. Under higher powers vast numbers of needle-like crystals, "slate needles" (rutile), appear (see Pl. XXXV, fig. B, lower half). These needles measure from 0.0017 to 0.009 mm. in length, rarely attaining 0.012, and 0.0024 mm. in diameter. They average from about 1000 to 1850 per square millimeter of the sections, which amounts to from about 645,000 to about 1,200,000 to the square inch. These sections, under polarized light, do not polarize as one mineral (see Pl. XXXV, fig. B, upper half), but bring out on a dark groundmass[1] the quartz fragments, plagioclase fragments, and the carbonate plates and rhombs. These rhombs measure from 0.003 to 0.015 and even to 0.052 mm. in diameter. They sometimes consist of two crystals, an inner rhomb and an outer one, but having a different orientation, possibly in twinned position. In some cases the central rhomb has fallen out, leaving a black center under crossed nicols. Here and there a muscovite scale appears and under high power the orange-yellow rutile needles. The conspicuous features in parallel sections under polarized light are the brilliantly double refracting carbonate rhombs and the quartz grains.

[1] Some European writers insist on the presence of an isotropic mineral in roofing slates. See on this subject, p. 283.

THE DISCOLORATION OF THE SEA-GREEN SLATES.

As is well known, the sea-green slates pass, on a few years' exposure, from a greenish gray to a brownish gray. In exceptionally bad beds the change is from a pale bluish (chloritic) green to a dark yellowish brown, producing a marked contrast when fresh and weathered pieces are placed side by side. In those slates in which discoloration is pronounced, the fresh slate surface effervesces somewhat rapidly with cold dilute hydrochloric acid, as they all do slightly on the edges. In order to ascertain the cause of the discoloration a thin section was made across the discolored surface of a slate which had been exposed for three years. The section showed that while the rhombs of carbonate within the body of the slate were transparent in ordinary light, those at the edges were changed to the color of burnt sienna, i. e., to the characteristic limonitic staining. These particular rhombs measured 0.047 millimeter in diameter. Dr. Hillebrand succeeded in showing this still better. A cleavage surface, discolored by a three-years' exposure, was affixed to the glass slide and the other side was ground down the requisite amount. This section showed a multitude of rhombs—from 0.004 to 0.030 mm., but generally from 0.008 to 0.013 mm. in diameter—entirely or partially altered to limonite. In some cases there was a yellowish-brown zone of alteration surrounding an unaltered nucleus. By applying dilute hydrochloric acid to a section (parallel to cleavage) of the undiscolored slate placed under polarized light the brilliant rhombs are dissolved more or less rapidly and the dark matrix with a few mica scales alone remains. Dr. Hillebrand regards the rhombs as an isomorphous mixture of dolomite and siderite, i. e., a carbonate of lime, magnesia, and iron, in which the iron oxidizes into limonite. His chief reason for supposing them to be dolomite rather than calcite is their behavior toward cold acids, which, together with other reasons, are detailed in his remarks appended to this paper. Calcite, however, is abundant both in the veins and in the beds of quartzite in the slate. Bischof attributed the discoloration of certain German slates to the formation of limonite from a protoxide, and endeavored to restore their original color by immersing them in dilute hydrochloric acid, but he found that although this proved effective, new discoloration took place within a short time.[1]

"HARD" AND "SOFT" SEA-GREEN SLATES.

The microscopic and chemical tests to determine the cause of this difference were inconclusive. It seems probable, however, that the "soft" slates are due to a greater percentage of carbonate and the hard ones to the large size of the quartz grains rather than to the greater percentage of silica.

[1] Lehrbuch der chemischen und physicalischen Geologie, Vol. II, pp. 350-351, footnote. The only way to prevent the discoloration would be to coat the slates with something which would protect them from oxidation.

THE "UNFADING GREEN" ROOFING SLATE.[1]

CHEMICAL ANALYSES.

The following analyses were made in the laboratory of the United States Geological Survey by Dr. W. F. Hillebrand:

Chemical analyses of green roofing slates.

Constituents.	Specimens. *a* E.	Specimens. *a* F.
	Per cent.	*Per cent.*
SiO_2 (silica)	59.27	59.48
TiO_2 (titanium dioxide, rutile)	.99	1.02
ZrO_2 (zirconia)	....	Trace?
Al_2O_3 (alumina)	18.81	18.22
Fe_2O_3 (ferric oxide)	1.12	1.24
FeO (ferrous oxide)	6.58	6.81
MnO (manganous oxide)	.13	.07
NiO (nickelous oxide)	Trace?	Trace.
CoO (cobaltous oxide)	Trace?	....
SrO (strontia)	....	Trace?
CaO (lime)	.42	.56
BaO (baryta)	.05	.05
MgO (magnesia)	2.21	2.50
K_2O (potassa)	3.75	3.81
Na_2O (soda)	1.88	1.55
Li_2O (lithia)	Trace.	Trace.
H_2O (water below 110° C)	.32	.17
H_2O (water above 110° C)	3.98	4.05
P_2O_5 (phosphoric oxide)	.11	.10
CO_2 (carbon dioxide)	.21	.39
FeS_2 (pyrite)	.15	.13
SO_3 (sulphuric oxide)	Trace.	....
C (carbon)	None.	None.
Fl (fluorine)	....	.08
Total	99.98	100.23
S (total sulphur included above)	.08	.07
Specific gravity of E	2.795	....

a E(=D. XIV, '95, 314 F), Eureka quarries, 3¼ miles north of Poultney, in Poultney Township, Vermont. F(=D. XV, '96, 645 a), Valley Slate Company quarry, 2½ miles north of Poultney, in Poultney Township, Vermont.

MICROSCOPIC ANALYSIS.[2]

The "unfading green" slate is a pale greenish gray with less luster on the cleavage surface than the sea green. Several years' exposure

[1] Lower Cambrian, Horizon ℞, in table, p. 278; Olenellus zone. [2] See Pl. XXXVI, figs. A, B.

produces little or no change in color.[1] Cold dilute hydrochloric acid does not produce any effervescense when applied to the hand specimen. Sections across the cleavage in ordinary light show considerable inequality in texture, coarser and finer bands alternating with one another, the coarser with imperfect cleavage. Even where the cleavage is more regular there is still much irregularity in the size of the particles. There are not a few grains and lenses of pyrite, some irregular opaque grains, dull yellowish in incident light and of doubtful character, green dichroic scales up to 0.039 by 0.006 mm., which, in sections transverse to "the grain," lie edgewise across the cleavage, and finally, slate needles (rutile) from 0.003 to 0.008 mm. in length, and some granular lenses.

Similar sections under polarized light show a matrix of fibrous muscovite (sericite), polarizing as one mineral and inclosing angular quartz grains from 0.013 to 0.043 by 0.004 to 0.017 mm., rarely 0.07 by 0.017 mm., with inclusions; also rarely grains of plagioclase. There is much less carbonate than in the "sea green" slate, some brilliant scales of muscovite. In sections transverse to the grain many of the more minute scales of muscovite lie at right angles to the cleavage. Finally, some lenses of cryptocrystalline quartz.

Sections parallel to the cleavage, under ordinary light, show the usual brownish matrix and abundance of slate needles measuring from 0.003 to 0.009 by 0.0003 to 0.0005 mm, some specks of pyrite 0.0043 by 0.022 mm, and large pyrite octahedra surrounded by a rim of chlorite scales, rarely a transparent scale (muscovite).

Under polarized light the parallel sections show the same carbonate rhombs, but in very much smaller number than in the fading "sea-green" slates, size 0.026 to 0.065 mm, quartz grains 0.008 to 0.043 mm, and muscovite straps from 0.015 to 0.060 mm in length.

The reason these slates are "unfading" is manifestly because they have fewer rhombs of carbonate of iron and lime and magnesia. The sections also show why they cleave less perfectly than the "sea-green" slates (compare Pl. XXXVI, A, with Pl. XXXV, A).

SLATE-PENCIL SLATE.

In the unfading green slate portion of the belt, about 1¼ miles north of Bomoseen and a little east of the lake, is an abandoned quarry where certain greenish slates were obtained and made into slate pencils. In Europe slate pencils have long been made by utilizing a secondary cleavage, which breaks the rock up into squarish sticks which are easily rounded. Here, however, the method was to take tile-shaped blocks of slate and carve out first on one side, then on the other, by means of set gauges, a whole series of hemicylindrical pencils which readily broke apart into roundish pencils. A microscopic section of this rock shows essentially the same composition as the unfading green slates, excepting that sections parallel to the cleavage show no carbon-

[1] In repairing roofs covered with this slate the fresh slate makes a slight contrast with the old.

ate whatever, but a greater abundance and larger scales of muscovite (probably clastic), some limonite(?) specks, and a cleavage perhaps not quite so good as that of the Eureka quarries. The usual quartz, sericite, chlorite, rutile needles, and lenses are present.

THE PURPLE AND VARIEGATED ROOFING SLATES.[1]

CHEMICAL ANALYSES.

The following analyses were made by Dr. W. F. Hillebrand in the laboratory of the United States Geological Survey:

Analyses of purple and variegated roofing slates.

Constituents.	Specimens. *a*			
	G.	H.	I.	H[2].
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2 (silica)	61.63	60.96	60.24	....
TiO_2 (titanium dioxide)	.68	.86	.92	....
ZrO_2 (zirconia)	....	Trace?	Trace?	....
Al_2O_3 (alumina)	16.33	16.15	18.46	....
Fe_2O_3 (ferric oxide)	4.10	5.16	2.56	5.28
FeO (ferrous oxide)	2.71	2.54	5.18	2.36
MnO (manganous oxide)	.09	.07	.07	....
NiO (nickelous oxide)	Trace?	Trace.	Trace.	....
CoO (cobaltous oxide)	Trace?	Trace.	Trace.	....
CaO (lime)	.50	.71	.33	....
BaO (baryta)	.06	.04	.03	....
MgO (magnesia)	2.92	3.06	2.33	....
K_2O (potassa)	5.54	5.01	4.09	....
Na_2O (soda)	1.26	1.50	1.57	....
Li_2O (lithia)	Str. tr.	Trace.	Str. tr.	....
H_2O (water below 110° C.)	.31	.17	.18	....
H_2O (water above 110° C.)	3.24	3.08	3.81	....
P_2O_5 (phosphoric oxide)	.16	.23	.11	....
CO_2 (carbon dioxide)	.41	.68	.08	....
FeS_2 (pyrite)	.04	None.	.16	....
SO_3 (sulphuric oxide)	Trace.	....	....	....
C (carbon)	None.	None.	None.	....
Total	99.98	100.22	100.12	....
S (total sulphur above)	.02	.07	.087	....
Specific gravity	2.8064$_0$	....	2.8053	....

a G (=D. XIV, '95, 260 a), purple roofing slate, McCarty quarry, east of center of Lake Saint Catherine, South Poultney, Vermont. H (=D. XV, '95, 760 a), purple roofing slate, Francis & Sons quarry nearly a mile south of Hydeville, in Castleton, Vermont. I (=D. XV, '95, 314), variegated roofing slate, from Eureka quarry, 3¼ miles north of Poultney, in Poultney Township, Vermont, "unfading green" area. H[2] (=D. XIV, '95, 614 a), dark reddish bed a few inches thick in purple of sea-green area, west of Lake Saint Catherine; determination of iron oxides only.

[1] Lower Cambrian, Horizon B, Olenellus zone.

MICROSCOPIC ANALYSIS.

The "purple" slate is a dark purplish brown. The "variegated" is like the "sea green" or "unfading green," but is irregularly patched with purplish brown. (See Pl. XXXVII, figs. A, B, for the purple.) The discoloration of the purple is less marked than that of the "sea-green." It effervesces more or less with cold dilute hydrochloric acid.

Sections of the purple across the cleavage seen in ordinary light show a cleavage corresponding in fineness to that of the "sea green." Numerous very minute reddish specks of hematite (Fe_2O_3) and exceptionally a hexagonal scale of the same are conspicuous. Under polarized light such sections are seen to consist of a matrix of fibrous muscovite polarizing as one mineral, with the usual quartz fragments, carbonate rhombs, chlorite scales, muscovite straps, and rarely a fragment of plagioclase feldspar and of zircon.

Sections parallel to the cleavage under ordinary light show rutile needles (TiO_2) and very minute and irregularly shaped red dots of hematite. Under polarized light the quartz fragments, carbonate rhombs, chlorite scales, and muscovite straps are brought out. The chief microscopic difference between the purple and the "sea green" seems to be the presence in the purple of the additional mineral, hematite, and the scarcity of pyrite, and the somewhat smaller number of carbonate rhombs.

The variegated slate from the Eureka quarries does not effervesce with cold dilute hydrochloric acid applied to the edges, and in the irregularity of its cleavage resembles the "unfading green" from the same quarry. Even transverse sections show the irregular distribution of the hematite dots which produce the mottled appearance. There are also specks of pyrite and large flakes of chlorite throughout.

Under polarized light quartz appears up to 0.047 and even 0.071 mm. There are lenses of quartz a millimeter long, and muscovite and chlorite scales without definite arrangement, about which the sericite matrix bends. Many muscovite and chlorite scales in other parts of the slide lie at an angle to the cleavage. A few slender prisms of tourmaline appear.

Sections parallel to the cleavage also show the irregular distribution of the hematite dots, which measure from 0.001 to 0.0035 mm. in diameter, and the usual rutile needles. There are also spherules of pyrite from 0.007 to 0.027 mm. in diameter. The same sections under polarized light bring out the quartz, the carbonate rhombs, and the chlorite and muscovite scales.

THE RED ROOFING SLATE.[1]

CHEMICAL ANALYSES.

The following analyses were made in the chemical laboratory of the United States Geological Survey, the complete analyses by Dr. W. F. Hillebrand, the partial ones by Mr. George Steiger:

Constituents.	Specimens. *a*					
	J.	K.	L.	M.	K^2.	N.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2 (silica)	67.61	67.55	56.49	63.88		
TiO_2 (titanium dioxide)	.56	.58	.48	.47		
Al_2O_3 (alumina)	13.20	12.59	11.59	9.77		
Fe_2O_3 (ferric oxide)	5.36	5.61	3.48	3.86	7.10	1.02
FeO (ferrous oxide)	1.20	1.24	1.42	1.44	1.00	1.67
MnO (manganous oxide)	.10	.19	.30	.21		
NiO (nickelous oxide)	Trace?	Trace.	Trace.	Trace.		
CoO (cobaltous oxide)	Trace?	Trace.	Trace.	Trace.		
CaO (lime)	.11	.26	5.11	3.53		
BaO (baryta)	.04	.31	.06	.05		
MgO (magnesia)	3.20	3.27	6.43	5.37		
K_2O (potassa)	4.45	4.13	3.77	3.45		
Na_2O (soda)	.67	.61	.52	.20		
Li_2O (lithia)	Trace.	Trace.	Str. tr.	Str. tr.		
H_2O (water below 110° C)	.45	.40	.37	.27		
H_2O (water above 110° C)	2.97	3.03	2.82	2.48		
P_2O_5 (phosphoric oxide)	.05	.10	.09	.08		
CO_2 (carbon dioxide)	None.	.11	7.42	5.08		
FeS_2 (pyrite)	.03	.04	.03	Trace.		
SO_3 (sulphuric oxide)	Trace.	Trace.	Trace.			
C (carbon)	None.	None.	None.	None.		
Total	100.00	100.02	100.38	100.14		
S (total sulphur)	.016	.02	.016			
Specific gravity			2.7839		2.8085	

a J (= D. XIV, '95, 358 d), red slate, H. H. Matthews's quarry, 1 mile west of Poultney, in Hampton, Washington County, New York; K (= D. XIV, '95, 201 e), red slate, Empire Red Slate Company's quarry, 1 mile north of Granville, in Granville, Washington County, New York; L (= D. XIV, '95, 397 e), red slate, National Red Slate Company's quarry, 1 mile north-northwest of Raceville, in Granville, Washington County, New York; M (= D. XIV, '95, 397 a), red slate, same locality as L, but near a green and purple spot; K^2 (= D. XIV, '95, 201 h), red slate, same as K, but finer grained; N (= D. XIV, '95, 284 a), purple bed in red slate at Fair Haven Red Slate Company's quarry (not worked) 2 miles north of Truthville, in East Whitehall, Washington County, New York. For presence of chromium and vanadium in these see Dr. Hillebrand's appendix, p. 304.

[1] Ordovician (Lower Silurian), Horizon Irs (Hudson red and green slate.)

MICROSCOPIC ANALYSIS.[1]

The "red slate" is a decidedly reddish-brown, not so dark generally as the purple, and becomes still brighter on exposure. An outcrop of it, even at a distance, is a conspicuous object on account of its color. It is not infrequently speckled with minute protuberances or "eyes." Some of this slate effervesces with cold dilute hydrochloric acid.

Thin sections across the cleavage show in ordinary light much irregularity in the size of the transparent particles, and therefore of the cleavage. These particles measure from 0.015 to 0.06 by 0.006 to 0.03 mm. Multitudes of red dots (hematite, Fe_2O_3), from 0.01 down to much less than 0.001 mm., and a greater or lesser abundance of lenses, up to 0.032 by 0.15 mm., of fine granular material of a slightly bluish color. Under polarized light such sections polarize as one mineral, but not so brilliantly as cross sections of the Cambrian slates, either because the muscovite is in part obscured by the pigment of Fe_2O_3, or because there is less of it and this slate approaches a clay slate. The transparent grains prove to be partly quartz fragments, partly carbonate in rhombs or irregular plates up to 0.047 mm., rarely grains of plagioclase feldspar. There are also chlorite scales up to 0.075 by 0.036 mm., and, exceptionally, a fragment of zircon. The granular lenses under high power resolve themselves into a matrix which closely resembles in color and structure thin sections of the small beds of rhodochrosite (carbonate of manganese) heretofore referred to as occurring in these same slates.[2] This matrix consists, however, in part of cryptocrystalline quartz, and contains rhombs of carbonate and considerable muscovite. One of the slides has a lens one-half millimeter long, containing a rhomb partly of calcite and partly of chlorite.

Sections parallel to the cleavage in ordinary light, under an enlargement of 1100 diameters and immersion, show the hematite dots in circular or irregularly oval outlines (see fig. B, lower half, Pl. XXXVII, showing the purple slate, on which they are larger), measuring from 0.0004 to 0.009 mm. and, under polarized light, quartz grains 0.043 by 0.029 mm.; carbonate, chlorite scales, and tourmaline prisms up to 0.005 by 0.001 mm.

Associated with the red slate is generally a little purple slate, sometimes speckled, but not of commercial consequence. Under the microscope this shows the same composition as the red, excepting that there is less of the iron pigment and possibly more chlorite. Analysis N, on page 251, shows from $2\frac{1}{2}$ to over 4 per cent less Fe_2O_3 and about one-third of 1 per cent more FeO. The specks or lenses consist of cryptocrystalline quartz or rhodochrosite, and are surrounded by the meshes of sericite. Rarely a zircon fragment occurs.

[1] See Pl. XXXVIII, figs. A, B, C, the latter enlarged only 155 diameters.
[2] For analysis see p. 260.

THE BRIGHT-GREEN ROOFING SLATE.[1]

The following analysis (specimen O = D. XIV, '95, 397c), by Dr. W. F. Hillebrand, is of a bright-green speckled slate from the National Red Slate Company's quarry, 1 mile north of Raceville, in Granville, Washington County, New York.

CHEMICAL AND MICROSCOPIC ANALYSIS.

Constituents.	Specimen O.	Constituents.	Specimen O.
	Per cent.		*Per cent.*
SiO_2 (silica)	67.89	Na_2O (soda)	.77
TiO_2 (titanium dioxide)	.49	Li_2O (lithia)	Trace.
Al_2O_3 (alumina)	11.03	H_2O (water below 110° C.)	.36
Fe_2O_3 (ferric oxide)	1.47	H_2O (water above 110° C.)	3.21
FeO (ferrous oxide)	3.81	P_2O_5 (phosphoric oxide)	.10
MnO (manganous oxide)	.16	CO_2 (carbon dioxide)	1.89
NiO (nickelous oxide)	Trace?	FeS_2 (pyrite)	.04
CoO (cobaltous oxide)	Trace?	SO_3 (sulphuric oxide)	Trace.
CaO (lime)	1.43	C (carbon)	None.
BaO (baryta)	.04	Total	100.08
MgO (magnesia)	4.57	S (sulphur, total)	.022
K_2O (potassa)	2.82		

Specific gravity = 2.7171.

These are generally interbedded with the red slates and probably, in places, merge into them along the strike. The color is a light bluish green, more decidedly greenish than the Cambrian slates. The green is peculiarly bright by lamplight. The surface is also sometimes speckled. It effervesces very slightly with cold dilute hydrochloric acid. It is said not to fade readily.

Thin sections across the cleavage show a cleavage not remarkably good on account of the large size of the particles, and more inferior when the slate is speckled. The speckling is due to lenses of granular material which measure up 0.375 by 0.128 mm. There are some grains of pyrite. Under polarized light such sections show the usual polarization of the matrix as one mineral more brightly than the red slates do, quartz grains up to 0.065 mm, chlorite scales up to 0.043 mm, carbonate up to 0.056. The lenses consist of cryptocrystalline quartz, with some very minute rhombs of carbonate and scales of chlorite.

Sections parallel to the cleavage under ordinary light show the lenses with more of a roundish outline, from 0.077 to 0.385 mm. in diameter, rutile needles, and dots of pyrite.

Thin sections under polarized light yield quartz fragments 0.084 by 0.056 mm., carbonate rhombs from 0.002 to 0.03 mm., chlorite scales, tourmaline prisms, zircon, actinolite?

[1] Ordovician (Lower Silurian). Horizon Irs (Hudson red and green slate).

THE BLACK ROOFING SLATES.[1]

CHEMICAL ANALYSIS.

The following analysis (specimen P = D. XIV, '95, 305d) of black slate from the American Black Slate Company's quarry, one-fourth mile east of Benson Village, Rutland County, Vermont, was also made by Dr. W. F. Hillebrand.

Constituents.	Specimens.	
	P.	(a)
	Per cent.	*Per cent.*
SiO_2 (silica)	59.70	55.880
TiO_2 (titanium dioxide, rutile)	.79	1.270
Al_2O_3 (alumina)	16.98	21.849
Fe_2O_3 (ferric oxide)	.52	....
FeO (ferrous oxide)	4.88	9.033
MnO (manganous oxide)	.16	.586
NiO (nickelous oxide)	Trace?	....
CoO (cobaltous oxide)	Trace?	Trace.
CaO (lime)	1.27	.155
BaO (baryta)	.08	....
MgO (magnesia)	3.23	1.495
K_2O (potassa)	3.77	3.640
Na_2O (soda)	1.35	.460
Li_2O (lithia)	Strong tr.	....
H_2O (water below 110° C.)	.30	3.385
H_2O (water above 110° C.)	3.82	
P_2O_5 (phosphoric oxide)	.16	....
CO_2 (carbon dioxide)	1.40	....
FeS_2 (pyrite)	1.18	.051
SO_3 (sulphuric oxide)	Trace.	.022
C (carbon)	.46	1.794
Total	100.05	99.620
S (total sulphur included above)	.63	....
Specific gravity	2.7748	....

a This analysis is inserted for comparison. It is by Andrew S. McCreath, Second Geological Survey Pennsylvania, Report of Progress, 1877, Vol. CCC, pp. 269, 270, 1880; Peach Bottom slates (black) from J. Humphreys & Co.'s quarry, one-half mile east of Delta, York County, Pennsylvania. The footing given is 99.800.

[1] Ordovician (Lower Silurian) or Lower Cambrian, Horizon G or D.

MICROSCOPIC ANALYSIS.[1]

This slate is quite black. The luster is not so bright as that of the Maine slates, but similar to that of the Pennsylvania slates. It effervesces with cold dilute hydrochloric acid.

Sections across the cleavage in ordinary light show a fairly good cleavage and abundance of minute opaque spherules, which, under incident light, glisten like pyrite. They are sometimes in rows along the cleavage. There are also slate needles and transparent grains. Under polarized light the sericite matrix polarizes as one mineral; quartz fragments and carbonate in plates and lenses appear.

Sections parallel to the cleavage under ordinary light show a cloudy grayish matrix with transparent minerals, large and small black dots and blotches, and slate needles in abundance from 0.0017 to 0.0952 mm. in length. The pyrite spherules measure from 0.0017 to 0.007 mm. Under polarized light these sections show carbonate rhombs 0.0043 to 0.035 mm., quartz grains 0.013 to 0.030 mm., and muscovite scales.

Fig. D, Pl. XXXVIII, representing a section parallel to the cleavage and bedding of an Ordovician slate (Hudson) from Hoosic, New York, is added, because it shows the slate needles of rutile (TiO_2) so well.

MICROSCOPIC ANALYSIS OF "MILL STOCK."

There remain yet to be described those slates which are designated as "mill stock." In consequence of their less perfect cleavage they are not well adapted for roofing slates, but are sawn up for a great variety of other purposes—blackboards, billiard tables, tiles, mantles, vats, tablets, etc.

They are purple or green or red. The purple is frequently paler than that of the roofing slates and spotted with green, while the green is fully as bright and sometimes brighter than that of the "unfading-green" roofing slates. The red is the Ordovician red. No chemical analyses of these were undertaken, but the following results were obtained from microscopic analyses of specimens of purple and green from the Scotch Hill quarries, 2 miles north-northeast of Fairhaven; from the Meadow quarry, one-fourth mile east of Fairhaven; from the Lake Bomoseen Slate Company's quarry, at Cedar Point, in Castleton; and from the J. Jones quarry, 2½ miles north of Castleton village. These are all of Lower Cambrian age (Horizon B).

Sections of the green across the cleavage in ordinary light show a cleavage greatly inferior to that of the "sea-green" roofing slates, and somewhat inferior to that of the Eureka "unfading green." There is an unusual abundance of large green dichroic scales (chlorite), many of which lie at right angles to the cleavage; also large transparent angular grains, some octahedra of pyrite, and rutile needles.

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[1] See Pl. XXXIX, figs. A and B.

Under polarized light such sections polarize as one mineral, owing to the matrix of sericite and the cleavage. The chlorite flakes measure up to 0.087 by 0.043 mm., and are interleaved with muscovite (or talc). The quartz fragments measure up to 0.060 by 0.036. Muscovite scales occur in various orientations.

Sections parallel to the cleavage show under ordinary light the usual abundance of rutile needles and under polarized light the quartz grains, chlorite scales, muscovite scales, and some carbonate rhombs. The large chlorite scales are conspicuous under incident light. The purple mill stock is similar to the green, with the exception of the additional dots of hematite (Fe_2O_3).

The specific gravity of purple mill stock from Cedar Point was found to be 2.83, and of green mill stock from the J. Jones quarry 2.84, both a little higher than any of the roofing slates.

THE SPOTTED SLATES.

The spots in roofing slates have long attracted attention.[1] In this region the purple slates often have green spots of circular or oval, but frequently of irregular outline. These spots sometimes occur only along lines of bedding and correspond or pass into green "ribbons." In places, however, an entire bed of purple slate several feet thick is irregularly spotted throughout. The red slates are also often spotted. The spots are frequently circular or oval and measure from a fraction of an inch to several inches in diameter and of pale-green color with or without a purple border. Some of the spots, however, have no symmetry whatever. In order, if possible, to throw some new light on this subject a few thin sections were prepared across small spots in directions parallel to and across the cleavage, and in the case of the spotted red slates chemical analyses were made by Dr. Hillebrand of the green center of the spot, of its purple rim, and of the outer red slate.

MICROSCOPIC ANALYSES.

An elliptical green spot, 1 by $\frac{3}{4}$ inch, in purple Cambrian slate from the Lake Bomoseen Slate Company's quarry, at Cedar Point, Castleton, Vermont, in a section cut parallel to cleavage, shows, in the green part, muscovite scales lying in all directions, large chlorite scales, quartz fragments, carbonate rhombs, and a few irregular spherules of pyrite. In the center is some opaque noncalcareous matter partly surrounded by an aggregation of spherules of pyrite in a cloud of rutile needles. There are also cracks filled with secondary sericite. In the surrounding

[1] Comparative view of the cleavage of crystals and slate rocks, by John Tyndall: Phil. Mag., vol. 12, July, 1856. On the disposition of iron in variegated strata, by George Maw: Quart. Jour. Geol. Soc., Vol. XXIV, p. 379; also On variegated Cambrian slates, by the same author, Pl. XIV, figs. 29, 31, 32, London, 1868. Les schistes de Fumay, by Gosselet: Ann. Soc. Géol. du Nord, Vol. X, pp. 63-86, Lille., 1884; same author, L'Ardenne, 1888, p. 35. Text-book of Geology, by Archibald Geikie, 3d ed., p. 343, (2) 1893. Lehrbuch der Petrographie, by F. Zirkel, 2d ed., Vol. III, pp. 296-297, 1894.

purple the same elements recur, but the pyrite is much more abundant, measuring up to 0.021 mm. There are also many dots of Fe_2O_3 from less than 0.003 to 0.009 mm. and rutile needles up to 0.012 in length.

An elliptical green spot, 3 inches long, with a purple rim, in Ordovician red slate from the National Red Slate Company's quarry north-northwest of Raceville (Specimen D. XIV, '95, 397a), when cut transversely to the cleavage, measures a half inch in thickness and shows a black streak 1 inch long in the center. The central streak consists of strings of minute irregular lenses of cryptocrystalline quartz and possibly carbonate of manganese (rhodochrosite) containing spherules of pyrite. The green part consists of a mass of fibers of muscovite, which polarize as one mineral, with much carbonate and many lenses, and also quartz grains. In the purple rim there is a decrease of carbonate and the hematite fragments begin to appear and become still more abundant in the surrounding red slate itself.

A green spot in Ordovician red slate (D. XIV, '95, 201c) from the Empire Red Slate Company's quarry, a mile north of Granville, cut parallel to the cleavage, shows slate needles (TiO_2) up to 0.043 mm. long, carbonate rhombs up to 0.030 mm., chlorite scales up to 0.030 mm., angular quartz grains up to 0.039 mm., and prisms of tourmaline up to 0.021 by 0.002 mm. The surrounding red slate, that of Analysis K, p. 250, has been described in the general description on p. 251.

Another spot, almost circular, 0.44 inch in diameter, from a piece of red slate (D. XIV, '95, 201 l) from the same quarry, cut parallel to the cleavage, shows a central dot 0.03 inch in diameter, consisting mainly of carbonate and of a dense brown material. About this is a zone about 0.1 inch wide, of elliptical shape, of carbonate, with some fibrous quartz along the margin. Then comes a zone 0.08 inch wide, of green slaty material, containing angular quartz grains, muscovite scales, rutile needles, nodules of pyrite, and thinly disseminated areas and rhombs of carbonate; then a very narrow zone made up entirely of carbonate and pyrite. Outside of this, another green slate zone 0.08 inch wide, like the first, but with very little carbonate. The angular quartz grains measure up to 0.030 mm. There are also slender tourmaline prisms. Outside of all comes the red slate, full of Fe_2O_3 pigment. Chlorite was not detected in the green zones, but it may be present in minute scales.

CHEMICAL ANALYSES OF SPOTS IN RED SLATE.

The specimen (Q, R) analyzed by Dr. Hillebrand came from the same quarry as the large spot described on p. 256. It was a green spot with purple rim, in red slate. The analysis of the red slate M, on p. 250, is repeated for comparison.

Chemical analyses of spotted red slate.

Constituents.	Specimens. *a*		
	M.	Q.	R.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2 (silica)	63.88	64.59	65.44
TiO_2 (titanium dioxide, rutile)	.47	.51	.52
Al_2O_3 (alumina)	9.77	10.23	9.38
Fe_2O_3 (ferric oxide)	3.86	1.79	1.09
FeO (ferrous oxide)	1.44	1.19	1.06
MnO (manganous oxide)	.21	.26	.32
NiO (nickelous oxide)	Trace.	Trace.	Trace.
CoO (cobaltous oxide)	Trace.	Trace.	Trace.
CaO (lime)	3.53	4.07	4.53
BaO (baryta)	.05	.05	.06
MgO (magnesia)	5.37	5.12	4.92
K_2O (potassa)	3.45	3.70	3.57
Na_2O (soda)	.20	.23	.22
Li_2O (lithia)	Str. tr.	Str. tr.	Str. tr.
H_2O (water below 110° C.)	.27	.28	.25
H_2O (water above 110° C.)	2.48	2.29	2.10
P_2O_5 (phosphoric oxide)	.08	.08	.08
CO_2 (carbon dioxide)	5.08	5.84	6.55
FeS_2 (pyrite)	Trace.	Trace.	.04
Total	100.14	100.23	100.13

a M (=D. XIV, '95, 397 a), red slate, 1 mile north-northwest of Raceville, in Granville, Washington County, New York, about a spot; Q, purple rim of the spot; R, green portion of the spot.

Dr. Hillebrand adds this observation:

Calculation shows that with no CO_2 there would be only enough CaO for the P_2O_5, and, further, that the result would be no MnO. How much FeO, if any, exists as carbonate is not indicated. If, after allowing for apatite, for $MnCO_3$, and $CaCO_3$, the remainder of the CO_2 is charged to MgO, we find the proportions shown in the columns below.[1]

	M.	Q.	R.
CaO_3	6.14	7.11	7.93
$MgCO_3$ (in part Fe CO_3	4.22	4.77	5.36
$MnCO_3$	.38	.47	.57

[1] See Appendix, p. 302.

DISCUSSION OF THE SPOTS.

From Dr. Hillebrand's analyses it would appear that there is a decrease of the carbonates of lime and manganese and magnesia and of silica and rutile from the center of the spot outward and an increase of Fe_2O_3 in the same direction.

The main results of the microscopic and chemical analyses agree even as to the relative amount of pyrite. The difference in color from the green to purple to red is manifestly due to the differences in the amount of hematite. Pyrite, rutile, carbonate, and tourmaline are more abundant within the spots than without them.

The green fossil impressions in purple slate, referred to on page 200, may throw some light on the origin of these spots. In this case the effect of organic matter, whether the carbonaceous matter of the lining of an annelid boring or from a marine alga, has been to diminish the quantity of Fe_2O_3 in the slate, and possibly to increase the amount of chlorite.[1] Gosselet regards the spots as the result of the reduction of the hematite (Fe_2O_3) by decaying organisms to the ferrous oxide (FeO) and its removal as an organic salt or as a carbonate. He observes that the green spots in purple tiles wear less readily than the rest of the tile, because they contain more quartz, and this SiO_2 he attributes to infiltration.[2]

In the spots examined from the New York and Vermont slates the marked decrease of Fe_2O_3 is accompanied by a marked increase of carbonate of lime, iron, and manganese,[3] and of SiO_2, also by a slight increase, in some of the thin sections at least, of FeS_2. Carbonates are also characteristic of the spots in some European slates.[3] The increase of the carbonates may be directly connected with the production of CO_2 by decaying organisms and the consequent decrease of the Fe_2O_3. Not impossibly the organism may have had a calcareous exoskeleton which was dissolved and then redeposited as crystalline $CaCO_3$. The infiltration of SiO_2 and the formation of chalcedony may be purely secondary, and likewise the deposit of FeS_2, or there may have been some precipitation of FeS_2 about the decaying organism, as seems to have been the case in some fossils. At any rate, the rim of intermediate composition would be the zone in which chemical reaction was less effective.

In view of all these facts and indications, the spots may be safely regarded as probably produced by chemical changes in the sediments consequent upon the decay of organisms.

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[1] See Tyndall, Maw, Gosselet, Geikie and Zirkel, as indicated by titles given in footnote on p. 255.

[2] Maw (loc. cit.) had analyses made of dark greenish ribbons in the Welsh blue slates, and found that the ribbons contained 6 per cent more SiO_2, 7 per cent more Al_2O_3, $4\frac{1}{2}$ per cent more MgO (= 7 times as much), but 4 per cent less Fe_2O_3, 1 per cent less FeO, and $3\frac{1}{2}$ per cent less K_2O than the adjacent blue beds. Under the microscope the green ribbons showed more feldspar and chlorite. He attributes these differences to change in sedimentation.

[3] See Zirkel, loc. cit.

If this be the correct view, the green ribbons, which traverse both purple and red slate, would correspond to small deposits of decomposing organic material that effected similar changes in the Fe_2O_3 of the argillaceous sediments. Where a bed of quartzite forms the center of such a ribbon quartzose sedimentation must have taken place also, and possibly may have been the very condition which proved favorable to marine life.

MINERALS ASSOCIATED WITH THE SLATES.

As the minerals of visible size associated with the slates throw light on the nature and origin of the microscopic constituents of the slate itself, they will now be described.

Quartz is the most common accessory mineral. It is usually segregated in the veins already described, but occurs also as an infiltrated cement between the quartz grains in the beds of quartzité or in veins traversing the quartzite. In both of these modes it is crystallized whenever cavities admit of it.

Next in abundance is *calcite*, occurring also in veins with or without quartz, or as delicate films on joint planes, or as a sediment in the beds of quartzite. The quartzite beds sometimes contain minute rhombs which effervesce readily with hydrochloric acid and weather a limonite brown, and are therefore probably a double carbonate of iron and lime.

Squarish or oval concretions an inch by three-fourths of an inch and one-half inch thick, consisting of radiating crystalline lamellæ of *barite* with the intervening spaces filled with slate and calcite and with many minute cubes of pyrite round about, occur in the Cambrian green slates of Middle Granville. Barite also occurs with calcite in crystalline films on joint planes in both Cambrian and Ordovician slates.

Chlorite is common in quartz veins or almost alone makes up small veins, or coats slickensided joint or bedding planes.

Pyrite occurs in cubes up to one-fourth inch across or in botryoidal concretions, coated with fibrous quartz (chalcedony) or with calcite or, more rarely, chlorite. This coating of chalcedony is often confined to some of the sides, filling a space produced by motion or compression, as described by Renard. Pyrite may collect in the vicinity of calcareous and quartzose veins or beds or form dendritic crystallizations on cleavage planes or minute cubes on joint faces. That this mineral is pyrite and not marcasite is shown by its not decomposing readily after long exposure on the slate dumps.[1]

[1] See in this connection Alexis A. Julien, On the variation of decomposition in the iron pyrites; its cause, and its relation to density. Annals N. Y. Acad. Sci., Vol. III, pp. 365-403; Vol. IV, pp. 125-221 and Pls. VIII, IX; 1886, 1887.

Beds of *carbonate of manganese* (rhodochrosite) a half inch thick, with calcite and quartz, occur in the red Ordovician slates. An analysis of this (Specimen D. XIV, '95, 201d), made by Mr. George Steiger, yielded the following:

Analysis of rhodochrosite.

Constituents.	Per cent.
Al_2O_3	0.68
Fe_2O_3	0.14
FeO	1.13
MnO	32.22
NiO and CoO	0.10
CaO	3.81
MgO	2.61
CO_2	25.06
Insoluble matter, including all silica from dissolved silicates	32.75
Total	98.50

Under the microscope thin sections of this bed show, under polarized light, a fine-grained bluish-brown matrix identical in color and texture with that of the small lenses in the red slate and with some of the lenses in the green slate; also large areas of calcite and some quartz.

Rarely a little *galenite* occurs in the quartz veins of both Cambrian and Ordovician slates. It will be observed that all these minerals, excepting the last, have already been mentioned as occurring in the slates, as shown either by the chemical or microscopic analyses.

SLATES FROM OTHER REGIONS.

It is not within the scope of this report to make a comparative study of slates, either for economic or scientific purposes, but a selection from the published analyses of various slates is here given, and the results of microscopic analyses by the writer of a few sections of slate from Wales, Pennsylvania, and Maine are added, and a few comparisons drawn.

Very few complete analyses of roofing slates are given in scientific literature. Several of the rarer elements are usually omitted in the determinations. FeO and Fe_2O_3 are not distinguished, nor CaO and CO_2, so that several of the percentages are more or less misleading.

The following, however, are the most reliable and complete analyses readily accessible:

Selected analyses of slates from other regions.

Constituents.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
SiO_2 (silica)	58.30	61.57	65.63	61.43	67.56	59.35	55.880	55.06	60.68
TiO_2 (titanium dioxide)	.23	1.31	.94	.73	......	1.00	1.270	......	.59
Al_2O_3 (alumina)	21.89	19.22	20.20	19.10	12.23	13.56	21.849	22.55	21.20
Fe_2O_3 (ferric oxide)	7.05	6.63	2.72	4.81	2.87	1.10	......	1.97	5.68
FeO (ferrous oxide)	2.57	1.20	.85	3.12	6.99	4.75	9.033	5.96	.46
CaO (lime)	.39	.22	.19	.31	.27	5.20	.155	1.30	1.71
MgO (magnesia)	1.09	2.00	1.54	2.29	3.03	3.60	1.495	2.92	.88
K_2O (potassa)	2.45	3.63	3.81	3.24	1.76	1.77	3.640	3.82	3.64
Na_2O (soda)	1.18	.93	.71	.83	1.28	1.48	.460	2.17	2.09
CO_2 (carbon dioxide)	......	......	......	......	......	4.45	......	......	......
C (carbon)	......	......	......	......	3.11	......	1.794	......	.07
MnO (manganous oxide). P_2O_5 (phosphoric oxide). SO_3 (sulphuric oxide)	....	......	......	......	.10	.31	.608	......	.16
H_2O	4.61	3.25	3.17	3.52	1.00	3.41	3.385	4.35	2.88
FeS_2	......	......	......	......	......	......	.051	......	......
Total	99.76	99.96	99.76	99.38	100.20	99.98	99.620	100.10	100.04
Specific gravity	2.81	......	......	......	......	......	......	2.78	......

I. Gray roofing slate, best quality, Delabole, Camelford, Cornwall; two analyses by J. A. Phillips, London, Edinb. & Dublin Phil. Mag., 4th ser., No. 27, pp. 95-96, Feb., 1871.

II. Purple roofing slate, Fumay, Ardennes, northwest France; by A. Renard, Recherches sur la composition et la structure des phyllades ardennais; Bull. Mus. Roy. d'Hist. Nat. de Belgique, Vol. I, p. 239, 1882.

III. Green roofing slate beds from purple, Fumay, Ardennes, as above.

IV. Blue-gray roofing slate, La Richolle quarry, Rimogne, Ardennes, northwest France; by Klement, pub. by A. Renard, op. cit. supra, p. 233.

V. Roofing slate (probably black, Devonian), Westphalia; by H. von Dechen; Roth. Allgem. und Chem. Geol., II, pp. 586, 587, 1884. (107.)

VI. Roofing slate (color not given, Devonian), Frankenberg, near Goslar, in Prussia; by A. von Groddeck; Jahrb. pr. Geol. Landesanst., 1885-86; quoted in Roth. Allgemeine Chem. Geol., II, pp. 586, 587.

VII. Black roofing slates ("Peach Bottom") from J. Humphreys Co.'s quarry, half a mile east of Delta, York County, Pennsylvania; by Andrew S. McCreath, in 2d Geol. Surv. Pa., Report of Progress, 1877, Vol. CCC, pp. 269, 270, 1880. The footing given in original is 99.800. (Repeated from p. 253.)

VIII. Bluish roofing slate of Carboniferous age, Mohradorf, near Wigstadl, Austrian Silesia; by Nikolic, in Tschermaks Min. Mitth., 1871, p. 207; quoted by Roth, op. cit. supra, pp. 588-589.

IX. Blue slate, Glyn quarries, Llanberis, Wales; analysis made at Museum of Practical Geology, London, for George Maw, Geol. Mag. London, 1868, Vol. V, p. 123.

MICROSCOPIC ANALYSES OF SLATES FROM OTHER REGIONS.

Dark purple (so-called "red") roofing slate from Penrhyn, Wales.—Does not effervesce with cold dilute hydrochloric acid. A section across the cleavage in ordinary light shows an irregular orientation of particles and not a little irregularity in their size. The cleavage is inferior to that of the Vermont "mill stock" slate, although the irregularity in size of particles is no greater. Under polarized light this section does not polarize as one mineral, or polarizes very faintly so. It is a clay slate. The minerals are muscovite (sericite), quartz up to 0.037 mm., chlorite up to 0.093 mm., pyrite, hematite. A section parallel to cleavage shows muscovite scales, quartz grains up to 0.187 mm., chlorite scales from 0.1 up to 0.24 mm., hematite dots from 0.0005 to 0.017 mm., rutile needles not very plentiful. The absence of carbonate is noticeable. Many of the dots which appear black in center of section are reddish under incident light and translucent at edge of section and are therefore hematite.

Black roofing slate from Festiniog, Wales.—Does not effervesce with cold dilute hydrochloric acid. A section across the cleavage shows a much better cleavage and fewer coarse particles than the Penrhyn section. It polarizes as one mineral under polarized light, yet the orientation of the particles is not so regular as in the "sea-green" of Vermont and New York. The constituent minerals are muscovite (sericite), quartz fragments up to 0.065 mm., chlorite scales up to 0.09 mm., plagioclase feldspar up to 0.027 mm. Sections parallel to the cleavage show the entire absence of carbonate, abundance of rutile needles, and the other minerals just named.

The specific gravity of this slate tested by the same methods as the American roofing slates was found to be 2.751.

Purple (so-called "red") roofing slate from Cilgwyn Nantlle, in Wales.—Effervesces with cold dilute hydrochloric acid. The transverse section shows a cleavage about as good as that of the Festiniog slate. The parallel section shows much more and more brilliant Fe_2O_3 than that of the Penrhyn slate. The hematite dots measure from 0.0005 up to 0.01 mm. There are quartz grains, plagioclase grains, chlorite scales up to 0.047 mm., and carbonates up to 0.035 mm.

Black roofing slate ("Lehigh"), Pennsylvania.—The specimen, after being exposed for several years, had become discolored to a brownish gray on the surface. It effervesces with cold dilute hydrochloric acid applied to the unweathered edge. Sections across the cleavage show a fair cleavage. The matrix polarizes as one mineral, but not very brilliantly, owing probably to the abundance of carbonate. A piece of the weathered surface attached to a slide and the other side ground down, as was done in the case of the "sea-green" slates (p. 245), shows the surface covered with carbonate rhombs more or less completely altered to limonite, showing that the cause of the discoloration is the same as in the "sea-green" slates of eastern New York and western Vermont. Ordinary parallel sections show quartz grains up to 0.056 mm., chlorite scales up to 0.205 mm., carbonate rhombs up to 0.056 mm., spherules of pyrite from 0.002 to 0.019 mm., needles of rutile and carbonaceous particles.

Black roofing slate from quarry of the Bangor Slate Company, Easton, Pennsylvania.—This effervesces on the edges with cold dilute hydrochloric acid. The constituents, arranged in the order of their relative abundance, are: Matrix of muscovite (sericite), carbonate in rhombs from 0.009 to 0.065 mm., and also in irregular plates (these rhombs sometimes have an opaque spherule as a nucleus), then quartz fragments up to 0.075 mm., pyrite and rutile, and black specks probably carbonaceous; lastly, chlorite up to 0.075 mm.

Black roofing slate from the Brownville and Monson quarries, Piscataquis County, Maine.—This has a lustrous surface, does not discolor on exposure, does not effervesce with cold dilute hydrochloric acid. Sections at right angles to the cleavage polarize brilliantly as one mineral and show an unusual fineness in the particles, but there are a few lenses of pyrite measuring nearly 0.01 inch, and more numerous and pretty regularly disseminated black tabular crystals measuring 0.086 by 0.004 mm. with their long axes in the cleavage foliation. As a magnet applied to the powdered slate attracts these crystals, they are magnetite ($FeOFe_2O_3$), probably distorted octahedra. The quartz grains in transverse sections measure up to 0.043 by 0.013 mm. Sections parallel to the cleavage show magnetite octahedral faces up to 0.10 mm., pyrite, biotite scales up to 0.093 and even 0.12 mm. quartz grains, hemimorphic prisms of tourmaline, chlorite rarely, few, if any, rutile needles, no carbonate whatever. Some secondary fibrous quartz (chalcedony) surrounds the magnetite plates and the biotite scales.

The absence of carbonate and the consequent permanence of color, the very micaceous matrix and regular cleavage make this a very superior slate. It is a true phyllite.[1]

SUMMARY OF CHEMICAL COMPOSITION OF THE SLATES.

By taking the average of the analyses, wherever several were made of one kind of slate, and throwing together the rarer elements and the water below 110° C. we arrive at the following as the general chemical composition of the roofing slates of this region:

[1] See a description of the microscopic characters of the Maine slates, by W. S. Bayley, in Bull. U. S. Geol. Survey, No. 150, pp. 311–313, which reached the author of this paper after his manuscript was completed. Professor Bayley gives a general analysis of this slate by L. M. Norton, showing .52 of CaO. This analysis is repeated in Part VI of this annual report (Part VI, continued), in a paper on Stone, by William C. Day, p. 255.

Analyses of roofing slates of eastern New York and western Vermont.

Constituents.	Sea green. (3) *a*	Unfading green. (2)	Bright green. (1)	Variegated (Eureka). (1)	Purple. (2)	Red. (4)	Black. (1)	General average.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per cent.*
SiO_2 (silica)	63.33	59.37	67.89	60.24	61.29	63.89	59.70	62.24
TiO_2 (titanium dioxide)	.73	1.00	.49	.92	.77	.52	.79	.87
Al_2O_3 (alumina)	14.86	18.51	11.03	18.46	16.24	11.80	16.98	15.41
Fe_2O_3 (ferric oxide)	1.12	1.18	1.47	2.56	4.63	4.56	.52	2.29
FeO (ferrous oxide)	4.93	6.69	3.81	5.18	2.62	1.33	4.88	4.21
CaO (lime)	1.20	.49	1.43	.33	.60	2.25	1.27	1.08
MgO (magnesia)	2.98	2.36	4.57	2.33	2.99	4.57	3.23	3.14
K_2O (potassa)	4.06	3.78	2.82	4.09	5.27	3.95	3.77	3.96
Na_2O (soda)	1.22	1.71	.77	1.57	1.38	.50	1.35	1.21
CO_2 (carbon dioxide)	1.41	.30	1.89	.08	.54	3.15	1.40	1.25
FeS_2 (pyrite)	.11	.14	.04	.16	.04	.02	1.18	.24
H_2O (water above 110° C.)	3.37	4.01	3.21	3.81	3.16	2.82	3.82	3.47
C (carbon)	Trace.	....	....	....	....	....	.46	0 or .46
Sundry and water below 110° C.	.69	.51	.66	.39	.56	.77	.70	.62
Total	100.01	100.05	100.08	100.12	100.09	100.13	100.05	....
Specific gravity *b*	2.776	2.795	2.717	2.805	2.806	2.796	2.774	2.783

a Figures in parentheses indicate the number of analyses averaged.

b Hull (op. cit.) gives the specific gravity of the Welsh slates as ranging from 170 to 180 pounds per cubic foot—i. e., 2.65 to 2.88. Festiniog, black, proves to be 2.751 (see p. 262). Analyses I and VIII, on p. 261, give 2.81 and 2.78 for a Cornish and an Austrian slate. Bayley (op. cit.) gives 2.851 for the Monson (Maine) slates.

REMARKS ON THE ANALYSES.

If analysis K[2] of red slate on p. 250 be included with the four others, the per cent of Fe_2O_3 in the red slates would range from 3.48 to 7.10 per cent, and average 5.08. Comparing, then, the amount of Fe_2O_3 in the several slates we shall find that it steadily increases from the variegated to the purple and to the red, as the microscopic sections show.

On the other hand, there is a decrease of FeO in passing from the unfading green to the variegated, sea-green, bright green, purple, and red. This decrease corresponds to and is probably consequent on the decrease of chlorite, a hydrous silicate of MgO and FeO.

There is more lime (CaO) and carbon dioxide (CO_2) in the red than in any of the other slates. This CO_2 occurs in part as calcite or dolomite, but also as rhodochrosite (carbonate of manganese), as shown by the analysis of the small bed (p. 260), and the close resemblance thereto of the lenses under the microscope. There is less CaO and CO_2 in the unfading green and in the variegated analyzed than in any of the slates.

There is less pyrite (FeS_2) in the red, and most in the black.

Dr. Hillebrand finds the following amounts of NH_3 in the slates analyzed: Black (specimen 305d), 0.04; sea green (specimen 225f), 0.025, and (specimen 256e), 0.008; unfading green (645a), 0.035; purple (760a), 0.0075; red (specimen 358d), 0.005; bright green (specimen 397c), 0.015. Whether this ammonia occurs as a nitride of some metal or is of organic origin could not be determined. Traces of chlorine were found when looked for; boron was not tested for. Vanadium and chromium are probably present, in all the red slates at least.[1]

SUMMARY OF MINERAL COMPOSITION OF THE SLATES.

In the following brief descriptions both the chemical and microscopic analyses have, to a large extent, been utilized. Besides the minerals named some kaolin (hydrous silicate of alumina) is possibly also present in all the slates.

Sea green.—Largely muscovite (potash mica), quartz, chlorite, carbonate (dolomite with siderite), pyrite, with very little lime-soda feldspar, still less zircon, rutile, cryptocrystalline quartz lenses.

Unfading green.—The same as above, but much less carbonate; more pyrite and chlorite.

Bright green.—Similar to sea-green, but less carbonate; more quartz lenses and chlorite, little pyrite, tourmaline, zircon.

Variegated (Eureka).—Like the unfading green, but with irregular areas over which hematite (Fe_2O_3) is thickly disseminated.

Purple.—Like the sea-green, but with less carbonate, less FeS_2, and more thickly and evenly disseminated Fe_2O_3 than in the variegated.

Red.—Not so largely muscovite (potash mica), very thickly disseminated Fe_2O_3. More carbonate, but less $FeCO_3$ and less FeS_2 than in any of the preceding. Quartz, carbonate of manganese, chlorite, very little plagioclase, feldspar, zircon, little rutile, tourmaline.

Black.—Matrix like the other slates of potash mica. Carbonates about as abundant as in sea green, quartz, less Fe_2O_3 and more FeS_2 than in any of the others. Rutile, coal, or graphite.

Mill-stock purple and green.—Like the unfading green and the purple, but with more chlorite in the green.

GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF THE VARIETIES OF SLATE.

The quarry maps, Pls. XL and XLI, show that the slate quarries within the Cambrian areas are generally very near or not far from the edge of the Ordovician belts. In some cases (Pawlet, Wells, West Castleton) the Cambrian slates occur within 100 or 200 feet of the Hudson grits. This is the case in such a variety of situations that the proximity of the two formations can hardly be explained by faulting. The Cambrian roofing slates are, therefore, regarded as occurring not far from the top of the Lower Cambrian series as exposed in this region and very near the overlying Ordovician. As the Cambrian belts are

[1] See Appendix.

made up of numerous folds, generally close and overturned, the slates also occur toward the center of the belts, but their stratigraphical position is still the same. The first place to look for the Cambrian roofing slates is near the Cambro-Ordovician boundary. Where the red slate occurs in close proximity to and on the west side of the Cambrian green and purple slates and the dip is easterly, as it usually is, the red slate may be found underlying the sea green, unfading green, or purple slates, and vice versa; on the eastern side of the Cambrian areas, the green and purple slates of the Cambrian may be found underlying the red of the Ordovician when both dip easterly. At several points (Blissville, Eureka, etc.) away from the Ordovician boundary the rock which appears to immediately underlie the Cambrian slates is the Olive grit (Horizon A), one of the so-called "wild rocks" of the quarrymen. As has been stated, it is still uncertain whether there may not be one or more beds of slate interbedded with this. The rock which overlies the Cambrian slate is either the Black Patch grit (Horizon C) or the Cambrian black shale (Horizon D) or the Ferruginous quartzite and sandstone (Horizon E). Perhaps most generally there is a bed of limestone conglomerate or breccia, followed by black shales or slates (Horizon D; see table facing p. 178). These vertical relations are pretty well established.

When we come to the areal distribution of the Cambrian slates the matter is not so clear. West of a line running from Center Falls (2 miles east of Greenwich) north to Lake Cossayuna, Belcher, one-half mile west of Slyboro, and to Truthville, the Cambrian roofing slates scarcely occur, or if they do are either shaly or coarse grained. The sediments seem to have been different and the conditions of pressure also different in the western part of the region. Nor are the areal relations of the "sea green" and the "unfading green" at all clear. There is nothing as yet to show that the stratigraphical position of these two varieties of Cambrian slates is not identical. It seems probable that, at the latitude of a point within 2 miles north of Poultney, a change in the sediments occurred in Cambrian time sufficient to account for the diminished percentage of carbonate and the increase of chlorite and pyrite.[1] Whether this difference in composition is alone sufficient to account for the difference in the cleavage is uncertain. There may have been some difference in the resistance to pressure which would account for more perfect cleavage at the south than at the north. Possibly, as has already been suggested, the greater abundance of beds of quartzite at the north may have restrained the cleavage structure, and so with more lime deposited at the south and more quartz sand at the north the whole structural difference may be traced back to changes in sedimentation.

Even this demarcation between the fading and unfading green

[1] The most southerly outcrop of decidedly unfading green observed by the writer occurs 2½ miles north-northeast of Poultney and three-fourths of a mile east of the railroad.

QUARRY MAP SHOWING THE SITUATION AND SIZE OF THE MORE IMPORTANT SEA-GREEN, PURPLE, AND RED SLATE QUARRIES IN THE TOWNS OF HAMPTON AND GRANVILLE, NEW YORK, AND POULTNEY AND PAWLET, VERMONT, WITH THE GEOLOGY OF THE VICINITY.

Scale: 1 ⅛ ¼ ½ 0 1 2 MILES

Contour interval 20 feet

Scale $\frac{1}{31250}$

slate areas is not absolute, for fading green slates occur well within the unfading green area, as at an old quarry 1½ miles southwest of West Castleton and again 1¼ miles south of Castleton and also a half mile south of Bomoseen. Slates which fade little are reported as occurring on the ridge west of Lake Saint Catherine. In an old quarry about a half mile east of Jamesville, in a belt which seems to be directly continuous with that in which lie the Eureka and adjacent quarries, the slates fade comparatively little. In the Jamesville belt, at a quarry about 180 feet above the road and west of the chapel, there is a purple bed probably overlying a green one; both purple and green fade badly, but on the west side of the purple, i. e., underlying it, is a green bed which scarcely fades and which, under the microscope, shows very few carbonate rhombs.

A few things should be noted in connection with the general map (Pl. XIII). The continuation of the West Pawlet slate is to be looked for in the lenticular Cambrian area which begins 2 miles south of West Pawlet and stretches across the New York State line into Hebron. Sea green and purple slates also occur in the Cambrian area southeast of West Pawlet. The Jamesville belt continues south into the village of Granville. About the north end of Lake Saint Catherine the Cambrian slate belt divides in two, one part passing a half mile east of Poultney and the other a half mile east of East Poultney, where it crops out in the small gorge of the Poultney River. North of Castleton the strikes frequently change to the northwest or the north-northwest, and the beds of slate sometimes follow this direction. Barker Hill and Wallace Ledge both have Cambrian slates about them.

As heretofore stated, there is much irregularity in the vertical order of the Ordovician series, and particularly of the red Hudson slate (Horizon Irs). The rocks in most frequent proximity to the red slate are black graptolite shales, the gray Hudson grits, and the reddish or greenish shales and slates with small quartzites. Perhaps the best indication of the proximity of red slate is the presence of the reddish slates with small quartzites, but this is not infallible.

The geographical distribution of the red slates is much less regular than that of the Cambrian slates. Toward the southern end of the belt the red slates run into red shales, and even where the rock is a true slate its continuity is more or less uncertain. It may anywhere along the strike run into shale or a green slate of inferior quality. Red slates occur as far south as North Cambridge and possibly beyond; as far north as a point in Hampton, 3½ miles south of Fair Haven; as far east as East Poultney, and as far west as North Granville, but always within the areas marked Sl on the map.

In like manner the Cambrian green, variegated, and purple slates may occur within any of the areas marked Ꞓl on the map, but more particularly east of the line given, running from Center Falls, Belcher to Truthville.

ECONOMIC GEOLOGY.

THE QUARRY MAPS.

These maps, Pls. XL and XLI, drawn on a scale sixteen times as large as that of the general map, show the portions of the slate belt which have been most worked. Nearly all the quarries have been instrumentally located and their areal dimensions have been drawn to scale. The design of these maps is to show the relations of the slate outcrops to the geological boundaries and to facilitate systematic exploration with the geological compass. The structural symbols are sufficiently explained in the legends. The numbered lines indicate the position of the cross sections on Pl. XVI.[1]

DIFFICULTIES IN SLATE QUARRYING.

The difficulties in all slate quarrying are numerous, and particularly so in this region. In the first place, the conditions of sedimentation and pressure here have varied so that a series of slate beds does not preserve its character for any great distance. Differences in composition, in hardness and softness, or in cleavage may occur unexpectedly along the strike. In the next place, the folding is so close that it is not easy to ascertain where a bed ought to recur on the east or the west. Then the stresses to which the slate mass has been subjected have been so various that irregular fissures, resulting in as irregular veins of quartz, occur at the most unexpected points.

The east-and-west jointing is sometimes so abundant as to cut up the slate into blocks of too small a size to quarry. Masses so cleft are called "posts." "Hogbacks" may also appear unexpectedly, or faults, or dikes, not to mention "false cleavage" (slip-cleavage) or lenticular beds of quartzite. The amount of overlying gravel or of weathered or shattered rock ("top rock") to be removed and the proportion of waste to product are also vital matters.[2] Besides these are the questions as to the drainage of the quarry, as to a convenient place for the "dumps," and as to the means of transporting the product. The cost of slate at some of the quarries is increased by the necessity of removing the dumps of former workings, which, for want of capital, were placed close to the quarry and on good slate. Sometimes the only way to remove these dumps is to throw the material into the quarry and hoist it up again. Several of these difficulties could be set aside by a more generous use of common sense or capital. Others, however, are not so easily disposed of; but even these may be somewhat dimin-

[1] The red slate quarries about Hatch Hill, as well as nearly all the other quarries, will be found located on the general map, Pl. XIII. Pls. XL and XLI can be aligned by the course of the Poultney River and mounted together.

[2] Davies (op. cit.) states that this ranges from 5 to 28 per cent, 8 per cent being considered a fair proportion. Watrin (op. cit.), referring to the Ardennes slate, gives the total waste as from 70 to 75 per cent in weight, of which from 20 to 25 occurs in quarrying and 50 in splitting and trimming.

QUARRY MAP

SHOWING THE SITUATION AND SIZE OF THE MORE IMPORTANT SLATE QUARRIES IN THE "UNFADING-GREEN" SLATE BELT BETWEEN POULTNEY AND WEST CASTLETON, VERMONT, TOGETHER WITH A FEW OF THE "SEA GREEN" SLATE QUARRIES NEAR POULTNEY

Scale

0 1/8 1/4 1/2 1 Mile

Contour interval 20 feet

Scale $\frac{1}{31250}$

LEGEND

Sl — Lower Silurian, Ordovician, slate, shale, grit etc. (slate red, bright green, or black) } of same age

Sb — Lower Silurian Berkshire schist } of same age

€l — Lower Cambrian Olenellus zone, slate, quartzite, grit, limestone, and shale (slate green, purple, or variegated)

Green, purple, or variegated slate quarries

Strike and dip of bedding (vertical line-dip, when short-steep dip)

Horizontal bedding

Strike and dip of cleavage (vertical lines-dip, when short-steep dip, cleavage and bedding symbols are also combined)

Strike of "hog back" (shear zone)

Strike of vertical joints

Strike of fold (the curved line shows character of fold)

Dike of camptonite or augite-camptonite (basic eruptives)

Section lines

Topography and nearly all quarries by J. H. Jennings.
Geology by T. Nelson Dale.
L. M. Prindle, and F. H. Moffit Assistants
1896

This map illustrates a report on the slate belt of eastern New York and western Vermont by T. Nelson Dale
1898

RELIEF
(printed in brown)

3804

Figures
(showing heights above mean sea level instrumentally determined)

Contours
(showing height above sea, horizontal form, and steepness of slope, of the surface)

DRAINAGE
(printed in blue)

Streams

Lakes and ponds

Swamps

CULTURE
(printed in black)

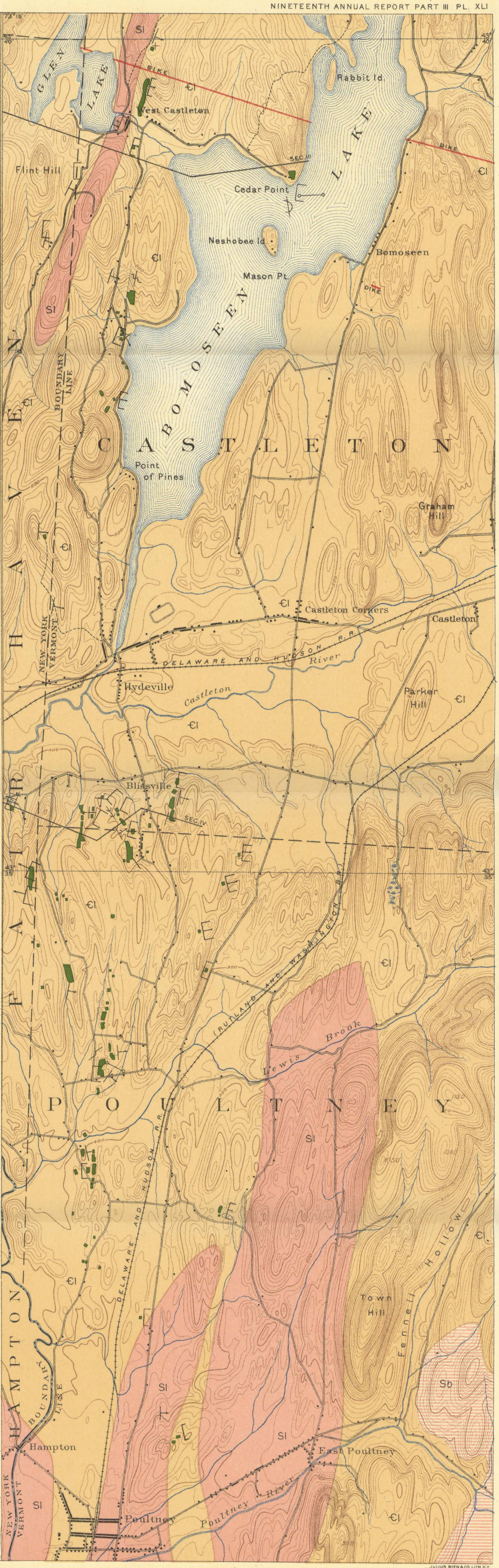
Roads and buildings

Villages

Trails

Railroads

State boundary lines



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ished by understanding their nature and origin, and by the application of a few simple geological principles not infrequently neglected by quarrymen. The following suggestions may be of service in this way.

BEDDING AND CLEAVAGE, HOW DISTINGUISHED.

Wherever the slates are traversed by "ribbons," gray in the green slates, or green in the purple and red, or marked changes in color occur and persist through a thickness of several feet, or wherever strips of quartzite or limestone occur at intervals and continue longitudinally for several hundred feet, quarrymen of any experience know that they have to do with beds, and that the quality of the slate of any one bed may be expected to continue along that bed unless some change should occur in the character of the cleavage. The quality of the slate is primarily dependent upon the character of the sediment. This changes less frequently in horizontal than in vertical directions. The changes in the character of the materials brought into the sea and deposited at one time throughout a moderately large area were fewer than between those brought in at different times at any one spot. Cleavage, being the result of a later compression, may traverse sediments of slightly different composition with little change in direction, but will be very much affected by great changes in the material or the grain of the sediment (see Pl. XXIV, A). The prime factor is, then, the bed, the second one the cleavage.

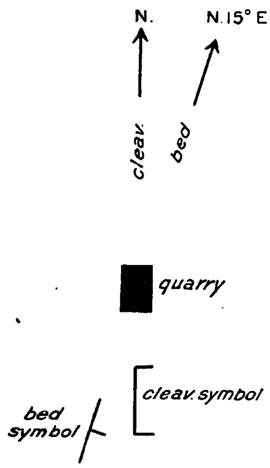

FIG. 13.—Diagram illustrating divergence in strike of slate bedding and cleavage.

In the southern part of the slate belt, as between West Pawlet and Poultney, where beds of quartzite or limestone are few and inconspicuous and the difference of color is slight, the distinction between bedding and cleavage is not so easily made. Quarrymen and prospectors sometimes regard them as identical when they differ. Where the strikes of the bedding and cleavage are divergent, if that of the cleavage be mistaken for that of the bedding a new opening may easily be made at the wrong point and the looked-for bed may be missed. (See fig. 13.) In such places the readiest means of distinguishing cleavage and bedding are:

(1) The fossil impressions (trails or algæ, sometimes called "wavers") are always on a bed surface.

(2) Minute plicated beds of calcite and quartz, as in Pls. XXIV, B, XXV, B, indicate bedding.

(3) A microscopic section transverse to the cleavage, if other means fail, may indicate the amount of divergence between the bedding and the cleavage. (See fig. C, Pl. XXVIII.)

In some places, however, bedding and cleavage are identical in both strike and dip.

"FLINTS"—THEIR NATURE AND CAUSE.

Beds of quartzite, often calcareous, micaceous, pyritiferous (see Pls. XXI, *B*, and XXVII, *A* and *B*), should never be confounded with veins of quartz (see Pl. XXXI, *A* and *B*). They are both indiscriminately designated by the quarrymen as "flints." The former are sediments mainly of quartz sand, and, although varying considerably in thickness, are generally more persistent than the veins which, as has been already shown, are chemical infiltrations into fractures produced at a much later time in consequence of various stresses. Ordinarily the quartzite has a more granular and less glassy surface than the vein quartz. A microscopic section under polarized light will almost always show the difference when ordinary means fail. The importance in not confounding the quartzite beds and the quartz veins lies in this—that while the quartzite beds indicate the direction and thickness of adjacent beds of slate, and thus prove helpful, the quartz veins constitute perhaps the most fortuitous and pernicious element in slate quarrying in this region. The strains which the slate masses have suffered have been so various that it is almost impossible to foretell the probable presence, course, extent, or thickness of a quartz vein. A few things should, however, be noted. While the fractures which occasioned the veins are to be looked upon somewhat as accidental, they are the result of stresses affecting large areas or of the complex interactions of pressure in a few definite directions. The course of a vein which is tapering out should be taken with a compass, and another should be somewhat expected in the same line or in directions parallel to it, or at right angles to it. The parallelism which does exist in quartz veins is shown in Pls. XXXII, *A* and *B*, and is frequently illustrated on a still larger scale.

RELATIONS OF JOINTS, DIKES, AND HOGBACKS.

The prevalent systems of jointing are shown in the table facing p. 178 and the quarry diagrams (Pls. XXXIII, XXXIV) to be N. 10° to 25° E., N. 65° to 90° W., and N. 65° to 82° E., N. 30° to 40° E., and N. 45° to 50° W.

In proximity to a dike joints may be expected parallel to the sides of the dike and in large number, so as to form "posts." The more frequent courses of the dikes within the slate belt are, as shown by the general map, N. 25° to 40° E. and N. 50° to 70° W., more rarely east and west.

Certain systems of joints, the diagonal ones, N. 30° to 40° E. and N. 45° to 50° W., and the dip joints, N. 70° W., therefore, correspond to the usual courses of the dikes, and where such joints occur in any frequency dikes should be anticipated. The observed courses of the "hogbacks" (shear zones) are N. 37° to 55° E., and also, but less frequently, N. 55° W., and north, also east and west (see pp. 213, 287, and Pls. XXXIII, XXXIV, XXXIX). As these break up the cleavage, they must be due to a movement more recent than the pressure which induced the cleavage.

From the similarity of the courses of the diagonal joints and many of the dikes, and also of many of the hogbacks, there would seem to be a close relationship in their origin. They may all have been produced by the same stress at the same time, in some cases the strain resulting in a hogback, in others in a diagonal joint; and these joints, when very deep, may have given rise to dikes. The practical application of this is that the possibility of such a relationship should lead the quarryman, whenever he finds diagonal jointing, to suspect the proximity of hogbacks and dikes with a similar course, and so with either a hogback or a diagonal dike, and this suspicion may sometimes save expenditure of time and labor.

THE USE OF A GEOLOGICAL MAP AND COMPASS IN PROSPECTING FOR SLATE.

Both the general map, Pl. XIII, and the quarry maps, Pls. XL and XLI, are designed to be of practical utility. The coloring shows where the Cambrian green and purple and the Ordovician red slates may be looked for or not looked for. The general map, if carefully studied, will show where the continuation of certain slate belts may be expected. The dovetailing of the Cambrian and Ordovician areas, as has been explained, represents to a certain extent structural relations and not mere "accidents" of erosion. Thus, the Jamesville Cambrian belt is closely related to the Cambrian belt which lies west of South Granville.

On the quarry maps (Pls. XL and XLI) the course of bedding and cleavage has been shown at several quarries by special symbols. The scale of these maps is sufficiently large to admit the entry of many more quarries and symbols. By using a small geological compass to determine the strike of any bed of good slate at any of the located quarries, and transferring it to the quarry map by means of a protractor, the probable direction of the recurrence of the bed can be ascertained, and so with joints, hogbacks, or dikes. Such a compass should be provided with sights, spirit levels, movable ring to set off magnetic variation, and have a clinometer attachment to indicate angle of dip.

Where, as at West Pawlet (see Section VII, Pl. XVI, and figs. *A*, *B*, *C*, Pl. XXXIII), the slate is closely folded, a succession of repetitions of the same series of beds may be looked for in an east and west direction at varying intervals. The possibility of the pitching of the axis of a fold in a northerly or southerly direction should be looked out for. In such cases older or newer beds are traversed in following the direction of the pitch. Where an Ordovician belt abruptly terminates a Cambrian one on the north or south, the Cambrian one must ordinarily be supposed to plunge under the Ordovician one.

From the relations already explained, quarrymen need not be surprised, here and there as the excavation proceeds, to come upon the Ordovician red and bright green slates at the bottom of a sea-green or unfading green quarry, or to come upon these Cambrian slates at the bottom of a red slate quarry (sections I, II, V, VI, VII, Pl. XVI).

Quarrymen are very skilled in detecting the presence of good slate from the peculiar appearance of the weathered edge surface, and that skill appears to have been their only guide in prospecting in this region. It would be well if this skill were reenforced by the use of the following method in exploration:

First. Make reference to a geological map for the areas in which the various slates may occur.

Second. Determine on quarry map or general map the good slate beds already exploited.

Third. Make compass determination of the strike of such beds.

Fourth. Explore along that strike.

Fifth. Explore at right angles to that strike to see if the series is repeated by folding. (Note order of horizons in table facing p. 178.)

Sixth. Trench at promising localities across the strike to expose as large a series as possible.

Seventh. When surface indications are favorable, make an opening large enough to determine angle of dip of both bed and cleavage and to obtain specimens sufficient for tests given on pages.

Eighth. Bore with diamond or steel-shot drill at 45° to cleavage dip so that the core will split up into elliptical pieces sufficiently larger than diameter of core to be conveniently tested.

Ninth. Measure thickness at right angles to bedding planes on the core.

METHODS OF TESTING SLATE.

Methods of testing the elasticity, absorption, fissility, and resistance of roofing slates have been in use for many years, and many more or less complete chemical analyses of slate have been published. In recent years, however, more exact methods of reaching these results have been devised. All such methods have here been brought together. If parts of one specimen, fairly representing the average quality of the product of any quarry or prospect, or if parts of each of a series of specimens, fairly representing all the different varieties and qualities there obtained, were to be subjected respectively to the tests described, such a slate or slates may be said to have been for all economic purposes exhaustively investigated. Several of these tests are of so simple a character as to be very easily applied. This list of methods is largely compiled from Böttinger, Fresenius, Hutchins, Jannetaz, Merriman, Reverdin and De la Harpe, Sorby, Umlauft, and J. F. Williams.[1] Although they all offer valuable suggestions, the most useful papers on the subject are those of Fresenius, Umlauft, and Merriman.

Sonorousness.—One of the first and most time-honored tests of roofing slate is to suspend a good-sized piece of the usual thinness and tap it with some hard object. If it possesses the molecular structure of a slate it will yield what might be termed a semimetallic or semivitreous ring. It is because of this property that when at the quarries refuse slates are thrown upon the dumps the sound produced is not unlike that made by the smashing of a large quantity of crockery.

Cleavability.—This test should be applied by an experienced workman. The block should be freshly quarried, unfrozen, and moist. The chisel should be very thin and about two inches wide. The cost of slate is closely related to the degree of its cleavability.

Cross fracture ("*sculping*").—This is to determine the character of the "grain." This test should also be applied by an experienced hand to a large block several inches thick, with a stout chisel and a long-handled, heavy mallet. Jannetaz[2] published a method for determining with scientific precision the direction of the grain in slate when it is but obscurely shown on the cleavage surface. The slate is sawn in a direction parallel to its cleavage and one of the sawn surfaces is made exceedingly smooth and covered with an even and very thin coat of grease. The point of a red-hot platinum wire is applied to the slate opposite the center of the greased surface. The greased area reached by the heat will, in cooling, leave an oval outline, the long axis of which will show the direction of the grain, the heat having traveled more rapidly within the slate in the direction of the grain than in any other. He also made a disk of slate 5 inches in diameter of ordinary thickness, with a central perforation. This disk was fastened by the extremities of the diameter parallel to the grain and afterwards by that at right angles to the grain, and was made to vibrate by tapping the side of the perforation. The sound produced when the disk was fastened by the diameter at right angles to the grain was louder than when fastened by that parallel to it. In other words, the direction of the grain was that in which elasticity and vibration were greatest.

Character of cleavage surface.—The cleavage surface should be examined with an ordinary magnifying glass. A superior slate should scale along the cleavage surface into very thin chips with translucent edges. If the grain is pronounced it will appear in fine transverse lines. If false cleavage, which is fatal, be present, it can usually be detected on the cleavage surface. Ribbons, which are sometimes lines of weakness, should be noted. There is great difference in the smoothness of the surface in slates of different regions. Ordinarily the constituent min-

[1] Full titles are given in the economic bibliography, pp. 173-174. A useful bibliography of purely technical works on building stone, by Geo. P. Merrill, appears in the Annual Report of the Smithsonian Institution for the year ending June 30, 1886, pp. 519-520.

[2] Relations entre la propagation de la chaleur et l'élasticité sonore dans les roches, 1877, p. 417.

erals ought not to be visible. Minute lenses or crystals are not necessarily detrimental, but they retain dust and thus afford a foothold for mosses and other cryptogams, which gather moisture and thus aid the decomposition of the slate.

Presence of lime.—This can be determined by the application of cold dilute hydrochloric acid to the edges of a freshly quarried slate. Rapid effervescence implies presence of carbonate of lime; slow, that of a lesser quantity of it or of dolomite—carbonate of lime and magnesia.

Color and discoloration.—The color of the freshly quarried slate should be noted and compared with that of pieces exposed for several years to the weather, either on a roof or on the quarry dumps, or with that at the top of the quarry close to the gravel, although this last comparison may not always be perfectly conclusive. The value of slates is somewhat affected by the extent of their discoloration.

Presence of clay.—This should be tested by breathing upon a fresh and clean piece of slate and observing whether there is any argillaceous odor. The very best slate will not emit any such odor.

Presence of marcasite.—A slate containing lenses or crystals of a pale-yellowish metallic mineral which, on exposure, decomposes, forming a yellowish white film and rusty spots, is poor.[1]

Strength.—See Merriman's paper[2] for apparatus and method used in determining the modulus of rupture in pounds per square inch, which he finds in the best slates should range from 7,000 to 10,000 pounds. See also J. F. Williams's[3] tests of compression and elastic limit applied to purple, red, and green slates from Rutland and Washington counties. His results show a limit of compression ranging from 8,040 to 24,760 pounds per square inch, and an elastic limit at from 4,850 to 10,260 pounds. Campbell & Donald[4] give 20,000 pounds as the crushing weight for one cubic inch of slate. Wilkinson, in his Practical Geology of Ireland, gives 30,730 pounds as the crushing weight of the Killaloe slates.[5] Watrin[6] gives the maximum crushing weight of some French slates as 2,000 kilogrammes per square centimeter, but 1,700 as the average.

Toughness or elasticity.—Merriman finds the ultimate deflection in certain Pennsylvania slates, when placed on supports 22 inches apart, to range from 0.270 to 0.313 inch. Certain blue-black slates in Eldorado County, California, when split seven to the inch and 18 inches square, and fastened solidly at the two ends are said to bend 3 inches in the center without any sign of fracture.[7] J. F. Williams[8] tested beams of slate from Rutland and Washington counties, 1 inch square and 10

[1] See On marcasite and pyrite; a comparative study of the chemical behavor of pyrite and marcasite, by A. P. Brown: Proc. Am. Phil. Soc., Vol. XXXIII, pp. 225-243, 1894.

[2] Op. cit. An extended abstract of Merriman's paper is given by Wm. C. Day in Part VI, continued, of this annual report (pp. 257-263) and on p. 255 some data obtained by Prof. W. O. Crosby as to the strength of the Maine slates are presented.

[3] Op. cit. [4] Encycl. Brit., ninth ed., 1887. [5] Quoted by Hull; op. cit. [6] Op. cit., pp. 192, 193.

[7] California State Mining Bureau, Twelfth Report of State Mineralogist J. J. Crawford, September 15, 1894, p. 400. [8] Op. cit.

inches long, with supports 6 inches apart. Bending without breaking was effected by from 770 to 1,200 pounds, and when the supports were placed 3 inches apart by from 1,710 to 2,400 pounds. The great elasticity of the slates of eastern New York and western Vermont is apparent to any one visiting the shanties where the splitting is done.

Density, or specific gravity.—This is determined in the usual way, by weighing a piece of the slate in and out of water and dividing its weight out by the difference between its weight in and out. The specific gravity will be considerably affected by the amount of magnetite or pyrite. Merriman's tests of Pennsylvania slates give 2.761 to 2.817. Meyer's Konversations-Lexikon, 1894, gives 2.8 to 2.9 as the normal specific gravity of a good roofing slate.[1]

Porosity.—This is best determined by drying, then weighing, then immersing for twenty-four hours and weighing again, in order to ascertain the percentage of water absorbed. Merriman takes a piece 3 by 4 inches, with rough edges, dries it in an oven at 135° F. for twenty-four hours, cools to the normal temperature of room, weighs, and immerses it for twenty-four hours, and weighs again. His tests of Pennsylvania slates showed from 0.099 to 0.303 per cent of absorption. Porosity is sometimes roughly indicated by immersing a roofing slate edgewise one-half in water and observing how far the water ascends by capillary attraction. In good slates it ought to rise but very little.

Reverdin and de la Harpe[2] state that slates are liable to deterioration from the chemical action of gases arising from woodwork beneath the slate, as well as from the action of the atmosphere, and that they are also liable to an increase of porosity by the physical action of changes of temperature and by the unequal conductivity of heat in the direction of cleavage and of grain. They state that the porosity in a fresh slate should be below 0.1 per cent and after treatment less than 0.2 per cent. Their somewhat elaborate method is this: For determining porosity as produced by acids, the slate is treated with 10 per cent cold acetic acid and the flask is made vacuous from time to time. The piece is then washed, dried, weighed, and immersed in diphenylamine in a thick-walled tube 12 by $3\frac{1}{2}$ centimeters. The tube is exhausted, heated two hours in oil bath at 170° C., air pressure is restored, and heating continued for four to five hours at 150° C., after which the test pieces are removed, the diphenylamine wiped off with ether, and the increase in weight taken.

For determining porosity as produced by changes of temperature, the slate is heated in a wrought-iron tube for half an hour to 300° C., and the tube is then suddenly cooled by a stream of water for half an hour. This process is repeated twenty-four times, and the slate is then impregnated with diphenylamine and the procedure is as in previous test.

Fresenius is accredited with a method of testing the effect of heat

[1] See also p. 261. [2] Op. cit.

and cold on slate by saturating it with water and putting it for twenty-four hours in a freezing mixture and heating another from 250° to 350° for five or six hours and then immersing it in water. The porosity, strength, and elasticity of the pieces so treated should then be tested. Böttinger points out that the greater the porosity of a slate the more damaging is the action of frost likely to be.[1] The effect of frost on the microscopic structure has already been referred to, p. 209.

Corrodibility.—An important quality in roofing slates is their resistance to the acids of the atmosphere, particularly in cities, where gases increase its destructive power. Fresenius in 1868[1] suggested testing the weathering qualities of a slate by immersing it for three days in dilute sulphurous acid in a closed vessel. At the end of that time poor slates are softened or broken up into thin laminæ or easily fractured, while good ones preserve both their density and hardness.

Merriman for the same purpose prepared a solution consisting of 98 parts of water, 1 part of hydrochloric acid, and 1 part of sulphuric acid. Pieces of slate 3 by 4 inches were carefully weighed, then immersed in the solution for sixty-three hours, then dried for two hours in the air of the laboratory, and weighed again. The loss in weight ranged from 0.374 to 0.619 per cent.

Microscopic analysis.—One of the most satisfactory tests of slate is the examination of a thin section of it under the microscope. A cubic inch thus tested will suffice to show the character of the cleavage, the presence of false cleavage, if any, the probable durability or indurability of the color, as well as the presence of any mineral constituents likely to affect its general durability. The specimen should be carefully selected so as to fairly represent the general quality of the bed. It should be fresh, unfrozen, and about an inch thick across the cleavage. At least two sections should be prepared—although the more the better—one parallel to the cleavage and another at right angles to it, never diagonal to it. The sections should be exceedingly thin, much more so than ordinary sections of eruptive rocks, and the slide cover should be of the very thinnest kind, to admit the use of the highest objectives. Both slides should be examined first in ordinary light, then in polarized light with powers ranging from 140 to 700 diameters. The method indicated on pp. 231, 245 will sufficiently illustrate the procedure. The transverse section will show the quality of cleavage, the false cleavage if any, and, under polarized light, will, as pointed out by Sorby and others, show whether the specimen is a slate or a shale or something between the two by the entire matrix becoming in a true slate four times dark and four times light in complete rotation. Sections parallel to the cleavage reveal the amount of carbonate and indicate the probable amount of discoloration by exposure. Both sections under incident light will show pyrite if any exists.

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[1] Op. cit.

Chemical analysis.—This, in order to give a correct idea of the composition of the slate, should not be partial but complete.[1] Such an analysis should then be compared with complete analyses of the best slates of like color, and before a final conclusion is reached as to the value of the slate its microscopic analysis and the results of the tests of its strength, elasticity, porosity, and corrodibility should be considered in connection with its chemical analysis. Merriman concludes from six different kinds of tests applied to each of 24 specimens of old Bangor and Albion (Pennsylvania) slates, as well as from the results of several general chemical analyses, that—

> The strongest slate stands highest in weathering qualities, so that a flexural test affords an excellent index of all its properties, particularly if the ultimate deflection and the manner of rupture be noted. The strongest and best slate has the highest percentage of silicates of iron and alumina, but is not necessarily the lowest in carbonates of lime and magnesia. Chemical analyses give only imperfect conclusions regarding the weathering qualities of slates and do not satisfactorily explain their physical properties.[2]

Reverdin and de la Harpe[2] also call attention to the fact that good slate may have a high per cent of calcium carbonate and that others free from it may be poor, and that the presence of pyrite is not necessarily a bad indication, for it may not decompose. This statement needs modification, however, by adding that marcasite even in small quantities is very deleterious, for it decomposes very readily.[3]

Besides these tests there are a few others which are of scientific rather than economic importance. Umlauft suggests heating small splinters of slate under the blowpipe to determine the presence of pyrite and carbon and to ascertain the relative fusibility of different slates; also the test with bead of borax or phosphate of soda and ammonia to determine the presence of iron. He recommends putting a splinter of slate in pure hydrochloric acid in a watch glass and after evaporation examining the precipitate microscopically; also, the application of the same treatment to a splinter after fusion with the blowpipe. He recommends also the application of the ordinary mineralogical tests for hardness; e. g., scratching the slate with calcite and fluorite.

Hutchins finds that the presence of chlorite minerals can be detected by heating the slate to dull redness, thus dehydrating and discoloring those minerals, then preparing a thin section of the slate so treated and comparing it with sections of the normal rock.

TECHNICAL DESCRIPTION OF A SLATE QUARRY.

The following outline of a description of a slate quarry for economic purposes is proposed as covering the features of practical geological

[1] See, on the advantage of complete analysis, Principles and methods of analysis applied to silicate rocks, by W. F. Hillebrand, Bull. U. S. Geol. Survey, No. 148; Analyses of rocks and analytical methods, Clarke and Hillebrand, pp. 1-64, 1897.

[2] Op. cit.

[3] See under tests, p. 274.

and economic importance, aside from the ordinary statistical matters as to amount and value of product, number of employees, etc.:

Quarry name or number.
Location (exact).
Geological formation as given on the geological map.
Distance from railroad and means of transporting product.
Diagram of plan of quarry to scale.
Dimensions of working face.
Distance and direction of dumps from working face.
Means of drainage.
Number of inclines or of horse derricks.
Number of slate-trimming machines.
Kinds of slate produced.
Thickness of good and bad beds in natural order.
Strike and dip of beds.
Strike and dip of cleavage.
Strike and dip of strike joints.
Strike and dip of dip joints.
Strike and dip of diagonal joints.
Course of grain.
Strike and dip of hogbacks.
Location and diameter of posts.
Proximity of dikes.
Course and thickness of veins.

SCIENTIFIC GEOLOGY.

THE PRESENT STATE OF SCIENCE ON ROOFING SLATES.

However great may have once been the uncertainties as to the structural, mineralogical, and chemical constitution and the origin of slate, these are all now fairly well understood. Sedgwick, Sorby, Phillips, Tyndall, Daubrée, Gosselet, and Jannetaz have studied their structure and history, either in the field or the laboratory, or in both, and Sorby, Zirkel, Renard, and others have investigated their mineralogical composition. The most recent summaries on the cleavage of slate are those of Loretz (1880) and of Harker (1886), and on the petrography of slate those of Kalkowsky (1886), of Zirkel (1894), and of Rosenbush (1898). Chemical analyses are given in Roth's chemical geology (1890), and also in Zirkel's petrography (1894). The bibliography on pages 168–172, shows how much has been written on the different aspects of the subject. It is not proposed to give here a complete summary of all this literature, nor to go into the mathematical physics of the subject of cleavage, but to set forth the state of scientific opinion on the more important and interesting features of slate. This will be done in a series of statements and questions.

There is danger of confusion between what is termed a "clay slate" and a "phyllite" (or phyllade in France), both of which rocks are used for roofing purposes. Sir Archibald Geikie distinguishes them by their luster. "In England," he says, "the term slate, or clay slate, is given to argillaceous, not obviously crystalline rocks, possessing this cleavage structure. When the micaceous luster of the finely disseminated super-induced mica is pronounced, the rocks are phyllites. [The latter] form an intermediate stage between ordinary clay slates and mica-schist."[1] Zirkel and Rosenbusch, while giving microscopic and chemical analyses of both "thonschiefer" and "phyllit," admit the difficulty of the distinction in certain cases.[2] Sorby draws this distinction: "When a section of a fine grained slate cut at right angles to the cleavage is rotated in polarized light it becomes, over nearly the whole surface, very bright, and much darker at different azimuths, like a doubly refracting crystal, whereas there is little or no such change in the case of true clay slates of the normal granular type containing much kaolin and very little mica."[3] Judged by this criterion there is no difficulty in drawing a distinction. In a shale there is scarcely any orientation of the mica flakes. Clay slates are simply shales in which the pressure has been sufficient to produce a certain amount of cleavage, but still without effecting that complete parallelism of the mica flakes which makes a transverse section of phyllite polarize as one mineral.

A typical slate of the better quality, that is, a phyllite, is regarded as consisting to the extent of about 40 per cent of muscovite in scales or ribbon-like flakes (sericite)[4] lying parallel to the cleavage foliation, or, rather, whose parallelism causes the cleavage, and so compressed that a transverse section behaves under polarized light as a crystal of muscovite cut parallel to its vertical axis, extinguishing whenever the cleavage direction is parallel to the short diagonal of analyzer or polarizer. Sorby states that in the best Welsh slates the average size of these scales may be taken at one two-thousandth of an inch in breadth by one six-thousandth of an inch in thickness.[5] Scattered about among the meshes of the muscovite are minerals which extinguish irregularly. Chief among these is quartz, mostly in clastic grains, sometimes formed in situ or in lenses of cryptocrystalline quartz or chalcedony. Next in importance is a chloritic mineral, usually green and distinctly dichroic, but sometimes very pale, optically very faint or quite colorless and inert. This mineral occurs, first, in scales, sometimes intergrown with lamellæ of muscovite and lying transverse to the cleavage, i. e., parallel to the direction of the grain;[6] second, in more minute scales

[1] Text-book Geology, 3d ed., p. 134. [2] Op. cit.

[3] On the structure and origin of noncalcareous stratified rocks, op. cit., p. 76.

[4] See Laspeyres: Sericit. Zeitschr. für Kryst., IV, 1880, p. 224. [5] Op. cit. supra.

[6] "Sections parallel to cleavage show these chloritic areas to be composed of a series of lamellæ of a greenish tinge intercalated with a membrane of lighter shade or almost colorless. Sections transverse to cleavage occasionally show the scaly character of the mineral. These scales are arranged perpendicular to the cleavage. When the section cuts the chlorite scales perpendicularly they are plainly dichroic E = light yellow. O = somewhat dark green, but sections parallel to the scales remain dark between crossed nichols during a complete revolution." Renard, op. cit., Vol. III, p. 235 and Pl. XII, same volume. See also Zirkel, Lehrb., 1894, p. 298: "Some of the chlorite scales are parallel to the mica flakes, others cross the cleavage. They are often interwoven with lamellæ of mica." See G. Rose: Ueber die regelmässige Verwachsung der verschiedenen Glimmerarten mit einander sowie mit Pennin und Eisenglanz: Monatsber. K. Akad. zu Berlin, 1869.

which, together with quartz, constitute very small lenses with their long axes parallel to the cleavage direction. This chloritic mineral is regarded as of secondary origin.

Rutile needles are almost always present in great abundance,[1] hematite in very minute scales or grains.[2]

Rhombohedra or scales of calcite are sometimes evenly disseminated. There are also cubes of pyrite, tourmaline in hemimorphic crystals, carbonaceous matter in the black slates, limonite, and a few clastic grains of feldspar and of zircon.

The following minerals have also been identified in slate: Ottrelite, staurolite, garnet, biotite, hornblende, epidote, apatite, pyrrhotite, gypsum.

Slates are often speckled with minute protuberances which under the microscope resolve themselves into the lenses just referred to—so-called "eyes" or "knots." Instead of consisting of chlorite and quartz they may consist of an octahedron of magnetite partially surrounded by quartz and that entirely by chlorite.[3] This quartz is then regarded as a later infiltration into a cavity formed between the magnetite and the chlorite by pressure. Others consist of chlorite surrounded by calcite and that by quartz.[4]

Others have a central crystal of pyrite instead of magnetite,[5] or the pyrite may have been changed to limonite.[6] Still others consist of chalcedony surrounded by chlorite scales,[7] or of quartz surrounded by radial plates of muscovite.[8]

Finally the discoloration is attributed by Bishof to the hydration and oxidation of a ferrous oxide.

Dumont describes the purple slates of Fumay in the Ardennes as turning to a pinkish gray and the green to a yellowish gray, and both as losing their cohesion, hardness, and elasticity in weathering; but he states that these changes are more frequent on plateau than on cliff exposures.[9]

Leaving out the rarer and less significant constituents, and basing

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[1] On these see Zirkel, Ueber die mikroskopische Zusammensetzung von Thonschiefern und Dachschiefern: Poggendorff Annalen, Vol. CXLIV, p. 319, 1891; Van Werweke, N. Jahrb. Min. Geol., 1881, vol. 1, p. 178; Sauer, op. cit., N. Jahrb. Min. Geol., 1881, vol. 1, p. 227–238; Cathrein, Ueber das Vorkommen mikroskopischer Zirkone u. Titan-Mineralien in den Gesteinen, Würzburg, 1884; Kalkowsky, Elemente der Lithologie, p. 257, 1886. Sorby (supra, p. 68) gives the diameter of the slate needles as less than $\frac{1}{50000}$ inch.

[2] Renard gives the size of the granules of Fe_2O_3 as 0.020–0.005 mm; op. cit., Vol. III, p. 234. See also his Plate XII, fig. 2, of purple and green slate, in same volume. See also Gosselet (Études sur l'origine de l'ottrelite: Ann. Soc. Géol. du Nord, XV, 1887–1888, Lille, 1888, pp. 188–189) who describes hematite as occurring in three forms in the reddish slates: (1) in irregular grains 0.01 to 0.02 mm. or less; (2) in scales with a bluish steel-like luster under a mixture of reflected and transmitted light; (3) in minute granules which are always red, a brick-red under reflected light.

[3] See Geinitz, op. cit., also Renard, op. cit., Vol. II, 1883, p. 133 et seq., and Pl. VI.

[4] Renard, supra, p. 248.

[5] See Harker, on "eyes" of pyrite and other minerals in slate: Geol. Mag., Dec. III, Vol. VI, No. 103, p. 396. London, Sept., 1889.

[6] Loretz, Ueber Transversalschieferung: op. cit., 1882, pp. 283–289.

[7] Mallard, op. cit.

[8] Zirkel, Lehrb., p. 744, Thonschiefer.

[9] Dumont, Mém. Acad. Roy. Belg., XX, pp. 11 and 62, 1847.

his estimates on the chemical and microscopic analyses of the principal varieties of slate from the French Ardennes, Renard figures out the mineral percentages as follows:

Percentages of minerals in slates of Ardennes, France.

Minerals.	Purple.	Green.	Bluish black.	Grayish green.
Muscovite (sericite)	40.69	39.54	37.75	39.97
Chlorite	7.75	5.81	12.55	17.99
Quartz	40.41	45.78	40.58	30.97
Hematite	6.23	2.90	4.81	....
Rutile	1.55	1.04	....	1.34
Limonite	....	....	....	3.09

In round numbers this amounts to—

Minerals.	Per cent.
Muscovite	38 to 40
Chlorite	6 to 18
Quartz	31 to 45
Hematite	3 to 6
Rutile	1 to 1½

Renard calls attention to the fact that the green slates of Fumay in the Ardennes contain 4 per cent more SiO_2 than the purple ones and about 3½ per cent less Fe_2O_3.[1]

Summarizing the eight European analyses given on p. 261, and leaving out the less important elements, we reach these figures for the general chemical composition of roofing slates:

Summary of analyses of European roofing slates.

Constituents.	Per cent.
SiO_2	55 to 67.5
Al_2O_3	12 to 22.5
Fe_2O_3	1 to 7
FeO	1 to 7
TiO_2	up to 1.3
K_2O	1.8 to 3.8
MgO	1 to 3.5
Na_2O	up to 2.2
CaO	up to 5.2

[1] Op. cit., Vol. II, 1883, p. 147.

Rosenbusch[1] in comparing 18 analyses of clay slates from different parts of Europe calls attention to the strikingly characteristic preponderance of the MgO as compared with the CaO, along with a uniformly high percentage of iron oxides and of Al_2O_3, and also to the like preponderance of the K_2O over the Na_2O, which he explains thus:

> Clays and clay slates constitute the finest mechanical detritus from quartz feldspar rocks; whatever silicates of lime they contain was removed as a soluble bicarbonate and for this reason very little lime-soda feldspar can occur in such a detritus.

While there is substantial agreement as to the general microscopic and chemical character of roofing slates, there are differences of opinion as to the origin of some of the constituents, and even as to the presence of one of them. First, whether the muscovite (sericite), which makes up probably nearly one-half of the rock, is the product of dynamic metamorphism, the argillaceous sediments having furnished the elements for the construction of the muscovite, or whether these ribbon-like scales or shreds resulted from the disintegration of some micaceous rock (presumably granite or gneiss), and constituted the sediment, the result of the pressure having been simply to bring the shreds into more or less parallelism and to mat them together.

Rosenbusch[2] takes the first view, and Hutchins likewise, who concludes from his special study of fire clays and slates that even the mica of fire clays is of secondary origin.[3] Sorby once regarded "the micaceous mineral as formed in situ by an alteration of partially decomposed feldspar," but admits that the structure is "just such as would result from the deposition of material sorted by gentle currents and subsequently compressed," but he considers the chlorite as formed in situ.[4]

A similar question has been raised as to the origin of the rutile needles. Roth[5] is decidedly of the opinion that they belong to the

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[1] Elemente der Gesteinslehre, p. 424.

[2] "Of course the material of clay slates was mechanically brought together, but the mineral constituent of that part which is mainly micaceous and without feldspar was certainly the result of metamorphic processes which were intimately connected with dynamic-geologic processes." Neues Jahrb. für Min., etc., 1881, Vol. I, p. 399.

[3] "This fine mixture of biotite, muscovite, kaolin, the minutest waste of feldspar, and in less degree of quartz, and probably other substances, under the joint action of pressure, warmth, and mineral solutions, gives rise to various decompositions and recombinations, which result, among other things, in the formation of new mica, with the separation of titanic acid in the form of rutile. Into these reactions, whatever may be their exact course, even the muscovite in very fine state of division appears to enter; and there is good reason to conclude that in fine-grained sediments of suitable composition, exposed long enough to the necessary conditions as to pressure, temperature, and percolation of solutions, an almost complete regeneration of the 'paste' to mica can and does take place, and that this regenerated material, under intenser dynamo-metamorphic action, is converted into some of the forms of micaceous slates known to us. The mica so formed is probably what in its more advanced stages of development is often known as sericite." Op. cit., Vol. VII, p. 317.

[4] Op. cit. supra, p. 70.

[5] "Doubtless some of the constituents are of secondary origin (as quartz, pyrite, and the products of its oxidation, calcite, hematite, and limonite, gypsum), but the evidence of the secondary origin of the rutile needles does not seem to me convincing. Unstratified sands also contain a series of minerals.' Allgem. u. Chem. Geologie, Vol. II, p. 586.

original sediment. Thürach,[1] Pfaff,[2] and Credner[3] find an abundance of them in clay. Rosenbusch states that while zircon and apatite bear traces of their clastic origin, such traces are entirely absent in both the tourmaline and the rutile.[4]

Another question concerns the presence of an isotropic mineral like opal in the matrix of slates. Rosenbusch[5] and Pfaff[6] explain that in a very thin section a very slightly doubly refracting mineral may easily be mistaken for an isotropic one. Linck[7] claims to have been able to demonstrate the presence of 2½ per cent of amorphous SiO_2 in roofing slate by heating the section, then applying sodium hydroxide. Dr. Hillebrand, to whom the writer referred Linck's paper, calls attention to the fact brought out by Clarke and Schneider[8] that talc, when ignited and then treated with hot sodium carbonate, a much weaker solvent than that used by Linck, gives up freely as much as one-fourth of its total amount of silica, the silica having been made soluble by ignition and then taken out of its original combinations. As numerous other silicates behave in like manner, some of these may have furnished the amorphous silica in Linck's experiment. Some of the thin sections parallel to the cleavage examined by the writer in the preparation of this report do show under polarized light minute areas which remain dark in rotation, but some of those may be holes in the sections, which were made exceedingly thin, while others may be opaque kaolinitic matter. Still others are but very faintly doubly refracting and are probably muscovite scales lying parallel to the section.

Passing now to the geological structure of slate, there is the question recently discussed in this country as to the physical and mathematical principles involved in the assumption that the pressure which produced the cleavage operated in a direction at right angles to the cleavage.[9]

Relation of cleavage dip of slate to dip of inclosing hard beds.—Bearing somewhat upon this last question is the fact brought out by Gosselet that where a bed of slate lies between beds of a hard rock like quartzite there is a constant geometrical relation between the degree of the cleavage dip of the slate and of the dip of the beds of quartzite. The same thing is true, as he shows, in the horizontal relations between the

[1] Thürach, H., Ueber das Vorkommen mikroskopischer Zirkone u. Titan Mineralien in den Gesteinen: Verh. phys.-math. Gesellsch., Würzburg, N. F., Vol. XVIII, No. 10, 1884.

[2] Pfaff, E., Petrographische Untersuchungen über die eocenen Thonschiefer der Glarner Alpen: Sitzungsb. math.-phys. Classe k. k. Akad. der Wissenschaft., Munich, Vol. X, 1880, p. 479.

[3] Credner, G. R., Die Krystallinishchen Gemengtheile gewisser Schieferthone und Thone: Zeitschr. ges. Naturwiss., Halle, 1874.

[4] Elemente der Gesteinslehre, p. 424.

[5] Die Steiger Schiefer, op. cit., p. 120.

[6] Op. cit., supra, p. 480.

[7] Linck, G., Geognostisch petrographische Beschreibung des Grauwackengebirges von Weiler bei Weissenburg: Inaugural dissertation, Strasb., 1884.

[8] Bull. U. S. Geol. Survey No. 78, p. 13, 1891.

[9] See Bibliography, Becker, Van Hise, and Hoskins, and pp. 205–206 of this report.

strike of the cleavage, that of the quartzite bed, and the direction of movement:

Unless the ancient shore yielded to the pressure from the south the lower beds must have had a tendency to rise against that obstacle, to slide as a wedge between the obstacles and the overlying beds. The slaty material inclosed between the two beds of quartzite is thus pushed upward in a direction which is the component between a vertical line (i. e., vertical to the horizon) and the oblique movement of the wall (i. e., along the surface of the slate bed). Cleavage will be developed along that component, and we actually find that it dips 40° while the bed dips 27°.

His figure is here repeated (see fig. 14) with the construction added.[1] The gist of this is that if we knew the dip of the hard beds on either side of a bed of slate we could foretell the cleavage dip of the slate.

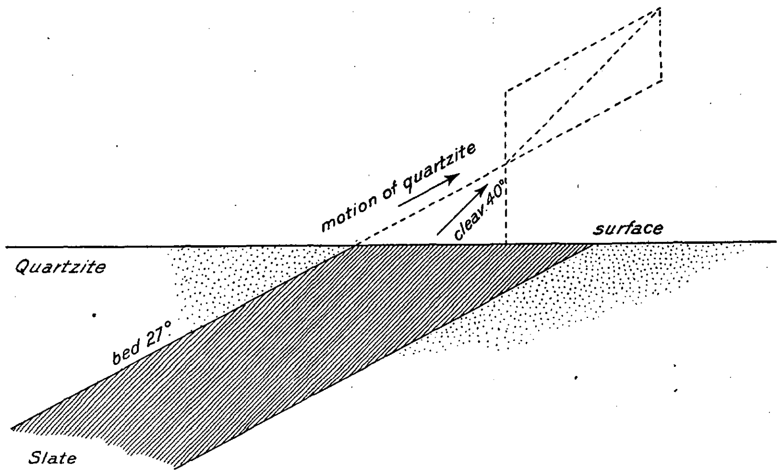

FIG. 14.—Diagram from Gosselet showing relations of cleavage of slate to dip of inclosing hard beds.

This, however, would be applicable only where no secondary disturbance of sufficient force to disturb the relations of the quartzite to the slate had occurred.

Amount of compression in the formation of slate.—Sorby calculated on a small bed of intensely plicated sandy slate, inclosed in ordinary slate, that the amount of shortening by plication was about 75 per cent, and reasons that the clayey material of the slate itself must, therefore, have been compressed to the same extent. This is the only way in which the amount of compression actually suffered by a mass of slate could be computed.[2]

Joint planes are simply ruptures of continuity. Exceptionally, later movements may cause slippage along joint planes and produce slickensides. The usual character of joint planes, however, points to a sudden

[1] Gosselet: Les schistes de Fumay, pp. 68, 69, fig. 5.
[2] On the origin of slaty cleavage, pp. 135, 140.

rupture of large masses of rock affected in all its parts by one and the same mechanical expression of energy.[1]

In the slate quarries of Angers, in western France, there are four systems of joints, one longitudinal with vertical dip, one lateral (also vertical and parallel to the cleavage), a horizontal one, and another at 45° to the vertical. At Rimogne in the Ardennes, in northeastern France, the cleavage dips 10°, forming an angle of 17° with the bedding. One set of joints is parallel to the grain. There are also two sets of longitudinal joints, one with vertical dip and the other intersecting the cleavage at about 22°. Leaving the bedding out each block of slate thus has a trapezohedral face.[2]

The grain.—Sharpe's explanation for slates splitting more readily along the "grain" than across it is that the particles lie with their flat surfaces parallel to the cleavage and their longer axes in the direction of the cleavage dip. A fracture across the cleavage and parallel to the dip is parallel to the longer side of the particles, whereas one parallel to the strike of the cleavage is across both longer and shorter sides.[3] The variation of the strike of the grain from the direction of the cleavage dip at Rimogne (Ardennes) is from 1 to 20°.[4] At Fumay, in the same region, that variation is 6 per cent.[5] At Rimogne the strike of the grain bisects the acute angle formed by two sets of joints. In some of the Ardennes slates plates of hematite lie in the "grain" and indicate its direction.[6] Renard states that the scales of chlorite lie perpendicular to the cleavage, i. e., about in the direction of the grain.[7] Jannetaz's experiments in reproducing grain have already been referred to (p. 210) and also his experiments showing that the direction of the grain is that of the greatest elasticity.[8] Daubrée, in one of his experiments, produces cleavage in the direction of pressure and motion—which is the relation of grain to pressure.[9] It seems, therefore, that besides the cause assigned to grain by Sharpe there is the formation of exceedingly obscure vertical divisional planes in the direction of the pressure and the crystallization of secondary minerals along these planes.[10] Watrin states that as the longer axes of distorted octahedra of magnetite all lie in the direction of the grain in some of the Ardennes slates, their combined magnetism gives a polarity to the slate in the direction of the grain and enables the quarrymen to ascertain its direction by the magnetic needle.

Relations of cleavage to axes of folds.—Some pre-Cambrian and Paleozoic schist masses have two transverse systems of folding which within limited areas interfere with one another; both systems are also inter-

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[1] Loretz, Ueber Schieferung, pp. 98-100.

[2] Renard, op. cit., Vol. II, p. 3; Daubrée, Études synthétiques, pp. 334, 335, and figs. 112, 113.

[3] Op. cit., p. 114.

[4] Daubrée and Renard, loc. cit.

[5] Renard, op. cit., III, p. 3.

[6] Daubrée, op. cit., p. 336.

[7] Renard, Vol. III, p. 235.

[8] P. 273.

[9] Op. cit., p. 422.

[10] See also p. 191, actinolite prisms with their broad sides transverse to cleavage and bedding of schist. Rosenbusch figures biotite scales transverse to cleavage: Elemente der Gesteinslehre, fig. 73 (p. 432), p. 437.

sected by a cleavage with a constant strike different from that of each.[1] Where only one system of folding occurs the strike of the cleavage is not necessarily parallel to that of the bedding. In such a case the cleavage is attributed to a change in the direction of the pressure[2] "The cleavage planes of the slate rocks of North Wales are always parallel to the main direction of the great anticlinical axes, but are not affected by the small undulations or contortions of these lines. The strike of the cleavage in a district is far more constant and regular than the strike of the beds."[3] To these facts should be added this—that in the case of a pitching fold the cleavage, although parallel to the axis of the fold, must necessarily intersect the strikes of the sides of the fold. Phillips gives a section from Sedgwick,[4] which he calls a local exception, in which the cleavage planes, while coinciding in strike with that of the anticline which they traverse, incline on either side of it toward its axis. Rogers[5] describes a case of this fan-like cleavage in an anticline. Such a structure could be produced by secondary movement creating an anticline in horizontal beds already possessing a vertical cleavage, and in the synclinal part of the fold the fan structure would radiate downward.

Sorby figures from Ilfracombe, North Devon,[6] a small, highly plicated bed of coarse-grained light-colored sandy slate traversing a mass of vertically cleft shaly slate. The gritty beds show a coarse and imperfect fan-like cleavage which curves slightly around the anticlines into the synclines. Here the fan structure seems to be due in part, at least, to the deflection of the cleavage by the coarser material, and there is no need of supposing a secondary movement. The fine and more plastic material has developed a vertical cleavage which in the coarser has become rudely fan-like.

Secondary cleavage.—Several writers—Sedgwick,[7] Phillips,[8] De la Beche,[9] Zirkel,[10] Loretz[11]—describe a striation or extremely fine plication on the cleavage surfaces of slate. This is the "bate" or "false cleavage" of quarrymen. Two systems of such lines or plications may occur in the same slate. These are due to a secondary and tertiary

[1] Loretz, Ueber Schieferung, pp. 69–70.

[2] Ibid., pp. 83, 84.

[3] Sharpe & Phillips, Contrib. to Geology of North Wales: Quart. Jour. Geol. Soc. London, Vol. II, 1846.

[4] Report on cleavage, p. 374.

[5] Geol. Surv. Pa., Vol. II, Part II, p. 903, fig. 715.

[6] On the origin of slaty cleavage, p. 138.

[7] "While my first observations on cleavage planes were made during long bygone years in Cumberland, I had hardly noticed the phenomenon of a second cleavage plane; but on many occasions I have subsequently collected, from various parts of England, a considerable and unpublished mass of materials in illustration of this second plane. The second cleavage plane is generally inclined at a great angle to the first plane. Most beautiful examples of this double structure were seen in 1839 by Sir R. Murchison and myself in the quarries of the Ardennes, where the fine, glossy surfaces of the slates are frequently marked by the parallel striæ of second cleavage, and the economical value of the slates is sometimes much deteriorated by the second plane. By a powerful reflected sunlight I have frequently been able to trace these striæ of a second cleavage on the surface of the Bangor slates which have been brought to Cambridge." Synopsis Classif. British Paleozoic Rocks, p. xxxv; London 1855. Also, by same author, Trans. Geol. Soc. 1840, p. 655.

[8] On a group of slate rocks, 1829, p. 1.

[9] Geol. Observer, second ed., 1853, p. 588, fig. 239.

[10] Lehrbuch, 1894, pp. 307, 308.

[11] Ueber Transversalschieferung, pp. 263, 264. Spurr, J. E., describes slates in Minnesota with two and three cleavages and bedding: Am. Jour. Sci., 3d ser., Vol. XLVIII, p. 159, 1894.

cleavage, a slip cleavage developed upon the primary slaty cleavage (see Pl. XXVIII). These may be sufficiently marked to allow the slate to break easily along the microscopic fault planes. Phillips describes abrupt changes in dip of the second cleavage.[1]

Faulting along cleavage planes is not uncommon,[2] and these faults are likely to be reversed faults.[3]

Zones of shearing, "hogbacks," Knickungsebenen, Querknicke.—These terms all apply to one and the same feature. Rosenbusch,[4] Brøgger,[5] Reusch,[6] and Turner[7] describe it from Norway, Saxony, Alsatia, and California. Its occurrence in the slate belt of eastern New York and western Vermont is fully described on pages 213, 214. These writers explain it as an angular plication, or a series of such plications, due to shearing pressure on somewhat rigid material. In places the pressure was great enough to produce a slight faulting on either side of the deflected portion or zone. Very rarely a cleavage foliation is produced within the zones. Mr. Turner's term abbreviated to shear zone affords a convenient designation, with the understanding, however, that in this sense it applies only to sedimentary rocks.

Curvature of the cleavage.—As far back as 1839 De la Beche called attention to the curvature of cleavage planes when approaching a bedding plane.[8] Baur in 1846 observed S-like cleavage foliation in Germany, and describes certain slates which were so much curved as to be fit for use only on the roofs of towers, but he does not explain whether this curvature was parallel or transverse to the bedding.[9] John Phillips, in his British Association Report, ascribed these curvatures to the differing density of the beds.[10] Harker in some cases attributes it to a gradual change in the texture of the bed.[11] In other cases a secondary motion is called in to explain it.[12]

Phillips in the same report[13] gives a figure, the original authorship of which is not mentioned, representing the cleavage surface of a piece of slate in which gently plicated ribbons are shown. A normal fault crosses the piece diagonally, displacing the beds. The cleavage surface also shows the "flexuous" lines of a third foliation oblique to the cleavage. Finally, two small calcite veins cross the primary cleavage, the plicated

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[1] Loc. cit., supra. [2] See Thirteenth Ann. Rept. U. S. Geol. Survey, Pl. CI, p. 320, fig. 26.

[3] Herbert, E. J., Reversed faults in bedded slates: Geol. Mag., N. S., Dec. II, Vol. IV, p. 441, 1877.

[4] Die Steiger Schiefer, 1877, p. 95.

[5] Brøgger, Die silurischen Etagen 2 u. 3 im Kristiania Gebiet auf Eker, p. 216, fig. 31, Kristiania, 1882.

[6] Reusch, H., Die fossilienführenden krystallinischen Schiefer von Bergen in Norwegen; German translation by R. Baldauf, pp. 52, 53, fig. 35; and p. 38, fig. 23, Leipzig, 1883.

[7] Turner, H. W., Further contributions to the geology of the Sierra Nevada: Seventeenth Ann. Rept. U. S. Geol. Survey, p. 662, fig. 22, 1896.

[8] Report on the Geology of Cornwall, Devon, and West Somerset, p. 620, fig. 31, London, 1839.

[9] Op. cit., pp. 392, 393, fig. 9.

[10] Op. cit., p. 384, fig. 23. See also Jukes: Quart. Jour. Geol. Soc., Vol. XXII, p. 359, 1866. That the angle and amount of cleavage change with the density of the rock was shown by Phillips in 1828. See also Harkness, op. cit., 1855. [11] On slaty cleavage, etc.

[12] Hughes, T. M., quoted in Lyell's Students' Elements, 7th ed., pp. 53, 573, fig. 625, 1871.

[13] P. 372, fig. 2.

bedding, the plicated secondary cleavage, and also the fault plane. The specimen thus bears traces of at least five, if not six, motions.

Slate folds.—Gosselet[1] gives some remarkable instances of intense and complex folding of beds of slate on a large scale. These great folds are very acute and overturned. In some places shafts have been dug through other rocks in order to reach underground portions of synclines and anticlines and quarry the slate. Slate quarrying in the Ardennes thus resembles coal mining in a region of intense folding.

Quartz veins in the cleavage foliation.—Sharpe alludes to many instances in North Devon of quartz veins occurring between the cleavage laminæ of slate. "The quartz, which is often an inch thick, lies partly between the beds, and then turns down the cleavage, forming irregular sheets between the slate, which frequently do not cross the whole thickness of the bed of slate. This has apparently followed upon the irregular gaping of some of the cleavage planes."[2]

Concretions of pyrite and quartz.—Müller describes such concretions in the slate quarries of Thüringen, and observes that the slate in their vicinity is of superior quality, containing less pyrite than it does at a distance from the nodules. The explanation is that all the pyrite has congregated in the large nodules instead of being more widely disseminated in small crystals. The nodules are thus of economic advantage.[3]

SCIENTIFIC RESULTS OF THE CHEMICAL AND MICROSCOPIC INVESTIGATIONS.

In view of the antiquity of the subject and the years of patient study which able men have given to it, it is not surprising that these investigations have done little more than to corroborate European ones and to transfer these methods to the study of American slates.

The slates of eastern New York and western Vermont seem to occupy a place midway between the phyllites of the Ardennes, in which the outlines of the clastic quartz grains are no longer visible, and clay slates like some of the Welsh slates, in which the sericitic matrix does not in cross section polarize as a uniaxial mineral. These slates polarize like phyllites and yet show many clastic grains of quartz and some of feldspar.

The presence of chlorite interleaved with muscovite (not talc), some of it lying across the cleavage, of tourmaline, of rutile, of zircon, hematite, cryptocrystalline quartz, pyrite, and carbonate are well-known features of slates. But the determination of the cause of the discoloration of the green and purple and black slates, about which statements have heretofore been somewhat vague, is an advance.

[1] L'Ardenne, p. 41, fig. 7, Les rapports de Ste. Marie avec les Trésfossés. Les schistes de Fumay, Pl. III, fig. 1: Bond dans les schistes de F may.

[2] On slaty cleavage: Quart. Jour. Geol. Soc. London, Vol. III, pp. 99–100, fig. 21, 1847.

[3] Op. cit., p. 218.

As to the question whether the sericitic matrix is of clastic or metamorphic origin, this may be said: There are here and there in the thin sections rather large and sometimes bent flakes of muscovite which may have been derived from the disintegration of a granitic or gneissic rock, as truly as were the angular feldspar and quartz grains, but these flakes would form but an insignificant part of the micaceous element, which constitutes probably about 40 per cent of the slate. As the pre-Cambrian or Archean rocks of the Green Mountain Range on the east and probably also of the Adirondacks on the northwest, the nearest sources of the slate sediments, are largely granitic or gneissoid, and as such rocks do not usually contain so high a percentage of mica, the products of their erosion, if evenly distributed over the sea floor, would hardly produce a rock of so micaceous a character. If, however, the materials were unequally distributed, the finer micaceous particles being separated from the coarser, the former furnishing material for an offshore slate, while the latter built up a quartzite inshore, our slate deposits might be accounted for. But it would have to be assumed either that the land mass contained muscovite in its sericitic form, or else that the ordinary flakes of mica were split up into these delicate shreds during erosion and sedimentation. The older rocks of the Green Mountain Range have not as yet been sufficiently explored to determine whether large areas of sericitic rock were above water in Cambrian time. In the absence of evidence it seems better to regard the sericite as formed in situ under metamorphic processes from the feldspathic part of the mud resulting from the disintegration of gneisses and granites. The sericite is the result of the sericitization of feldspar. The great scarcity of clastic grains of feldspar in the slates lends some support to this view. How much, if any, of this sericite was formed before or how much in direct consequence of the shearing compression which eventually brought the particles into the cleavage order is not manifest.

A comparison of the general average of the eight European analyses given on p. 261 with that of the American ones on p. 264 shows that the American slates fall in fairly well in chemical composition with the European ones. The European slates show an average of 3 per cent more Al_2O_3, almost 2 per cent more Fe_2O_3, 1 per cent less FeO, 1 per cent less MgO, nearly as much less K_2O, and 1 per cent less SiO_2. Such wholesale comparisons, however, have not much value.

The principal elements should be attributed to the following minerals:

SiO_2 to quartz, clastic or secondary, muscovite, feldspar, chlorite, tourmaline.
TiO_2 to the rutile needles.
Al_2O_3 to muscovite, feldspar, chlorite, tourmaline.
Fe_2O_3 to hematite, muscovite.
FeO to chlorite, the carbonate.
MnO to rhodocrosite in part, carbonate rhombs(?).
CaO to the carbonate of lime, iron, and magnesia.
BaO to barite and to(?).
MgO to chlorite, the carbonate.
K_2O to muscovite.

Na_2O to feldspar, muscovite.
Li_2O to tourmaline.
H_2O to chlorite.
P_2O_5 to apatite(?).
CO_2 to the carbonate and rhodocrosite, as above.
FeS_2 to pyrite.
SO_3 to barite, gypsum(?).
C to graphite or coal.

If the presence of kaolin could be shown it should be added opposite the H_2O, Al_2O_3, SiO_2.

The appendix by Dr. Hillebrand treats more fully of the chemical composition of the slates.

The mineral ingredients of the slates may be divided as to origin into (1) fragments of older rocks or (2) minerals formed within the deposits.

Clastic.	*Clastic or authigenous.*	*Authigenous.*
Quartz grains.	Rutile needles.	Cryptocrystalline quartz.
Felspar grains.	Tourmaline prisms.	Chlorite interleaved with muscovite.
Zircon grains.		Sericite (fibrous muscovite).
Muscovite scales.		Pyrite.
Carbonaceous matter.		Carbonate of lime, iron, and magnesia.
		Carbonate of manganese.

It is possible that a chemical deposition of the carbonates took place during the original sedimentation, and that it was subsequently transferred and crystallized, and so also with the pyrite.

The sizes of the mineral particles may be summarized:

Quartz grains, 0.013 to 0.347 by 0.0043 to 0.036 mm.

Feldspar grains, 0.043 by 0.052 mm.

Muscovite scales (clastic?) 0.015 to 0.060 mm.

Chlorite scales, 0.075 to 0.130 by 0.006 to 0.043 mm.

Carbonate rhombs, 0.002 to 0.065 mm.

Tourmaline prisms, 0.005 to 0.021 by 0.001 to 0.002 mm.

Rutile needles, 0.0017 to 0.0952 by 0.0006 to 0.0024 mm., averaging from 1,000 to 1,850 per square mm. or 900,000 per square inch of thin section.

Pyrite spherules, 0.0017 to 0.027 mm.

"Eyes" or lenses of cryptocrystalline quartz, or of rhodocrosite, 0.32 by 0.15 mm. (sometimes 1 mm. long).

Hematite dots, 0.0004 to 0.010 mm.

RELATIONS OF CAMBRIAN AND ORDOVICIAN IN THIS REGION.

A glance at the stratigraphical table (facing p. 178), at the sections (Pl. XVI), and at the general map (Pl. XIII) will show the apparently anomalous relations of the members of the Cambrian and Ordovician series throughout the slate belt. The Lower Cambrian, with Olenellus, is followed by the Calciferous and Hudson of the Ordovician. The

Calciferous is not certainly everywhere present and the Ferruginous quartzite (Horizon E) is intermittent, so that in many places but a few feet intervene between the Hudson graptolite (Normanskill fauna) and the Olenellus fossils. In other words, the Middle Cambrian (Paradoxides fauna) and the Upper Cambrian (Potsdam sandstone) are wanting and the section passes at once from Lower Cambrian to Lower Silurian, and that not at one exceptional locality or along one line or plane of apparent fracture, but at many exposures along intricate boundaries separating masses of complex folds. Another equally striking fact is

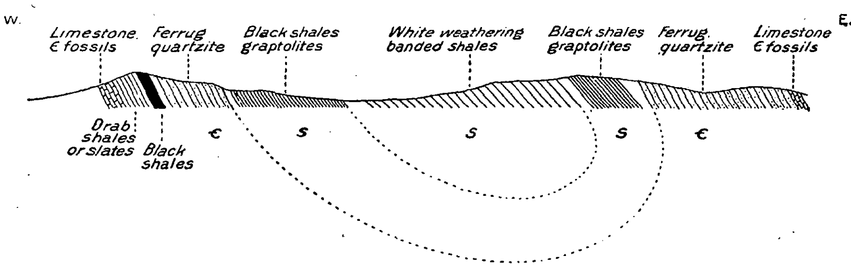

FIG. 15.—Field section showing relations of Ordovician and Cambrian in Granville, New York (by L. M. Prindle).

that the Lower Cambrian and the Ordovician, wherever their contact is fairly well exposed, occur in apparent conformity excepting at a few localities to be described. As illustrating these relations the field sections, figs. 15 and 16, are introduced. (See also fig. 9.) At the northern end and western side of the tongue of Silurian, which ends about a mile southwest of Middle Granville, Mr. Prindle found the following relations: A limestone breccia or conglomerate containing many fragments of Lower Cambrian fossils appears to pass a hundred feet south into a black shale containing flat lenticular limestone

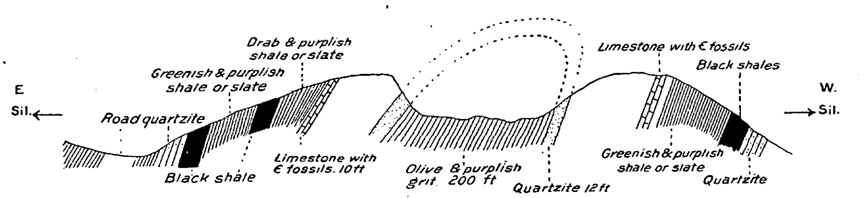

FIG. 16.—Field section showing order of Cambrian series in Hampton, New York (by L. M. Prindle).

nodules or pebbles, and this shale contains in places graptolites of undoubted Ordovician age. With this may be compared the relations along the Cambro-Silurian boundary at a point 1½ miles north of North Granville, where the Ferruginous quartzite series (Horizon E) and the Cambrian black shales (Horizon D) and the Olenellus limestone (Horizon B or D) all intervene between the Olive grit (Horizon A) and the Graptolite shales (Horizon G).

The apparent unconformities are these: At a point 2¾ miles north by northeast of West Granville, and the same distance north by northwest of North Granville, the Trenton limestone (Horizon Itl) occurs within a hundred feet of the Olive grits (Horizon A) of the Lower Cambrian, from 335 to 830 feet of Lower Cambrian being absent. There may possibly be other places along the western Cambro Ordovician boundary where the Ordovician rocks come in contact with some of the lower members of the Lower Cambrian series. Again, toward the southern end and western side of the same Cambrian area, 3 miles due south of the locality just described, at the top of a hill called the Pinnacle, Olenellus and Microdiscus occur in limestone dipping east, while 110 feet lower down the white weathering shales of the Ordovician (Horizon Hw) dip in minor step-like crenulations to the west. Along the western side of this isolated Cambrian area there may, therefore, be a thrust plane, but it would be difficult to explain all the Cambro-Ordovician boundaries of the map in that way because, first, the two formations usually succeed each other without the omissions noticed at these two localities; second, the beds of the region are all in minor folds, usually overturned to the west—i. e., with their axial planes dipping to the east—which has the effect of bringing the Cambrian beds on the eastern limbs of the syncline over the Ordovician ones, as shown in Sections I, V, VI, VII, Pl. XVI, which sufficiently explains their relations.

A longitudinal fault has long been known to exist along the east side of Lake Champlain. It is said to run from Quebec through western Vermont and along the east side of the Hudson south of Troy. One of its finest exposures is at Lone Rock Point (Seminary Point) on the shore of Lake Champlain, near and north of Burlington. This locality is well figured by Kemp and Marsters.[1]

The writer visited the spot in August, 1890, under Mr. Walcott's guidance, and the excursion was extended to Saint Albans and Highgate Falls, where the thrust reappears. At Burlington there are about 25 feet of Trenton (Hudson) shales at the edge of the lake, dipping easterly, overlain by about 40 feet of Winooski marble (Lower Cambrian), which project several feet beyond the shales toward the lake. The thrust plane dips 10 to 15° east, and the under side of the marble at the thrust plane is grooved in a southeast and northwest direction. The dip of the marble is not very different from that of the thrust, but is obscure. Mr. Walcott's measured section of the Cambrian series at Parker's quarry in the town of Georgia, south of Saint Albans Bay, was also visited.[2] The section is a mile long. The strata, which are continuously exposed, all dip east at 15 to 20°, belong to the Upper and Lower Olenellus zone, and measure about 1,000 feet in thickness. Along the shore of the bay there is a continuous outcrop of bluish Trenton limestone at the foot of low cliffs of Lower Cambrian limestone, and along the beach an outcrop of the Ordovician shales. At

[1] Kemp and Marsters: Bull. U. S. Geol. Survey No. 107, Pl. III.

[2] Walcott, C. D., Second Contribution to the Studies on the Cambrian Fauna of North America: Bull. U. S. Geol. Survey No. 30, pp. 15-19 and fig. 1, p. 16, 1886. Walcott, C. D., The Taconic System of Emmons, etc.: Am. Jour. Sci., 3d ser., Vol. XXXV, Pl. III, 1888.

Swanton the Winooski marble (Olenellus) dips 15 to 20° east, forming a line of cliffs facing westerly. East of these and overlying them are the Saint Albans shales of the Upper Olenellus zone. Low easterly dips continue for a considerable distance east, revealing a great series of Cambrian beds. At Highgate Falls the Missisquoi River cuts a gentle anticline and syncline of Chazy and Calciferous limestone thrust over a mass of westerly dipping brecciated limestone and slate, the thrust plane dipping low east. Here the relations of the two formations are reversed, the Ordovician being thrust over the Cambrian.

The striking features in all these localities, leaving out the last, are the unconformity of the dip, the great thickness of the Lower Cambrian, and the thrusting over of the latter on the Trenton. These features imply great rigidity in the beds and relief of compression through faulting. These, however, are just the features which are wanting along the slate belt. The Cambrian beds are all in minor folds, as are certainly the several isolated Ordovician areas and the large central ramifying ones. And there is no evidence of such a great overthrust as at Burlington and Saint Albans. But Mr. Walcott does find evidence of an overthrust on Bald Mountain, in the town of Greenwich, in Washington County, New York, west of the slate belt.[1] The exposures described near North Granville (p. 292) also indicate reverse faulting. Yet the course of the Cambro-Ordovician boundary along the western edge of the slate belt, particularly northeast and southwest of North Granville, New York, and in Benson and Hubbardton, Vermont, and again in the townships of Hartford, Argyle, and Hebron, New York, is hardly consistent with the existence there of a great longitudinal overthrust, nor do the vertical relations of the Ordovician and Cambrian outcrops favor such a construction. If such a thrust plane separates the two formations, it must be a folded thrust plane, which is not an ordinary probability.

It would appear, therefore, that the great mid-Silurian orogenic movement which, in northern Vermont, operating upon rigid beds, found relief in a great overthrust, at the south, near the slate belt, operating upon beds which were more plastic, compressed them into minute folds. In either case the compression at the south found relief chiefly in folding, and only here and there, as about North Granville and at Bald Mountain, in faulting. But evidences of faulting may be found west of the area here mapped.

For these reasons, assuming that the relations shown on the map between the Lower Cambrian with its Olenellus fauna and the Ordovician with its graptolites are not usually the result of an overthrust, the question remains, What are they? Several suppositions are possible:

1. That the Ordovician graptolites began in Upper and Middle Cambrian time, which paleontologists will hardly admit.

2. That the Upper Olenellus fauna continued through Middle and Upper Cambrian time, which they will be equally slow to admit.

[1] Walcott, C. D., The Taconic System of Emmons, p. 317, fig. 12.

3. That there was a slight unconformity between the Lower Cambrian and the Lower Silurian deposits which was afterwards concealed by the Green Mountain movement.

The presence of intraformational conglomerates[1] in the Cambrian of northern Vermont, and of conglomerates in the Cambrian Ferruginous quartzite (Horizon E) at Flint Hill (p. 184) shows that the region has been subject to frequent minor oscillations of level. The presence near the base of the Ordovician of a mass of grit containing fragments of slate, limestone, and quartzite, as shown on p. 187 (this grit being usually associated with Hudson graptolite shales) points plainly to some unconformity at that time. The chief objection to inferring from the particles of clastic rocks in the grits, an unconformity between the Cambrian and Ordovician is that these grits do not always occur at the contact with undoubted Cambrian rocks. Nonfossiliferous green slate beds with small quartzites of uncertain age sometimes intervene, and sometimes graptolite shales.[2]

Maps of the pre-Cambrian area about Lake George and Lake Champlain show isolated areas of "Potsdam" sandstone lying immediately on the pre-Cambrian and others intervening between the pre-Cambrian and the Ordovician limestone. If these areas should prove to be really Upper or even Middle Cambrian and not Lower Cambrian, it will show that the pre-Cambrian there was in places above water during Lower Cambrian time, while in others it was gradually subsiding during Cambrian time, so that the Upper Cambrian beds and in places even the Ordovician limestone covered the earlier formations by overlap.

That an unconformity between the Cambrian and Lower Silurian certainly did occur in eastern North America is shown at Point Levis, near Quebec, where limestone of the typical Calciferous (Levis) formation (lowest Ordovician) contains large and small bowlders of limestone carrying Potsdam or Upper Cambrian fossils. The difference between the relations in Canada and those of the slate belt of eastern New York lies in the apparent duration of the unconformity here through Middle and Upper Cambrian time.[3]

If suppositions 1 and 2 be inadmissible, 3 would, if adopted, mean that while the Potsdam (Upper Cambrian) beds were being deposited along the Adirondack shore, covering there by overlap the Lower and Middle Cambrian or else deposited directly on the pre-Cambrian, the Lower Cambrian beds of the slate belt were in places slightly

[1] Walcott, C. D., Paleozoic intraformational conglomerates: Bull. Geol. Soc. Am., Vol. V, pp. 191-198, 1894. Walcott, C. D., The Cambrian Rocks of Pennsylvania: Bull. U. S. Geol. Survey No. 134, p. 34, 1896.

[2] At a point in the town of Benson, about 3 miles northeast of Benson village, Mr. Prindle found an area of limestone with Ordovician gastropods. In contact with it on the west are dark shales containing a mass of fine quartz conglomerate 18 inches in diameter, such as characterizes the Cambrian in this region.

[3] See Ells, R. W., Second report on the geology of a portion of the Province of Quebec, Geol. and Nat. Hist. Survey of Canada, Rept. for 1887, vol. 3, pt. K, 1889. Walcott, Charles D., A review of Dr. R. W. Ells's Second report on the geology of a portion of the Province of Quebec, with additional notes on the Quebec group: Am. Jour. Sci., 3d ser., Vol. XXXIX, p. 111, 1890. Repeated in Bull. U. S. Geol. Survey No. 134, p. 35, 1896. Ells, R. W., The Potsdam and Calciferous Formations of Quebec and Eastern Ontario: Trans. Roy. Soc. Canada, Sec. IV, p. 29. 1894.

raised above water and furnished some of the material for the Hudson grits and the red slates. If this be the correct interpretation, it follows that some of the present boundaries between the Lower Cambrian and the Ordovician, after making liberal allowance for changes in level due to the mid-Silurian movement and to changes in surface due to erosion, may correspond more or less remotely to the shore lines of Ordovician time. Mr. Walcott closes his paper on Paleozoic intraformational conglomerates with these words: "The history of Appalachian sedimentation and mountain building proves that a more or less constant movement was taking place from Algonkian time to the close of the Paleozoic. This movement was at times greatly prolonged and resulted in marked topographic features. More frequently the minor movements produced local effects."[1]

In comparing the relations on the eastern side of the Taconic Range with those on the western a singular lack of correspondence between the beds on both sides of that synclinorium appears. On the east the marble beds (Stockbridge limestone) of Trenton, Chazy, Calciferous, and Lower Cambrian age,[2] measuring over 1,000 feet in thickness, dip westerly under the Ordovician schists of the range, while along the western foot of the range the Lower Cambrian slates, with Olenellus, crop out in close proximity to the Ordovician grits, graptolite shales, and schists.

If this condition of things were to be explained by faulting, we should expect to find the marble either part way up the western side of the range or else in the slate belt overlying the Lower Cambrian. Changes of sedimentation must evidently be called in to solve the problem. While the sediments east of the Taconic Range were largely calcareous in Cambrian and Trenton time, west of it they were mostly argillaceous and arenaceous. Some of the Ordovician series may thus represent the upper part of the Stockbridge limestone, and some of the Lower Cambrian series the lower part of the same formation. If the absence of the Upper and Middle Cambrian west of the range be explained by a slight unconformity, a similar one might exist on the east within the Stockbridge limestone.

As to the relations of the slate belt on the east: If the lower part of the Berkshire schist mass is the metamorphic equivalent of the Ordovician grits and slates, then that part stands in the same relations to the Lower Cambrian as do the grits and slates; i. e., wherever the western edge of the schist mass of the Taconic Range meets the Cambrian of the slate belt it is unconformably related to it, and also the Berkshire schist along its contact with the Lower Cambrian must represent a lower horizon than where, as on the east of the range, it overlies the

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[1] Loc. cit., p. 198.

[2] See Dana, James D., An account of the discoveries in Vermont geology of the Rev. Augustus Wing: Am. Jour. Sci., 3d ser., Vol. XIII, p. 332, 1877. Wolff, J. E., On the Lower Cambrian age of the Stockbridge limestone: Bull. Geol. Soc. Am., Vol. II, pp. 331-338, 1891. Dale, T. Nelson, On the structure of the ridge between the Taconic and Green mountain ranges in Vermont: Fourteenth Ann. Rept. U. S. Geol. Survey, pp. 525-529.

Stockbridge limestone. In other words, the lowest part of the Berkshire schist mass, where it meets the Cambrian, ought to correspond in age to the upper part of the Stockbridge limestone; i. e., the Trenton, Chazy, and Calciferous part. It is also probable that the schists of the Taconic Range represent a greater thickness of Ordovician than is present in the Ordovician areas of the slate belt. The Cambrian slates as they pass under the Taconic Range ought to become as metamorphic as the Silurian schists. The actual boundary between these slates and schists along the foot of the range is not well defined.

If a portion of the Cambrian areas of the slate belt were really exposed to atmospheric erosion during Ordovician time—i. e., during the deposition of the sediments which now constitute the Taconic Range—great changes of level must have taken place to lift the sediments of this Ordovician sea to such an altitude above the Cambrian lowlands.

The Hoosac schist of Hoosac Mountain[1] is a mass of metamorphic argillaceous sediments corresponding stratigraphically to the lower (Cambrian) as well as the upper (Ordovician) part of the Stockbridge limestone and also extending up into the Berkshire schist. It is, therefore, synchronous with at least a portion of the Lower Cambrian of the slate belt and also with the overlying Silurian grits and slates. What is seen to occur along the strike on Hoosac Mountain occurs in this region underneath the Taconic synclinorium. Again, in the western part of the slate belt Ordovician beds are represented by large areas of limestone with Trenton fossils, which may be simply the equivalent of the graptolite shales and red slates. We thus probably have here another change in sedimentation. As before, in passing from the eastern side of the range, the Cambrian and Ordovician beds change from marble to slates and grits, so still farther west the Ordovician sediments again become almost entirely calcareous.

Between Cambridge, New York, and Bennington, Vermont, the mutual surface relations of these two formations throw light on this question. First, there is a transition from north to south and from east to west between the Ordovician schists of the Taconic Range and the Hudson shales, slates, and grits. Second, the Stockbridge limestone here, owing to the erosion of the overlying schists of the range, crosses over from the Vermont Valley to the west side of the range. Third, part of the Stockbridge limestone in White Creek, New York, containing Lower Cambrian fossils, comes close to the Lower Cambrian sandstone, etc., on the north, and thus is of like age; while another part of the same limestone area, with such crinoid stems as are usual in the Ordovician, is in such relations to the Cambrian area and to the Ordovician shales and schists on the west side of the Taconic Range as to show that it is of the same age as the lower part of the mass. The

[1] See Mon. U. S. Geol. Survey, Vol. XXIII, Pumpelly, Wolff, and Dale, Geology of the Green Mountains in Massachusetts; Part I, General structure and correlation, by Raphael Pumpelly.

conclusion is that there were thereabouts local changes from calcareous to argillaceous, and arenaceous sedimentation during Cambrian time and again during Ordovician time.

Two features thus mark the region—frequency of movement and diversity of contemporaneous sediment.

The whole question of the relations of the Lower Cambrian and the Lower Ordovician to one another in this region is a complex one. It involves changes of fauna, of sediment, and of structure. The explanations offered in this chapter must be regarded as tentative rather than final.

STRUCTURE OF THE SLATE BELT.

The discussion of the relations of the two formations leads to the consideration of the structure of the slate belt in its broader aspects. Its features have already been described. If there was an original unconformity between the Cambrian and Ordovician, and if there is a great longitudinal overthrust along the western edge of the Cambrian area, both are now well obscured, the former by the great mid-Silurian movement which folded both series, the latter by erosion and Glacial and post-Glacial deposits. The Taconic Range, from its relation to those portions of it farther south which have been carefully studied, is regarded as a synclinorium. Its constituent folds are illustrated in Miss Bascom's Section VIII. At Pittsford the Stockbridge limestone dips conformably west under the schist of the range. The numerous north-northwesterly strikes which set in about the latitude of Fair Haven and Castleton, in the slate belt, and on the north side of the east-west cut in the Taconic Range, as well as in the marble at West Rutland, are related to the north-by-northwest trend of the range itself in Proctor and Pittsford.

Within the belt itself the abrupt termination of both Ordovician and Cambrian areas on the north and the south, the numerous projections and recesses by which the two formations are, as it were, dovetailed into each other, are probably due to the northward or southward pitch of the miniature anticlinoria and synclinoria; but if an unconformity at the close of the Cambrian be admitted, the possibility of some of these boundaries being the result of geographic relations in Ordovician time should not be forgotten. When the topography is compared with the geology it is difficult, in many places, to discern the connection between erosion and the structure or the material of the strata.

The structural feature, however, which most requires explanation is the relation of the Taconic synclinorium itself to the Cambro-Ordovician sediments of the slate belt. Why should the Ordovician sediments thin out at the west? Why should several hundreds of square miles of the underlying Cambrian be exposed? Were the Ordovician sediments originally thinner on the slate belt, i. e., was it an area of deeper water and, therefore, of less sedimentation, or, as previously suggested, was the slate belt a land surface submerged but here and there, with deeper water east of it? Or was the whole Cambrian area covered with the less metamorphic red and green slates, grits, and shales of the Ordovician, of which covering the present Ordovician areas of the west are but the shreds left by erosion? Or is the change in the topography from the range to the belt to be ascribed mainly to a change in the character of the folds in approaching or receding from the Green Mountain axis, the plication having been more intense and the thickening and metamorphism having consequently been greater eastward? And, for that reason, was the resistance to erosion greater eastward? If the theory of unconformity be not accepted, this latter view would have much to commend it. The conditions which produced slate in one place and schist in another during the same movement must have been different.[1] It is not clear here whether this was a matter of horizontal or of vertical zones, although more probably the former.

Another general question suggested by the structure of the region is as to the cause of the easterly inclination of the cleavage and of the axial planes of the folds wherever these are overturned. This easterly inclination of cleavage planes and generally of bedding also is such a conspicuous feature throughout the Taconic region that plowmen observe it and inquire as to its cause. Dana regarded the general structure of the Appalachians as indicating that the thrust was strongest on the side toward the ocean.[2] Professor Van Hise regards such folds as evidence that the preponderating force came from the east.[3]

GEOLOGICAL HISTORY OF THE SLATE BELT.

The geological history of the slate belt can not be written until the Adirondack border and the Green Mountain Range, as well as the Champlain Valley itself, shall have been carefully mapped and geologically studied. Some of the main outlines of that history, however, as generally received, are as follows:

First. A land surface chiefly of granites and gneisses.

Second. The advance of the sea in the earliest Cambrian. This is known as the "Cambrian transgression." The nearest land masses then were the Adirondacks and adjacent pre-Cambrian masses on the northwest and portions of the Green Mountain Range on the east. The ocean extended northward to the Saint Lawrence and westward to the Rockies, forming here, however, an inland arm between the Adirondacks and Green Mountain masses.

Third. The deposition of the Lower Cambrian sediments from the products of the erosion of these land masses. These sediments were mainly sandy and clayey, but sometimes calcareous and then largely of organic origin. The frequent alternation of fine and coarse sediments, and of these with calcareous ones, and the occurrence of con-

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[1] See Van Hise (op. cit.) on the causes of cleavage and "fissility."

[2] Dana, James D., Manual of Geology, 4th ed., 1895, p. 386.

[3] Op. cit., pp. 621-624, 664-668.

glomerates indicate changing conditions. There was deep and shallow water, quiet water and rapid currents, occasional exposure of the sea bottom to wave action and then its submergence, owing to minor oscillations of the earth's crust. These conditions were sometimes simultaneous but at different places or alternate at the same place. Slates and their interbedded quartzites correspond to extremely fine argillaceous sediments from the waste of feldspathic, micaceous and quartzose rocks (granites and gneisses) and to coarse sandy ones representing coarser material, probably from the same sources.[1] The purple slate probably indicates access of limonite from the land and the black slate more organisms on the sea floor. During this period there flourished a rich invertebrate fauna—sponges, anthozoans, hydrozoans, annelids, brachiopods, lamellibranchs, pteropods, trilobites, and phyllocarids. Trilobites, brachiopods, and annelids were the groups represented by the largest numbers, judging from the fossils. Minor oscillations of level characterize Cambrian time.

Fourth. Along the Adirondack shore Cambrian sediments may have continued to Upper Cambrian time, but within the slate belt, for some reason, there was no deposition during Middle and Upper Cambrian.[2]

Fifth. The Lower Cambrian sediments are followed by the grits, black, red and green shales and slates of the Ordovician. The same alternation of coarse and fine sediments continues. The Ordovician grits contain not only fragments from the granitic and gneissic masses, but also from sedimentary beds, limestones, slates, and quartzites, which must have been somewhere above water. The black Ordovician shales abound in graptolites and owe their carbon to organic matter. The red shales and slates, with their high percentage of ferric oxide and their proximity to the black shales, suggest the possible agency of decomposing organisms in their formations, and that either on land or in the sea.

Sixth. Probably at the close of Ordovician time the accumulated sediments, both Cambrian and Ordovician, gradually emerged in gentle folds which became closer and overturned to the west. Under increasing pressure new mineral combinations were formed in the sediments, particularly muscovite (sericite) and chlorite; limonite was reduced to hematite; cleavage foliation and grain were superinduced in the finer sediments. At the east, where the movement was more intense, the sediments were finely plicated and slip cleavage ensued. During the strain percolating alkaline waters took up silica and deposited it in such openings as were formed by the folding. Beds of quartz sandstone by the same agency were cemented into quartzite and veined

[1] Gosselet, in accounting for the alternation of slate and quartzite in the Ardennes, uses these words: "These inland seas were traversed, as are ours to-day, by currents which ran now in one direction, now in another. Wherever the current was strongest it carried more or less coarse-grained sand, which formed sandstones and arkoses, but wherever the waters were calm fine-grained sediments were deposited, giving rise to schists and slates; and the fauna became modified with the character of the sediments."—L'Ardenne, p. 178.

[2] See pp. 290-297 for discussion of this.

with quartz. Percolating acid waters took up lime and deposited it in new places. This folding resulted in such an elevation of the land that the sea retreated from the inland arm, but it still covered the area west and south of the Adirondacks, where its eastern shore was not far from the Hudson. To this period of folding probably dates also the great fault of the Champlain Valley.

Seventh. At some later time another movement occurred, resulting in various secondary structures, diagonal joints, slip cleavage superinduced on the slaty cleavage, quartz veins, minor faults and shear-zones ("hogbacks"). Some of the fractures were so deep as to occasion dikes, which traversed both the Cambrian and Ordovician sediments. New infiltrations of silica and carbonates took place in the openings made by this movement.

Eighth. The Cambro-Ordovician area between the Adirondacks and the Green Mountain highlands was then exposed to a long period of erosion from atmospheric agencies.[1] This period covers the remainder of Paleozoic, all of Mesozoic, and nearly all of Cenozoic time. Large areas of the Cambrian thus became denuded of their Ordovician sediments. The Ordovician schist mass became deeply dissected. Oscillations in level also took place during these ages.

Ninth. Direct atmospheric erosion was interrupted, however, by the southward extension of the north polar ice cap which rounded, furrowed, scratched, and polished the surface of every exposed slate ledge in the region.

Tenth. The retreat of the glacier left the surface covered with bowlders and morainal material, which was redistributed by the great streams from thawing ice.

Eleventh. A later depression of the Lake Champlain region, amounting to from 300 to 400 feet, let in the sea from the north, which formed a bay extending probably as far south as Albany and left sea beaches with marine shells above the lake.

Twelfth. The reelevation of the region brought in the present conditions and closed the history.[2]

[1] See an excellent statement of the principles of rock weathering by George P. Merrill, Jour. Geol., Vol. IV, p. 705, et seq., 1896.

[2] Since the completion of the MSS. of this chapter, Prof. J. F. Kemp's interesting paper on the Physiography of the Eastern Adirondacks in the Cambrian and Ordovician periods (Bull. Geol. Soc. Am., vol. 8, pp. 408-412, 1896), has reached the writer. Its views do not conflict with those here presented.

APPENDIX.

CHEMICAL NOTES ON THE COMPOSITION OF THE ROOFING SLATES OF EASTERN NEW YORK AND WESTERN VERMONT.

By W. F. HILLEBRAND.

Before the analyses of any of the slates were undertaken, it was well understood that the chief question of economic importance to be solved was the cause of fading observed in some, but not all, of the green slates after longer or shorter exposure to atmospheric influences. Attention was therefore primarily directed toward its elucidation, and the evidence accumulated will be herein set forth. Naturally, in the course of the work, opportunity was afforded for drawing conclusions as to the combination of certain chemical elements concerning which the microscope could furnish no satisfaction. A few remarks in this connection may therefore well be in place.

It soon became clear that there was no apparent connection between the percentage of iron sulphide (FeS_2) in any green slate and its liability to fade; that, furthermore, the visible sulphide was of an extremely resistant type, and often after years of exposure retained its original luster undimmed; that it was probably true pyrite. The possibility remained that there might be finely divided FeS_2 in the much more readily decomposable form of marcasite. Microscopical evidence made it clear that if present at all it was in amount altogether too trifling to produce the fading effect often observed.

It was found that the ferrous iron, other than that in the pyrite, was almost entirely in a very soluble condition. Even when carbonates were absent, a large proportion of it dissolved in moderately dilute acids after very few minutes boiling. But the ferrous iron thus shown to exist in the silicate minerals could not be accepted as the cause of fading, because it exists in all slates; and some of the most ferruginous, as 314 f, are "unfading." Microscopical evidence is also opposed to oxidation of ferrous silicates as the cause of fading.

There remained as its sole probable cause the carbonate found in nearly all of the slates. Its chemical behavior toward acids proves beyond question that this carbonate can be in no observed case calcite. Were it even in small part so, an instantaneous disengagement of gas would be apparent on adding acids, whereas their action is tardy and becomes pronounced only on application of heat. To those familiar with the behavior of different carbonates this evidence alone is decisive.

The carbonate is, therefore, an isomorphous mixture, and indeed the CO_2 found, as compared with the CaO, shows at once a great excess of the former. That $CaCO_3$ is one of the chief isomorphous constituents appears from the fact that absence of CO_2 uniformly accompanies the lowest trifling percentages of CaO, and that increase of CaO carries with it an approximately corresponding one of CO_2. The CO_2 is usually in molecular excess of the CaO, and sometimes of the MnO and FeO as well (compare analyses L, M, Q, R);[1] hence $MgCO_3$ is indicated as the next most important isomorphous element of the carbonate. Analyses M, Q, and R, taken together in the order named, afford positive evidence that $MnCO_3$ is present either as an independent mineral or as a component of the complex carbonate, for as CO_2 decreases from the green center through the purple rim to the outer red, so does MnO, and at such a rate that with no carbon dioxide MnO would likewise disappear. In general, too, those slates high in CO_2 show a relatively high MnO content. Analysis 201d (p. 260) shows also that manganese carbonate is found as a vein formation in the slates, and Professor Dale has found with the microscope some indications of its presence in the lenses of the red slate, at least. In order to be able to credit the fading to the carbonate, it is necessary still to show that it contains $FeCO_3$ as a constituent, for, while the manganese might produce discolorization by oxidizing, its amount is slight, and the color due to its oxidation products alone would be black rather than brown. Because of the above-mentioned ready solubility of the ferrous silicate or silicates in acids, chemical proof of the presence of ferrous carbonate is not obtainable, but from our general knowledge of its relations to those of magnesium and manganese it is in the highest degree probable that it does exist either as a distinct mineral or as a component of the dolomitic carbonate, and, in fact, it would be somewhat surprising if, with magnesium and manganese present as carbonates, iron should be absent. The needed proof, however, is supplied by the microscope, as detailed in the text of Professor Dale's report (p. 245).

If it is objected that some green slates comparatively rich in carbonate fade less than others which are much poorer, it may be reasonably urged that the relative proportions of the several carbonates are doubtless subject to change in different slates, as in the natural order of things, they must be, since the original composition of the slate-forming materials must have differed in each case. This being so, it

[1] See pp. 250 and 257.

follows that a mere test as to the relative amount of CO_2 can furnish no guide in advance as to the fading qualities of a slate, as might be the case were the composition of the mixed carbonates always constant.

While pyrite is never a visible constituent of the red slates, there seems no other way to account for the sulphur found, since careful tests failed by far to show an equivalent amount of SO_3. Hence in the analysis pyrite is reported in all cases.

The phenomenal percentage of barium in 201e (K), as compared with other slates, has been of service as showing that, in this case at least, it is mainly, if not altogether, a constituent of some silicate, or silicates, and not of barite only, which latter mineral, according to Professor Dale, has been observed on joint planes and in crystalline concretions, for the sulphur is totally inadequate to form barite in this case.

The condition of the nickel and cobalt has not been definitely ascertained. From the analysis of the manganese carbonate 201d it might appear as if they were constituents of the carbonate in the slates, but it is not impossible that they may be in combination with arsenic, or arsenic and sulphur, as arsenides or sulpharsenides, even if the presence of arsenic has not been revealed, no test having been made for that element. In all the tests made for nickel and cobalt, both elements were found, and in one case, probably a maximum, their combined percentage as oxides was 0.025.

Heating of the slates in tubes closed at one end gave without exception alkaline vapors and whitish sublimates, which latter reacted for SO_3, Cl, and strongly for NH_3. In eight cases the amount of ammonia thus given off in both conditions was ascertained by nesslerization and found to range from 0.0075 per cent in case of 760a (H) to 0.04 per cent for 305d (P). This last is a black slate carrying nearly 0.5 per cent of carbon, but the ammonia obtained was not sensibly higher than in some of the green slates, as 645a (F) with 0.035 per cent NH_3, or 3:4 of '95 (I), with 0.03 per cent NH_3.

Neither the condition nor the source of the nitrogen thus revealed can be stated with any degree of positiveness. It is found in the interior of fresh and unbroken masses, and hence is not to be regarded as derived from infiltration of nitrogenous matter since the opening of the quarries. Whatever may be its manner of combination, nitrogen is coming to be recognized as a primary constituent of many rocks and minerals. It seems probable that in the present instance its presence is to be attributed to that of the organic matter which was doubtless not wanting when the materials now composing the slates were originally laid down.

Chromium and vanadium are probably minor constituents of all the slates. They were not looked for in making the foregoing analyses, but in connection with some more recent work relating to the distribution of vanadium in the rocks of the earth's crust,[1] the sea-green slate 230a (A) and the red slates 201e (K) and 397e (L) were examined. In 201e there was found 0.017 per cent of vanadium as V_2O_5 and 0.007 per cent of chromium as Cr_2O_3. In a mixture of equal parts of the two red slates there was found of V_2O_5 0.008 per cent and Cr_2O_3 about as in the first case.

To the novice a cursory examination of the tabulated analyses might seem to indicate a greater diversity in essential composition than comports with the facts. Thus, there seems to be, perhaps, little relation in composition, except qualitatively, between the red slates 358d (J) and 397e (L). Yet, after deduction of all CaO as phosphate and carbonate, of all MnO as carbonate, and of enough MgO as carbonate to satisfy the remainder of the CO_2, also of the trace of pyrite, amounting to 16.58 per cent in all, and calculating the remaining 83.80 per cent to 100, there result the figures given in the first column below, for comparison with which analyses 358d (J) and 201e (K) of slates naturally altogether or nearly free from carbonates are partially reproduced.

Constituents.	397e (L).	358d (J).	201e (K).
SiO_2	67.40	67.61	67.55
TiO_2	.57	.56	.58
Al_2O_3	13.84	13.20	12.59
Fe_2O_3	4.15	5.36	5.61
FeO	1.70	1.20	1.24
BaO	.07	.04	.31
MgO	3.34	3.20	3.27
K_2O	4.50	4.45	4.13
Na_2O	.62	.67	.61
H_2O below 110° C	.44	.45	.40
H_2O above 110° C	3.37	2.97	3.03
	100.00	99.71	99.32

When it is borne in mind that a portion of the FeO in 397e should doubtless be credited to the carbonate, whereby an equivalent of MgO would be released for the silicate, it will be seen that the agreement as to FeO in the above comparison would be much closer, and the three slates may be said to have almost identically the same composition when compared in this manner.

Applying a similar correction to the three analyses of 397a R, Q, and M, in the order named, we obtain the following corrected figures for the green spot, the purple rim, and the outer red, which bring into

[1] Distribution and quantitative occurrence of vanadium and molybdenum in rocks of the United States, by W. F. Hillebrand: Am. Jour. Sci., Vol. VI, 1898, p. 209.

special prominence their relatively high silica contents as compared with all the other slates analyzed:

Constituents.	397a (R).	397a (Q).	397a (M).
SiO_2	76.04	73.64	71.59
TiO_2	.60	.58	.53
Al_2O_3	10.90	11.66	10.95
Fe_2O_3	1.27	2.04	4.33
FeO	1.23	1.36	1.61
BaO	.06	.05	.05
MgO	2.75	3.25	3.77
K_2O	4.15	4.22	3.87
Na_2O	.26	.26	.22
H_2O below 110° C	.29	.32	.30
H_2O above 110° C	2.45	2.61	2.78
Total	100.00	99.99	100.00

The foregoing calculations for 397e and 397a (L and M) show at the same time the general dolomitic character of the carbonate, as appears from the following table, wherein the percentages of carbonates are given as calculated on the above-predicated assumptions:

Constituents.	397e (L).	Molecular ratio.	397a (R).	Molecular ratio.	397a (Q).	Molecular ratio.	397a (M).	Molecular ratio.
$CaCO_3$	8.95	1.03	7.93	1.15	7.11	1.16	6.14	1.15
$MgCO_3$	6.93	1.00	5.36	1.00	4.77	1.00	4.22	1.00
$MnCO_3$	.48		.57		.47		.38	
Total.	16.38	....	13.86	....	12.35	....	10.74	....

If, as is quite probable, a small fraction of the CaO should be charged to the silicates, the true dolomitic ratio would be more closely approached. It is of no consequence for the above calculations that an undeterminable portion of $FeCO_3$ should appear as $MgCO_3$. The ratios are not thereby affected.

GLOSSARY OF GEOLOGICAL AND QUARRY TERMS.

As this report may be consulted for economic or other purposes by persons unfamiliar with geological science, a number of the commoner geological (mostly structural) terms used in it are here explained, and for the benefit of geologists some of the terms in common use among the quarrymen of the region are translated into scientific ones. Some of these quarry terms were given by Speer in the Report of the Tenth Census, but the list has been enlarged.

ALLOTRIOMORPHIC. Not freely crystallized; taking its shape from surrounding minerals.

AMYGDALOIDAL. Cellular. The vesicles formed by vapor become filled with mineral matter and are called amygdules.

ANTICLINE. The arch part of a folded bed.

ANTICLINORIUM. A mountain mass arch-shaped in its general internal structure.

AUTHIGENOUS. Minerals originating chemically within a rock are called authigenous.

BACK JOINT. Joint plane more or less parallel to the strike of the cleavage and frequently vertical.

BED. A continuous mass of material deposited under water at about one time.

BLIND JOINT. Obscure bedding plane.

BOTTOM JOINT. Joint or bedding plane horizontal or nearly so.

BRECCIA. Rock made up of angular fragments produced by crushing and then recemented by infiltrating mineral matter.

CLASTIC. Constituted of rocks or minerals which are fragments derived from other rocks.

CLEAVE. Slaty cleavage.

CONFORMITY. When two beds overlie in parallelism without any disturbance of the crust having affected the first one before the deposition of the second, they are said to be in conformity.

DIAGONAL JOINTS. Joints diagonal to the strike of the cleavage.

DIP. The degree and the direction of the inclination of a bed, cleavage plane, joint, etc.

DIP JOINT. Vertical joints about parallel to the direction of the cleavage dip.

DIKE. Molten material erupted through a narrow fissure.

END JOINT. Vertical joint about parallel to direction of the cleavage dip.

EROSION. The "wear" of a rock surface by natural mechanical, or chemical agencies.

FALSE CLEAVAGE. A secondary slip cleavage superinduced on slaty cleavage.

FAULT. A fracture resulting in a dislocation of the bedding or cleavage, one part sliding up or down, or both changing positions along the fracture.

FLINTS. A term applied alike to quartz veins or beds of quartzite.

FORMATION. A larger group of beds possessing some common general characteristics or fossil forms differing from those of the beds above and below.

GRAIN. An obscure vertical cleavage usually more or less parallel to the end or dip joints.

HOGBACKS. Zones of shearing (see p. 213).

HORIZON. A minor group of strata possessing some common characteristic.

ISOCLINAL. Folds with sides nearly parallel are said to be isoclinal.

OROGENIC. A movement of the earth's crust giving rise to mountains is called an orogenic movement.

PHENOCRYSTS. The large crystals first formed in the solidification of an eruptive.

PITCH. The inclination of the axis of a fold of rock.

POST. A mass of slate traversed by so many joints as to be useless. This term is also used to denote bands of hard rock.

RIBBON. A line of bedding or a thin bed appearing on the cleavage surface and sometimes of a different color.

SCULPING. Fracturing the slate along the grain, i. e., across the cleavage.

SHEAR ZONE. Hogback (see p. 213).

SLANT. Longitudinal joint more or less parallel to cleavage and often slickensided.

SLICKENSIDES. Surface of bed or joint plane along which the rock has slipped, polishing and grooving the surfaces.

SLIP. Occasional joint crossing the cleavage, but of no great continuity. Slips are not infrequently fault planes.

SLIP CLEAVAGE. Microscopic folding and fracture accompanied by slippage; quarrymen's "false cleavage" (see p. 209).

SPLIT. Slaty cleavage.

STRATUM. A bed.

STRATIFICATION. Bedding, in distinction from cleavage.

STRIKE. Direction at right angles to the inclination of a plane of bedding, cleavage, jointing, etc.

STRIKE JOINT. Joint parallel to the strike of the cleavage.

SULPHUR. Iron pyrite.

SYNCLINE. The trough part of a fold of rock.

SYNCLINORIUM. A mountain mass in general internal structure trough shaped.

TOP. The weathered surface of a slate mass, or the shattered upper part of it.

TRANSGRESSION. Submergence of a land surface and deposit of marine sediment thereon.

UNCONFORMITY. When the lower one of two contiguous deposits affords evidence of having been exposed to atmospheric erosion before the deposition of the upper one, there is said to be an unconformity between them.

WAVERS. Annelid trails.

WILD ROCK. Any rock not fit for commercial slate.

ZONE. Applied here to minor groups of strata characterized by a particular group of fossils.

THE COOS BAY COAL FIELD, OREGON

BY

J. S. DILLER

CONTENTS.

ILLUSTRATIONS.

THE COOS BAY COAL FIELD, OREGON.

By J. S. DILLER.

LOCATION AND SIZE.

The Coos Bay coal field, as shown in fig. 17, lies on the coast of Oregon somewhat more than 200 miles south of the mouth of the Columbia, among the foothills between the Coast Range and the Pacific. It has a length north and south of about 30 miles and a maximum breadth of about 11 miles, and it embraces nearly 250 square miles.

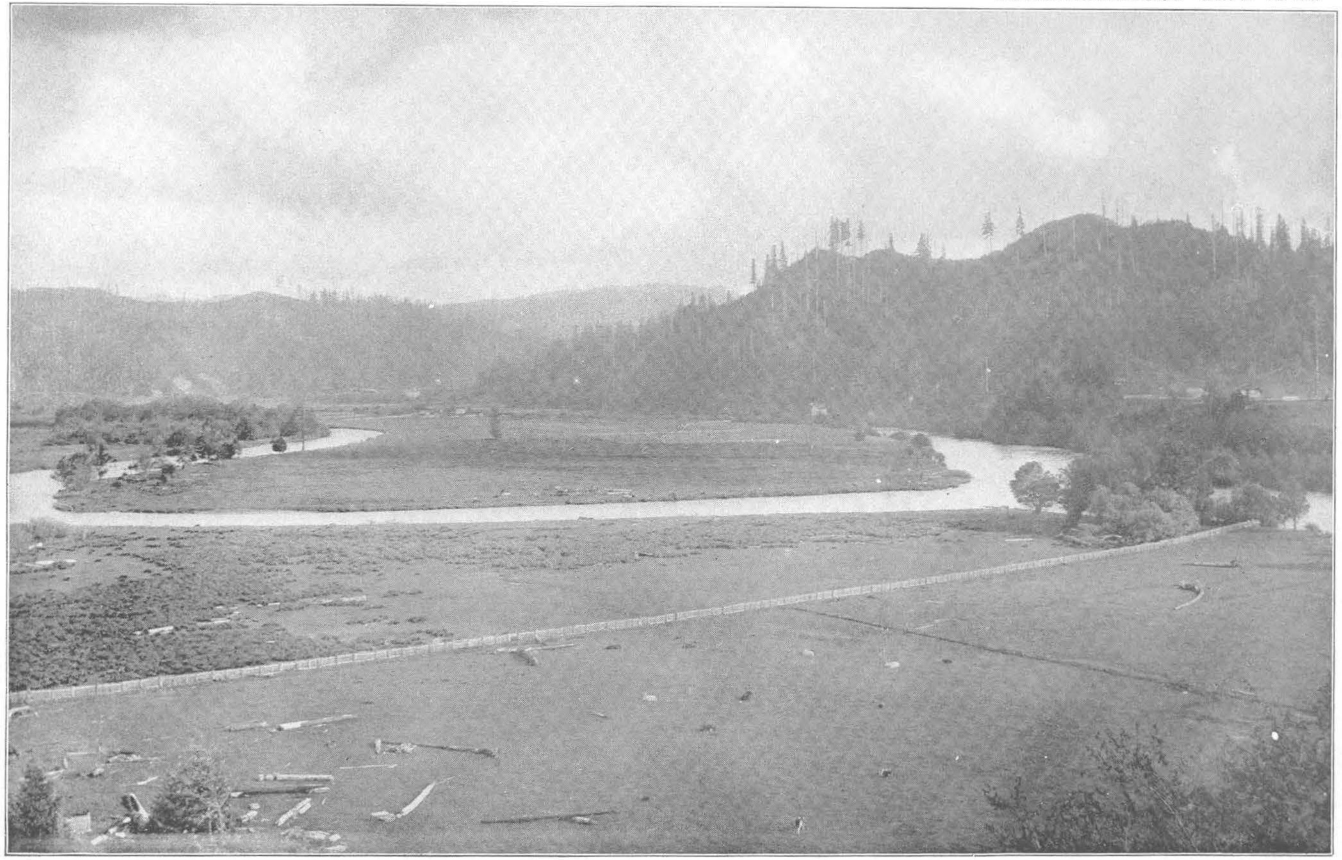
TOPOGRAPHY.

The region is decidedly hilly, but the hills have broad, flat tops and steep, terraced slopes leading down to the sea or tidal flats, with estuaries which furnish the natural outlet for the coal. These are the essential relief features of the coal field, and a knowledge of their origin will aid in understanding the development of the coal as well as the conditions under which it is mined.

The northern part of the field is intersected by Coos Bay, with its extensive flats and branching sloughs. The southern portion is traversed by the Coquille River, whose flats are, in places, equally as broad as those of the Coos, but are more generally raised above tide level, a feature which is due chiefly to the fact that the Coquille brings down and deposits along its course more sediment than does the Coos.

The flood plain of the Coos River is illustrated in Pl. XLII. Its elevation above the river increases upstream. Beyond the forks it rises about 15 feet above ordinary high tide, which extends up the river over 20 miles. It is formed of the sediment, mostly fine alluvium, brought down by the river. Here and there the flood plain is bordered by well-developed terraces, one of which may be seen at several points in Pl. XLII. The most sharply defined and persistent terrace is about 25 feet above the flood plain.

From the alluvial or flood plain the wooded slopes rise abruptly and steeply for a few hundred feet to the flat hilltops, which are generally broad. The highest of these within the coal field reach an altitude of about 800 feet above the sea. From that elevation down to the level of the beach and the tidal flats the descent is by successive terraces, such



FLOOD PLAINS AT FORKS OF COOS RIVER.

as are shown in Pl. XLIII in the distance upon the eastern slope of Seven Devils Hill. The meaning of these terraces can be most easily discovered by studying the seaward slope of the same hill, where the terraces are even more sharply developed and their relation to the beach is determinable.

In Pl. XLIV is a view of the coast at the mouth of Big Creek, a short distance south of Cape Gregory light-house, at the entrance of Coos Bay. There are three features which at once attract attention—two level tracts and a separating cliff. The first level tract is seen in the

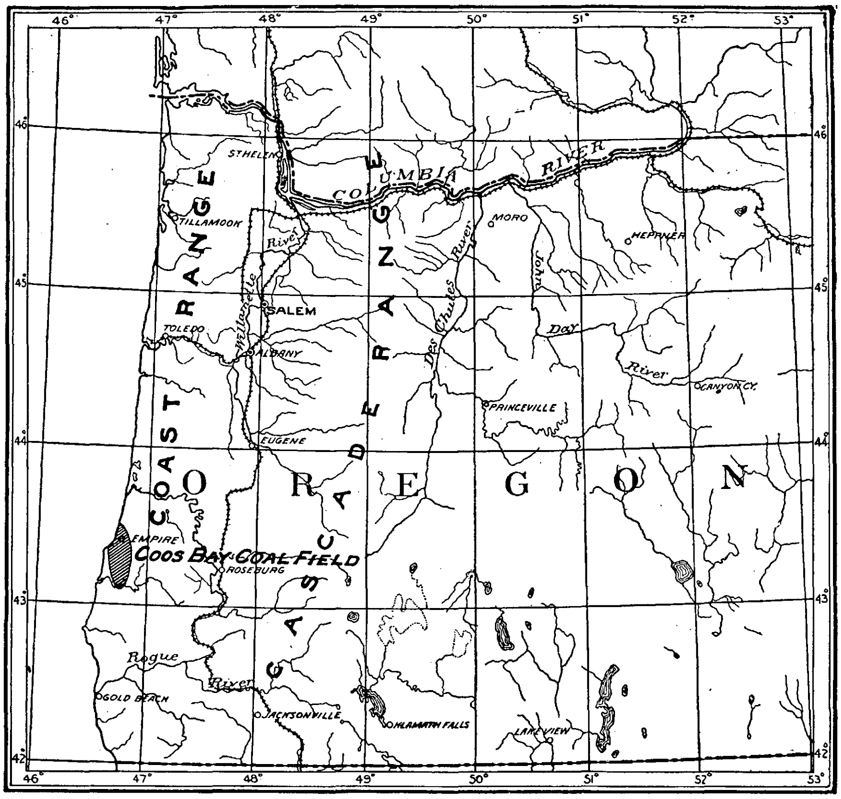
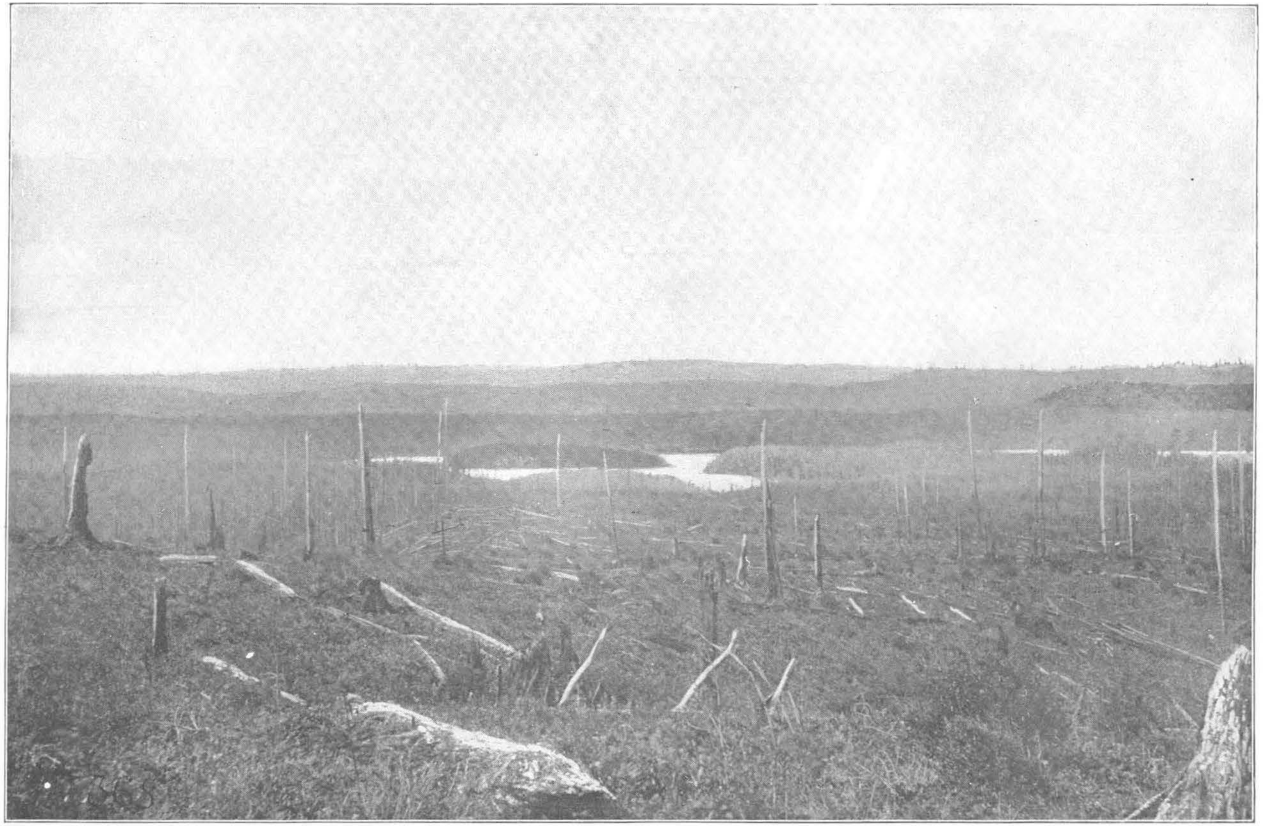


FIG. 17.—Map of western Oregon, showing the position of the Coos Bay coal field.

flat-topped hills rising to the same summit plain, which is marked upon the island at the left as well as upon the mainland. The second level tract is that of the beach, which extends to the sea cliff separating the two level tracts. The waves from winter storms dash landward against the cliffs and undermine them. Portions of the cliffs break off and fall upon the beach, and the material is removed by the retreating waves, thus developing, as shown in Pl. XLIV, a flat tract—a tract of marine planation at sea level. Upon the land, by long-continued action of rain and streams, the hills may be washed away and the land reduced to an



FLAT-TOPPED HILLS, LOOKING WEST ACROSS SOUTH SLOUGH.

approximate plain, which has been called the base-level plain of erosion because of its being determined by the sea level. Neither the sea itself nor the land streams can reduce the land to a lower level as long as the relative positions of land and sea remain unchanged.

In Pl. XLV appear the same two level tracts, and we see that they are cut upon sandstones and shales standing nearly on edge. It is evident from the relation of these level tracts in Pls. XLIV and XLV that when the upper one was developed the land stood lower than now and that what is now the flat top of the first terrace was then at sea level. Following the upper plain eastward from the coast, one soon comes to another cliff-like slope, which represents the sea cliff at the time the land stood at the lower level. The relation of the second cliff to the present coast line is shown in fig. 18. In Pl. XLVI is shown one of these old terraces or level-topped sea cliffs now nearly 2 miles from the sea, near the head of Whiskey Run, in sec. 21, T. 27 S., R. 14 W. At the base of these elevated sea cliffs are the ancient sea beaches, which frequently contain deposits of auriferous black sand. When the flat

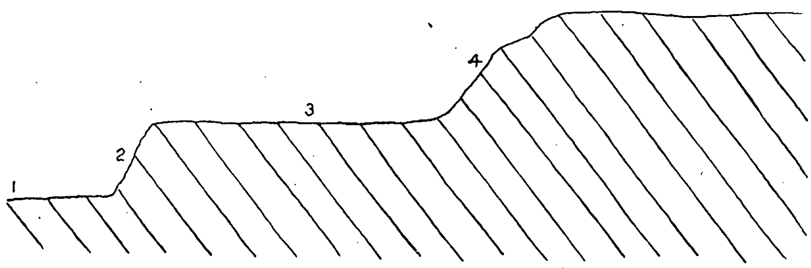


FIG. 18.—Section of present and elevated beaches 1 mile north of Cape Arago. 1, ocean; 2, present sea cliff; 3, ancient plain of wave erosion; 4, ancient sea cliff.

tract which forms the top of the terrace in Pl. XLVI was developed that tract was at sea level—i. e., at least 200 feet lower than it is at the present time. And so for each terrace to the highest, which is in places over 1,500 feet above the sea, upon the slopes and summits of the Coast Range. Many if not all of the successive terraces or elevated beaches were formed in order, beginning with the highest, as the land was raised above the sea. Each beach and sea cliff marks the level at which the land stood sufficiently long to allow the sea to carve out a plain of greater or less extent, in some measure proportional to the time the land remained at that level.

As the land was raised the streams acquired greater slope to the sea, and consequently greater power to carry away sediment and deepen their valleys. The Coos and Coquille rivers, with their tributaries, under such invigorating circumstances cut deep valleys, with steep slopes that extend far below the level of their present flood plains. This feature was discovered by borings made near the edge of the flood plains at Newport and Kentuck Slough.

Fig. 19 illustrates the boring made a few years ago by Mr. Campbell while prospecting for coal below the Newport vein near Newport. The boring was started in sandstone at the foot of a steep slope near the edge of the marsh. As reported by Mr. Campbell, it passed through about 20 feet of sandstone and then struck the marsh deposits, which it penetrated to a depth of 200 feet without reaching solid rock. The deposit contains logs in the mud, which is so soft that the boring could not be kept open and had to be abandoned. The outline of the valley below the surface of the flood plain, as indicated in the figure, must be a cliff. Some of the sandstone near the surface may have slid down from the adjacent slope, but it would not lessen the steep slope beneath the marsh. The slope beneath the marsh must be greater than above.

While prospecting for the Hardy and Steva coal beds along the northern shore of Kentuck Slough, a boring was made 60 feet from the slough. Starting on a steep slope 40 feet above the level of the slough, at a depth less than 100 feet the slough mud was struck, as at Newport.

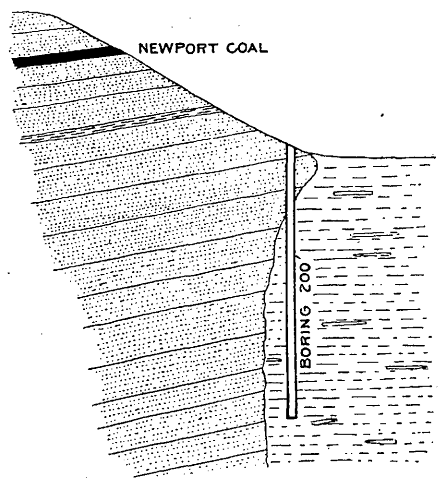


FIG. 19.—Section of bluff and marsh where boring was made near Newport (Libby) mine.

In neither of these cases was the solid rock beneath the slough reached. At Beaver Hill, near the border of the marsh, a boring was made to determine its depth. Mr. Whereat reports that solid rock was found 60 feet from the surface. The marsh at Beaver Hill is only a branch of the much larger one about Beaver Slough which flows into the Coquille. If the lateral valleys extend from 60 to 200 feet below tide level, the larger ones, like those of the Coos and the Coquille, must be much deeper.

It is evident that when these valleys were cut out to a depth far below the present sea level the land must have been elevated so that the bottoms of the valleys cut out by the streams were above sea level, where stream erosion is effective. At that time the coast must have been farther westward, and streams flowing into the ocean cut valleys across what is now the sea bottom. Such a submarine valley is clearly discernible by soundings opposite the mouth of the Columbia, but it has not been detected opposite the mouth of the Coquille or the Coos.

Since the land stood at a greater altitude and the deep valleys were cut the land has subsided, so that the tide extends far up the rivers, and the valleys have been filled with sediment up to tide level, making the flood plains bordering the rivers as we now see them.

GEOLOGY.

FORMATIONS OF THE COAL FIELD.

Having considered the forms of the surface and their origin, attention will now be given to the rocks—the geological formations of which the relief is made up. The areas occupied by some of the most important geological formations in the Coos Bay region are indicated upon the accompanying map, Pl. XLVIII. The legend shows that there are only four sedimentary rocks and one igneous rock whose outlines appear upon the map.

There are other formations, but they have been omitted from the map for various reasons. First, the gravels, sands, and clays of the marine terraces, which, although practically extending over the whole area mapped, have a complicated distribution in detail; and, second, the areas of chert and of amphibole-schist, like that of Tupper Rock at Bandon, which are generally too small for accurate representation upon a map of this scale. These will appear upon the map in the Coos Bay folio of the Geologic Atlas; they are of little consequence in considering the economic interests of the coal field.

ALLUVIUM.

The alluvium is chiefly fine silt, such as occurs upon the flood plains, with some sand and gravel, generally in the river terraces. This deposit is wholly the work of the present streams, principally the Coos and the Coquille. It is brought down from the rapid part of the streams in the mountains and deposited in their lower courses. The stream valleys in the mountains, as shown in Pl. XLVII, are rocky and contain scarcely any alluvium.

EMPIRE FORMATION.

The Empire formation is composed chiefly of shales and sandstones, often containing an abundance of Miocene fossils. This is especially the case along Coos Bay toward Empire from the mouth of South Slough. Coos Head is a massive sandstone, and along South Slough the shales are light colored, closely resembling some of those associated with the coal, and yet readily distinguished from them under the microscope by the curious minute fossils which they contain. The shales and thin sandstones along the coast south of Seven Devils are usually dark colored and much disturbed.

COALEDO AND PULASKI FORMATIONS.

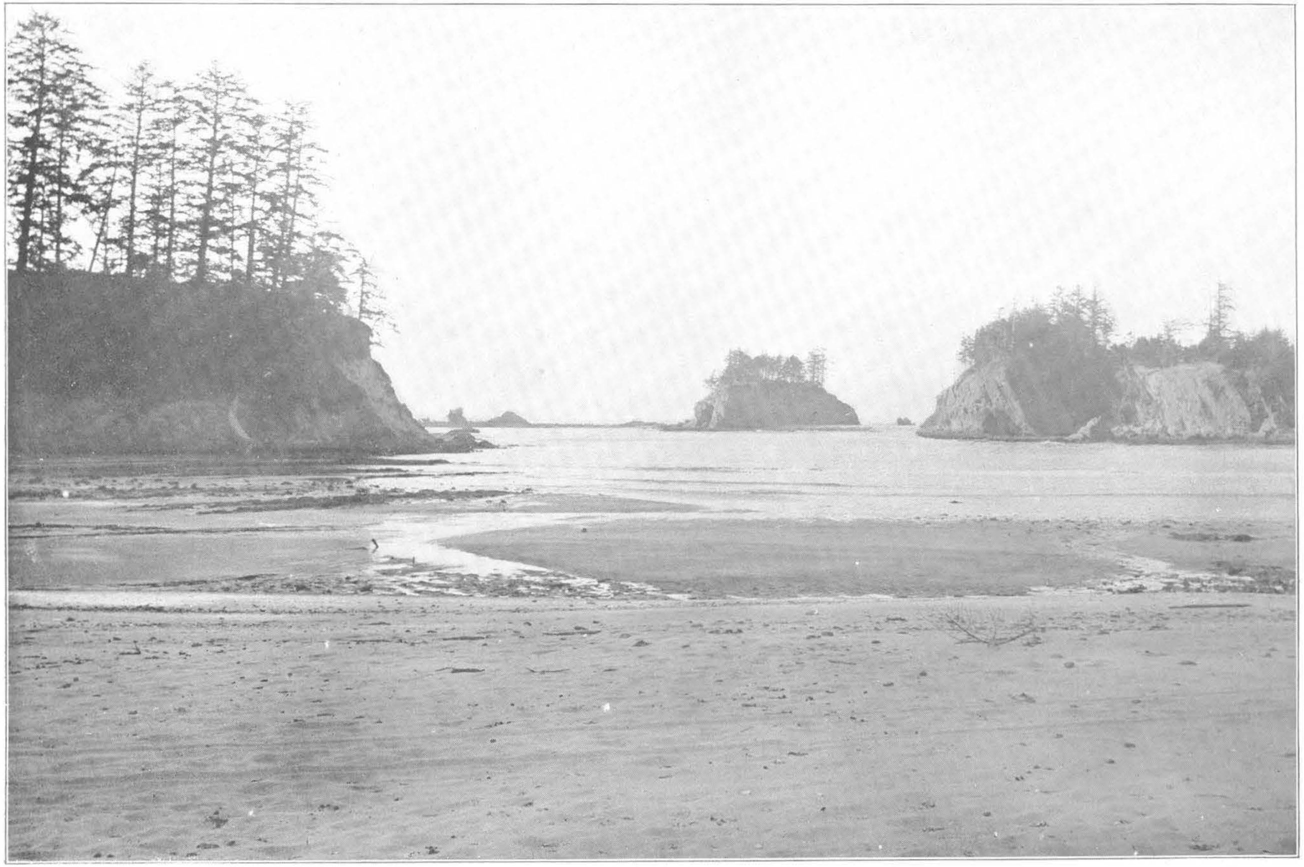
The formation which occupies almost the whole of the Coos Bay region is the Arago, which is composed generally of sandstones and shales. It is especially well exposed in the neighborhood of the mouth of Coos Bay and Cape Arago, where it contains *Cardita planicosta* and other characteristic Eocene fossils. Heavy-bedded sandstones prevail upon the eastern side of the area, toward the Coast Range, where the Eocene rocks have a wide distribution, and shales become abundantly interstratified with the sandstones toward the west, near the coast. Upon the eastern side of the quadrangle the sandstones are penetrated and separated by dark, heavy intrusions of an igneous rock—diabase—and the overlying sandstone near by generally contains much sediment derived from it.

The strata among which the coal beds are found contain at a number of places the fossils which characterize the Arago formation, and it is therefore evident that the strata immediately associated with the coal belong to that formation. For convenience and clearness, however, in describing the coal field it is necessary to consider the coal-bearing strata apart from the other portion of the Arago formation. For this purpose the coal-bearing strata will be designated the Coaledo formation, because it is well exposed in the vicinity of Coaledo. The other portion of the Arago formation will be designated the Pulaski formation, because it forms the hills about the head of Pulaski Creek and the Pulaski arch, which separates the Beaver Slough and Coquille coal basins.

The Coaledo formation, besides bearing coal, is found to contain characteristics by which it may be distinguished from the Pulaski formation. One of its especially interesting features is the occurrence of fresh- or brackish-water fossils in immediate connection with the coal, while between the coals, and sometimes rather close to them, purely marine fossils are occasionally found. The fresh- or brackish-water fossils most frequently occur in the roof, as at Newport, Beaver Hill, and Riverton, but may be found at some distance from the coal in the associated strata. They evidently indicate successive rising and falling of the land close to the sea level.

The Coaledo formation is younger than the Pulaski, which embraces the main body of the Arago formation surrounding the coal field. Brackish-water fossils have been found in rocks outside of the coal field at only a few places. Within the coal field, however, they occur at many places. The Coaledo formation is characterized not only by the presence of coal, but also by the relatively large proportion of beds containing brackish-water fossils. In the other portion of the Arago formation of the Coos Bay quadrangle more than mere traces of coal do not occur, and strata containing brackish-water fossils are rare.

Upon the accompanying map, Pl. XLVIII, is shown the area of the coal field, i. e., the region over which the Coaledo formation is exposed, except a small area which lies beyond the southern limit of the map. Besides coal the rocks of the Coaledo formation are sandstones and shales of considerable variety. In the lower portion sandstones predominate; then comes the portion where the workable coal beds occur,



BEACH, SEA CLIFF, AND FIRST TERRACE AT MOUTH OF BIG CREEK, NEAR CAPE GREGORY.

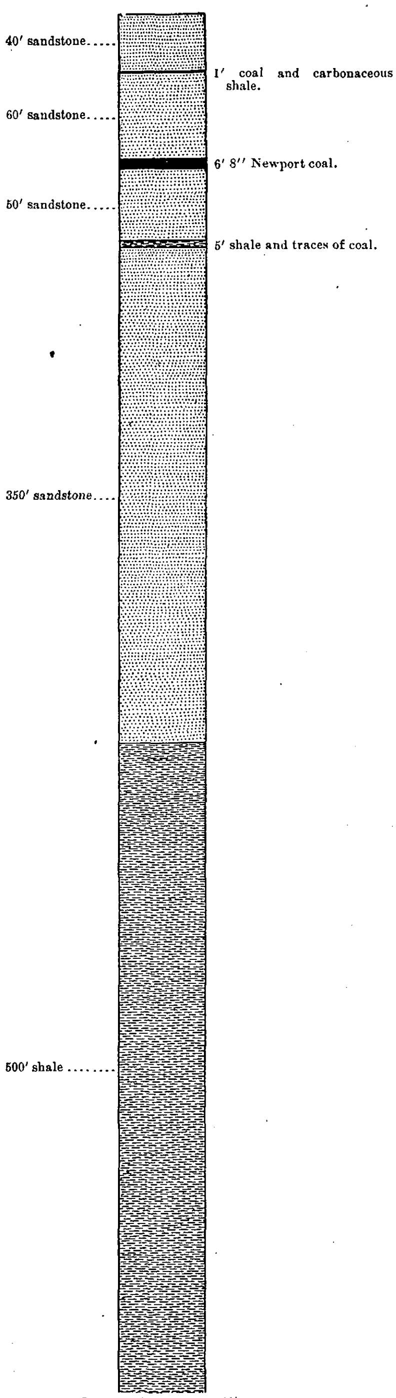
and the associated rocks are of about equal quantities of sandstones and rather dark-colored shales. In the upper portion light-colored shales are most abundant, and they are characteristic. Such shales do not occur in the Coos Bay quadrangle outside of the coal field. This fine, white shale of the Coaledo formation is well exposed by the roadside at a number of points between Coquille and Marshfield. When examined under a microscope it is found to contain numerous minute flakes of biotite-mica, with much clear, glassy material that looks like volcanic dust. A somewhat similar white shale occurs, as already noted, in the Empire formation on South Slough near the ferry, but under the microscope this is readily distinguished from the white shale of the Coaledo formation by means of the multitude of peculiar minute fossils which the former contains.

STRUCTURE OF THE COAL FIELD.

In its first stage of development the coal field must have been flat. The swamp in which the vegetation accumulated to form beds of coal extended more or less continuously over the whole field. It bordered upon the sea and was but little above the sea level. When the associated sandstones and shales containing fresh- or brackish-water shells were laid down the field must have been covered by fresh water or an arm of the sea, but when the sediments containing purely marine shells were deposited it must have been covered by the open ocean.

The gradual rising and sinking of the field, resulting in the alternate deposition of the coal, sandstone, and shale over the same area, was so slight that the strata were laid upon one another in parallel positions, but later, after the deposition of the coal was completed, there came a time of change, when the Coast Range was formed. The rocks, originally horizontal, were then compressed laterally and thrown into folds, i. e., into upward and downward flexures. On opposite sides of an upward flexure the strata incline away from each other, forming an anticline or arch, while on opposite sides of a downward flexure the strata incline toward each other, forming a syncline or basin. In either case, if the compression continues far enough the folds will be closed and the strata driven into a vertical position, or they may be overturned if the push is greater in one direction. During such folding the rocks are generally broken and displaced or faulted along lines of fracture. The coal fields have been affected in both ways, but most by folds. The faulting, so far as known, is of minor importance and the displacement is small.

Considering the folds of the coal-bearing rocks—the Coaledo formation—the coal field may be divided into six portions, four basins and two arches, all of which are marked upon the section sheet, Pl. XLIX. The basins contain the coal; the arches bring to the surface the underlying strata, which are generally without coal beds. The basins are the Newport, the Beaver Slough, the Coquille, and the South Slough.



Total thickness, 1,012′ 8″.

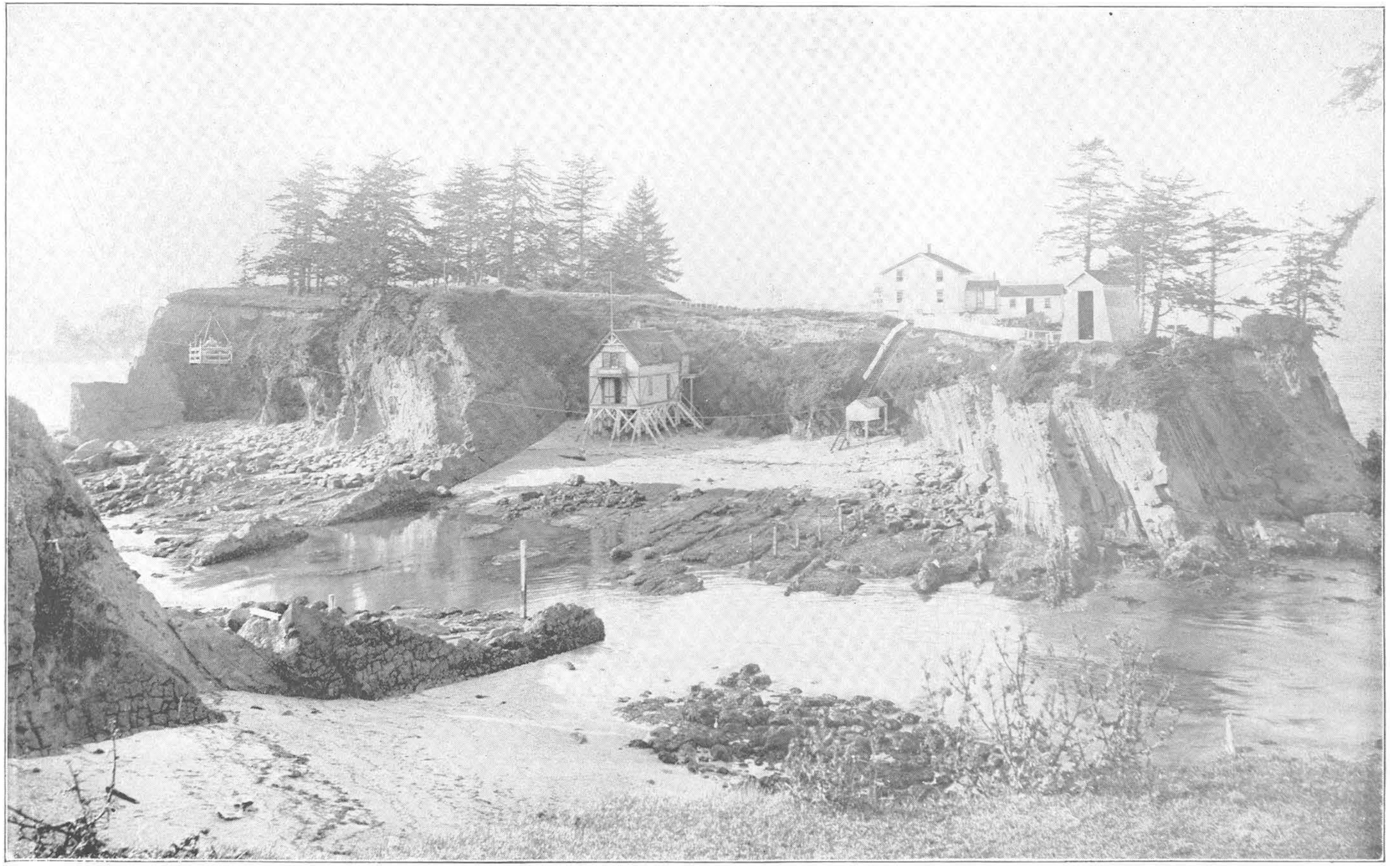
FIG. 20.—Section of coals and associated rocks, Newport mine.

These are separated by the Westport and Pulaski arches. Upon the structure sheet the attitude of the strata upon the surface is indicated by the strike and dip figure (—⊤—), and beneath the surface by a series of structure sections. The dark color used to represent the lower portion of the Coaledo formation, where coal occurs, makes the coal basins conspicuous, and these in turn bring out the anticlines between them. Upon the west the South Slough Basin appears in sections B, C, and D. The Newport Basin appears in B only, and the Coquille in D only, while the Beaver Slough Basin appears in all the sections.

NEWPORT BASIN.

The Newport Basin is named from its principal mine, the Newport, at Libby. Its length north and south from Yokam Hill to the neighborhood of Marshfield is about 3 miles. Excepting the trace of coal at North Bend, no coal has been found north of the ravine containing the Marshfield waterworks, although it is probable that the Newport Basin extends somewhat farther in that direction. The average breadth of the basin is about a mile, and it occupies the greater part of secs. 4 and 9, T. 26, as well as sec. 33, T. 25, besides small portions of several adjoining sections, so that the total area of the coal basin is nearly 3 square miles.

The Newport Basin has only one bed of coal extensively worked. The bed is generally known throughout the region as the Newport bed. It contains about 6 feet of coal in three benches, yielding 5 feet of workable coal. The basin originally contained over 6,000,000 tons of coal, a large part of which was available.



LIGHT-HOUSE ISLAND, CAPE GREGORY, AT MOUTH OF COOS BAY.

The Newport Basin is well defined, and the outcrop of its coal has been traced more carefully than that of any other portion of the field. It is the most conveniently situated with reference to coal shipment of all the productive portions of the coal field, and the attitude of the strata is such as greatly to facilitate mining. The basin is shallow, with gentle dips on both sides. It lies in a ridge so high above local drainage that the mine not only drains itself, but the coal is readily carried out of the mine by gravity alone. Three mines have been worked in the basin, but only one, the Newport, is now in operation. The Eastport was closed some years ago.

The most complete section of the strata involved in the Newport Basin is furnished by the borings made at Libby in prospecting for coal near the mouth of the Newport mine. One of the borings penetrated 800 feet. The section it revealed, together with that afforded by exposures near the mine, is shown in fig. 20. Overlying the Newport coal there is about 100 feet of sandstone, in which occurs a small bed of carbonaceous shale containing about 1 foot of coal. This is the only bed of coal known in the southern portion of the basin besides the Newport bed. Fifty feet below the Newport coal is a 5-foot bed of shale containing traces of coal. The deep boring was started at the bottom of the ravine, near the bunkers, about 100 feet below the Newport coal. According to Mr. Campbell, who was superintendent of the Newport mine when the boring was made, it penetrated 300 feet of sandstone and 500 feet of shale without finding any coal. This disclosed the fact that in the Newport Basin it is certain that there is no bed of coal within 900 feet below the Newport.

The Newport mine is operated by Goodall, Perkins & Co., of San Francisco, with Mr. P. Hennessey as superintendent, to whom I am much indebted for assistance while examining the mine. The opening of the mine is in Boatman Gulch, which cuts into the coal basin far enough to expose the coal at its lowest point, about 100 feet above sea level. The main entry of the mine may follow the coal along the bottom of the basin, and branching gangways lead from the main entry up the gently sloping (8°) sides of the basin. A stationary engine upon the coal outcropping at the edge of the basin draws the empty cars into the mine, and the loaded cars return to the surface by gravity, arriving at a sufficient elevation to allow for screening and storage before reaching the level of the railroad cars, in which it is taken down a gentle grade to the bunkers on the bay. Pl. L illustrates the bunkers at the mine; and in Pl. LI, on the left, is shown the bunker near Marshfield on the bay. The mine is so situated as to be operated very cheaply.

The southern end of the basin, under Yokam Hill, has been almost completely mined out. In that direction the bottom of the basin rises and the coal approaches the surface, but does not reach it to form a continuous outcrop of coal around the southern end of the basin. Mr. William Campbell was superintendent of the Newport mine when this portion was worked. He furnished me interesting data concerning the displacements found there. Figs. 21 and 22 show the position of the coal under Yokam Hill. Fig. 21 is a section east and west across the hill, the coal outcropping on both sides. Fig. 22 is a north-south section parallel to the axis of the basin. At *x* the coal runs out against a fault which is inclined to the north at an angle of 65°. On the south side of the fault the coal was found 50 feet higher than on the north side. At the time the faulting took place the coal on the north side slid downward upon the fault plane with reference to that on the south side, as indicated by the arrows. The plane of the fault indicated by the dotted line inclines (hades) toward the downthrow, and the fault is a normal one. Before reaching the surface at the southern end of Yokam Hill, the coal is cut off again by another fault. It was probably thrown up as before and is now washed away. The faults of the Coos Bay coal field are generally of the normal type—i. e., they hade to the downthrow, and this rule may be taken as a guide in searching for the continuation of a bed of coal cut off by a fault.

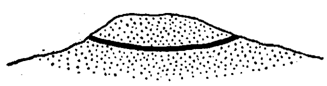


FIG. 21.—Section east and west across Yokam Hill.

A series of similar faults occurs about the limit between the old and the new portions of the Newport mine, near Boatman Gulch. The largest has a displacement of 50 feet, but the downthrow is on the southern side. The fault hades in the same direction. Fig. 23 illustrates the faults seen in one of the gangways recently worked. Although the strike of all the faults is approximately the same, lying between S. 60° and 90° W., they hade in different directions, and the displacement is generally small. The 50-foot faults already noted are among the largest found in the Coos Bay coal field. This group of faults is closely associated with the principal ravine, and in fact their presence may be taken as the feature which probably determined the development of the ravine at that point. The faults break up the strata and render them more easily eroded. It has been found to be generally true that near the ravines the coal beds are faulted.

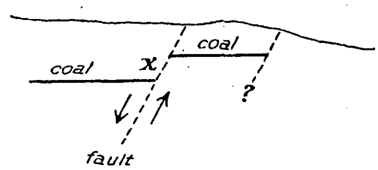


FIG. 22.—Section north and south across Yokam Hill showing fault of Newport coal bed.

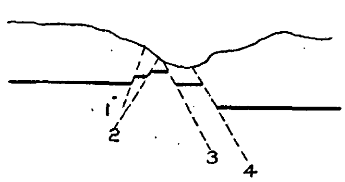
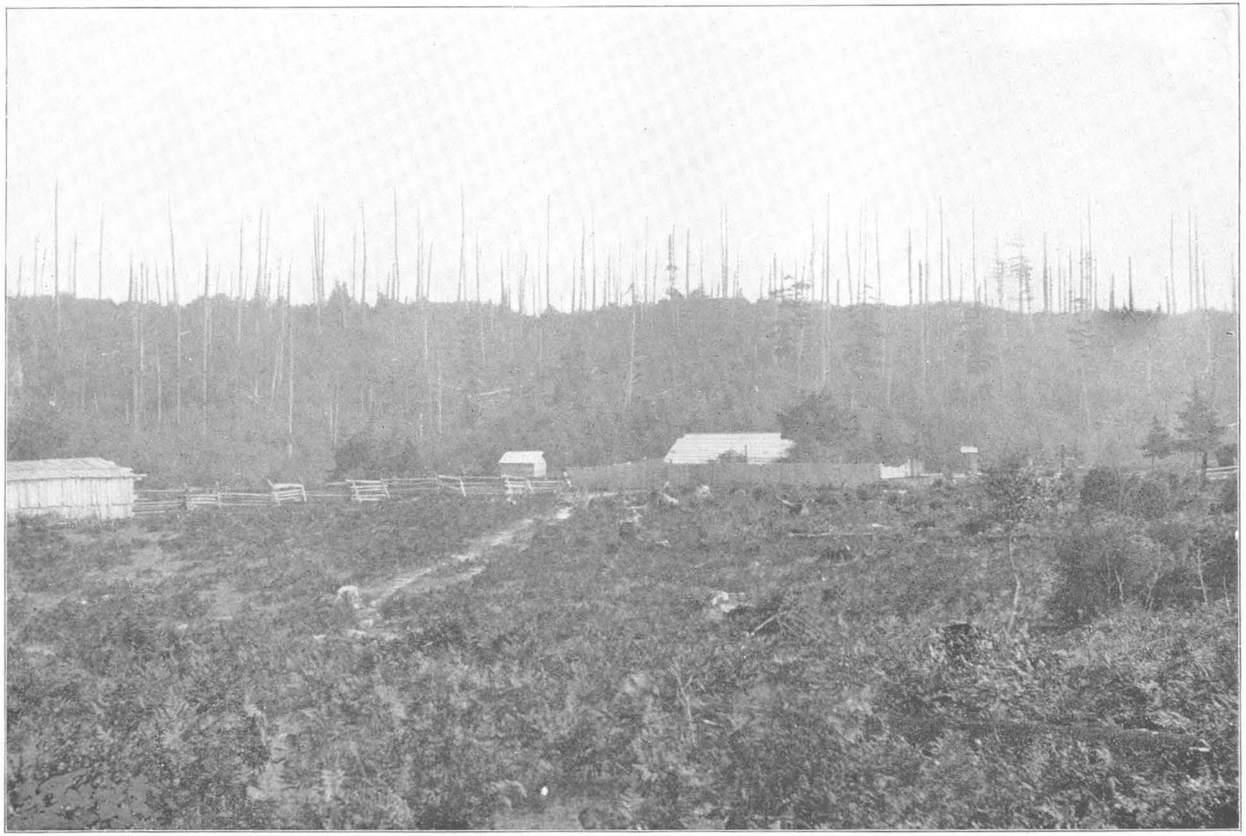


FIG. 23.—Section of faults at Newport mine.

Fig. 24 illustrates a section of the Newport bed in the Newport mine. The roof is generally sandstone, but locally shale, and requires comparatively little timbering. Where shale occurs in the roof it is usually full of brackish-water fossils. The top bench is usually left up with the



OLD TERRACE NEAR ROSE'S BLACK SAND MINE, 14 MILES SOUTHWEST OF MARSHFIELD, OREGON.

upper parting to form the roof. It occasionally contains small veins of pitch coal, which is of so much interest that it will be considered separately on page 368. The middle bench contains, within a few inches of its top, a red streak that is quite characteristic of the Newport bed, and is used by some as a means of identifying the Newport bed in various portions of the coal field. The bottom bench is regarded as the best coal at Newport, although it contains a little bony coal at the base. The different benches vary somewhat in thickness, but the triple arrangement extends throughout the Newport Basin, and even a considerable distance beyond, for it is possible to recognize the Newport bed over a wider area than any other one in the Coos Bay coal field, and it is found of much importance in working out the structure of the field. Analyses of coal from the Newport mine are numbered 1, 2, 3, and 4 in the list given on page 367.

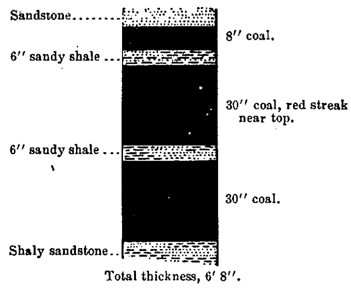


FIG. 24.—Section of Newport coal bed at Newport mine.

In the Newport mine the main entry is being extended northward along the bottom of the basin into the lowest underground openings of the Eastport mine, which has not been worked since 1881. The Eastport mine was operated from the side of the basin through a tunnel of nearly 1,000 feet and an incline of 1,600 feet, reaching not only the bottom of the basin, but ascending the western side a short distance. The incline runs westward, following the coal, first at an angle of 8°, but near the middle of the basin the coal lies flat, with small rolls and faults which render mining more expensive. Gangways were run north and south from the incline, in some cases for nearly 2,000 feet. The coal at the bottom of the basin is softer and not so good as that higher up on the slope. The coal was hauled up the incline, but the water was drained from near the bottom of the basin by a tunnel reaching the surface in Boatman Gulch. To the north the mine was limited by a fault running northwest and southeast, cutting the strata near the mouth of the tunnel, but crossing the bottom of the basin a considerable distance north of the foot of the incline. It is said that the downthrow is on the southern side; but as the tunnel has caved in, evidence concerning this matter could not be obtained. The coal has not been found immediately north of the fault. The Eastport was operated from 1855 to 1881. The property has lately passed into the

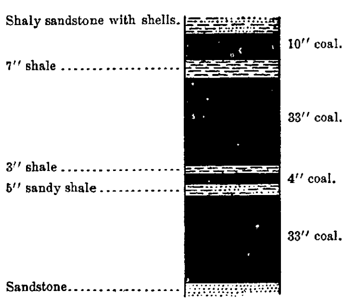


FIG. 25.—Section of Newport coal at South Marshfield mine.

hands of the company operating at Newport, from which side the mine can be worked most conveniently and cheaply. Although most of the coal has been removed from the southern half of the field, a large part of that in the northern half yet remains. The bottom of the basin appears to rise gently to the north, giving easy drainage in the opposite direction and forming the most natural outlet for the coal along the same line.

The outcrop of the coal about the northern end of the basin has not been traced so continuously, especially upon the slope of Pony Slough, as around the southern end and eastern side. North of the Eastport mine the Newport bed outcrops at the head of Galloway Gulch and swings around to the South Marshfield mine, which is at an elevation of about 200 feet above tide and scarcely a mile from Marshfield. The mine has been worked only for about a year, to supply local demand. One gangway is about 300 feet in length and another 100 feet, and over 600 tons of coal are said to have been removed. The dip is very gentle to the northwest, and the coal rises and falls in low wrinkles about a foot in height, so as to render the mining somewhat more difficult and expensive. The bed is evidently the same as that mined at Newport and Eastport, although on the whole somewhat larger, as shown by the accompanying section (fig. 25). The three benches are well marked, and in the overlying shales, as at Newport, brackish-water fossils are very abundant. The parting between the middle and lower benches varies in this small mine from 4 to 18 inches in thickness, and contains a thin layer of coal. The middle and lower benches of coal are somewhat thicker than at Newport. The middle bench in places, especially at the head of Galloway Gulch, contains a thin layer of shale about 6 inches above its base. The coming in of this bit of shale in the coal suggests that in the South Marshfield region we approach the limit of the swamp in which the Newport bed was formed. An analysis of the coal from the middle bench of the South Marshfield mine is given under No. 3 in the list on page 367.

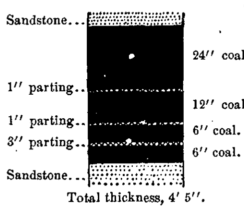


FIG. 26.—Section of coal near conduit of Marshfield waterworks.

The only coal bed of considerable size yet found in the Newport Basin as far north as the waterworks west of Marshfield is the one close to the pipe line where it descends the rocky bluff about a quarter of a mile from the reservoir. This coal was long since prospected by two tunnels, one 60 and the other 300 feet in length. For convenience of description this coal is called the Reservoir coal. It strikes a few degrees east of north and dips very gently northwest. It has the section indicated in fig. 26. The upper bench may be nearly 3 feet thick in places, and contains several thin layers of clay. It has recently been prospected by James Flanagan, and an analysis of the coal is No. 32

VALLEY OF SOUTH FORK OF COOS RIVER AT HEAD OF TIDE WATER.

on the list on page 367. The relation of this bed to the Newport bed is important.

At Newport, as shown in fig. 24, there is a small coal-bearing stratum 60 feet above the Newport bed, and another containing only a trace of coal 50 feet below the Newport bed. Which of these beds, if either, does the Reservoir coal represent? Judging from its location and position it would appear to lie below the Newport, but it is quite unlike the shale with a trace of coal found in a similar position at Newport. The distance between the two exposures at Newport and the Reservoir is only about 2 miles, and so great a change in the character of the bed, with the coal increasing away from the center of the coal field, would hardly be expected. No outcrop of coal below the Newport mine has been found between the two exposures, and the borings which are said to have been made on the hill half a mile east of the South Marshfield mine show no coal in that part of the basin for a distance of over 100 feet below the Newport. All these facts tend to show that the Reservoir coal is not below the Newport, but above it, and that there is an east-west fault along one of the ravines between the water-works and the South Marshfield mine. Although only one small bed occurs in the Newport Basin overlying the Newport bed, in the Beaver Basin, to be noted later, there are a number of coals within a few hundred feet above the Newport bed, and it is probable that the Reservoir coal is one of these. The reason why the other coals are not found throughout the Newport Basin south of the South Marshfield mine is because they have been washed away from the surface. The basin is too shallow to contain them.

If, as supposed, the Reservoir coal is one of the beds belonging above the Newport bed, then the Newport bed must extend somewhat farther north than Marshfield. The basin and a trace of coal also appear as far north as North Bend, but the thick covering of sand north of Marshfield renders prospecting especially difficult, and it is not surprising that so little coal has been discovered. Valuable information concerning the northern extension of the Newport coal and its relation to the Reservoir coal could be obtained by drilling a few hundred feet near the outcrop of the Reservoir coal.

A glance at the structure map will show that the Newport Basin is the smallest and shallowest basin of the coal field, and is the only one whose bottom lies above the tide level, thus affording a facility for economic mining which none of the other portions of the field enjoy. The reason for this exceptional position is due to its relation to the Westport arch, which is a broad one lying between the deeper basins of Beaver and South sloughs. The broad arch continues southwestward by the head of Davis Slough, where the strata are considerably disturbed. It is possible, but not probable, that there is another small basin, an extension of the Newport, in that region.

BEAVER SLOUGH BASIN.

The Beaver Slough coal basin takes its name from its principal slough, which lies near the middle of the most important portion of the basin. Beaver Slough Basin has a length of over 20 miles, extending from the neighborhood of Riverton northeast, between Isthmus and Catching sloughs, to the northern limit of Coos Bay. Its widest part is on the Coquille, where it is about 5 miles across. To the north it narrows as it approaches Coos Bay, and ends a short distance beyond Glasgow, where it joins the South Slough Basin. Its position, shape, and relation to the Newport Basin can be best seen upon the structure sheet.

The Beaver Slough Basin, although many times as large as the Newport Basin and containing much more coal, has not yet yielded so great an output, for the reason that it is not so conveniently located for economical mining. The basin is deep, extending far below the sea level, so that the removal of the coal to the surface, as well as the drainage and ventilation of the mine, is, in general, considerably more expensive than at Newport. Many mines have been started in this basin; the Beaverton, Timon, and perhaps several others are yet active, while the Glasgow, Southport, Henryville, and Utter mines are among those which have thus far proved unsuccessful. Only the lower portion of the Coaledo formation contains coal beds worthy of consideration. These crop out close to the border of the basin, or within the basin, only where brought to the surface by an upward bend of the strata.

In considering the details of the basin a section 1½ miles northeast of Beaver Hill will be noticed first, because it is one of the most complete sections known of the coal beds and their associated rocks. Beaver Hill will then be taken up, and the southwest side of the basin to Riverton and the southern end. Later the Utter, Henryville, Southport, and other mines and prospects will be considered in their order, and the northern end of the basin.

The section of coal beds most conveniently exposed for examination and measurement is on the land of Dean & Co., in the eastern part of sec. 9, T. 27, R. 13. It is illustrated in fig. 27. The total thickness of strata is 608 feet, containing 21 feet of coal in six beds, ranging from 1 to 6 feet of coal each, besides three beds of carbonaceous shale containing only traces of coal. Sections of the coal exposed on this property have been made by a number of other individuals, and a much larger number of coals have been reported. At the time the section noted in fig. 27 was made, the property had just been thoroughly prospected for Mr. R. A. Graham by a number of miners from Beaver Hill, and the coals opened for inspection. Detailed sections of the coal beds, on a larger scale, are given on the left of the complete section. Mr. L. A. Whereat, who has more carefully measured from the bottom

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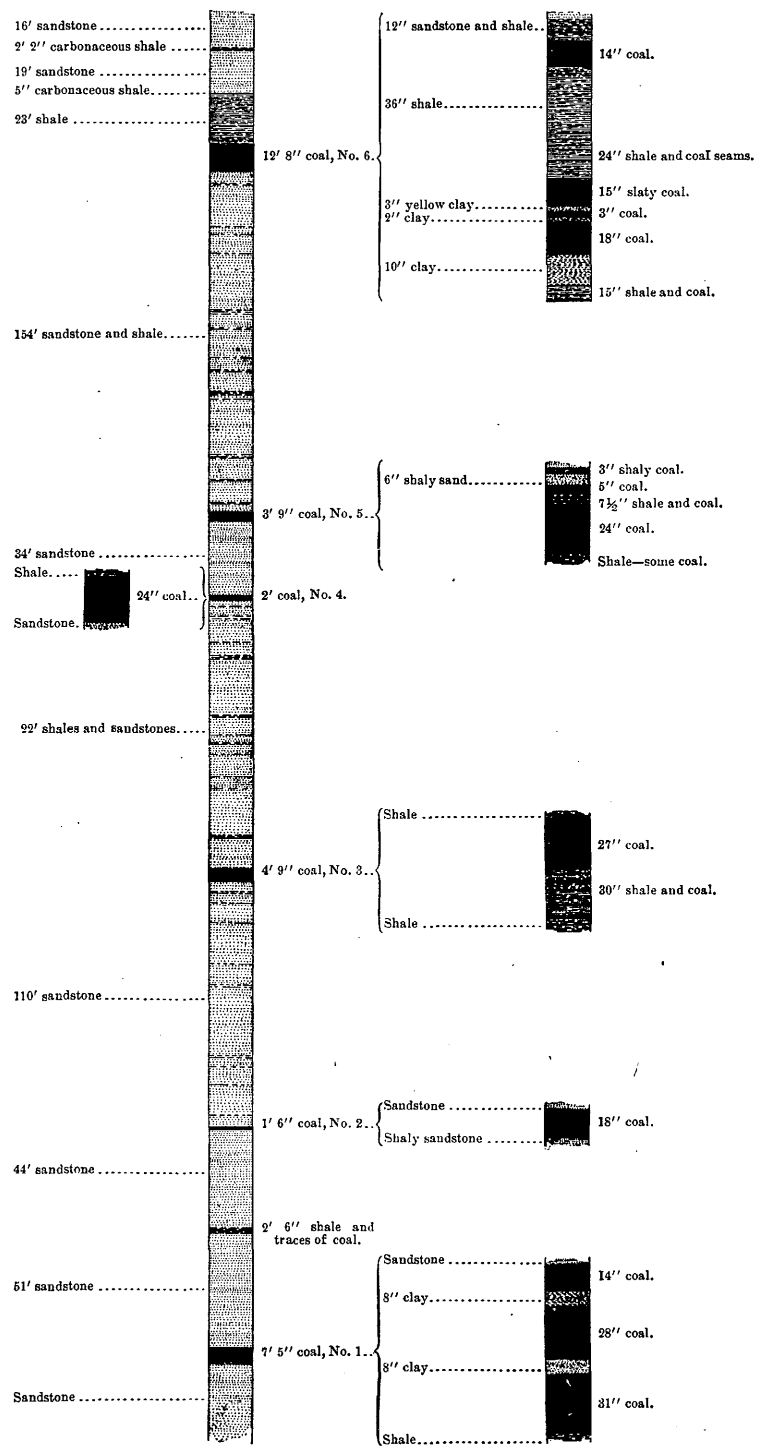


FIG. 27.—Sections of caols and associated rocks on Dean & Co.'s property, sec. 9, T. 27 S., R. 13 W.

of the Beaver Hill bed to the bottom of No. 2, found the distance 108 feet, or about 5 more than that given in the section.

The most important coal bed is the one at the bottom, which has over 6 feet of coal in three benches, with two small partings. Its general character at once suggests that it is the Newport bed, sections of which have been noted in various parts of the Newport Basin. The reasons for regarding it as the Newport bed are as follows:

(1) It has the same composition, structure, and size, and is unlike any other coal of the same series. The similarity in detail is marked, even to the red streak which occurs 3 inches below the top of the middle bench and the bony coal which occurs at the bottom of the lower bench. Not only the coal but the partings between the beds are quite alike.

(2) It is practically the bottom of the coal series exposed in the two basins. A trace of coal has been found below it on Dean & Co.'s land, as well as at Newport, but no workable bed has been found below it in either basin.

(3) It is in places immediately overlain by a layer of shale containing a multitude of brackish-water shells like those at Newport. This shell bed is not present everywhere in either basin, but is locally present in both.

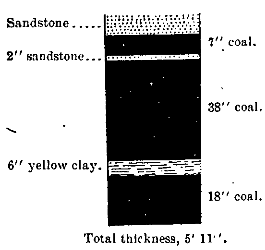
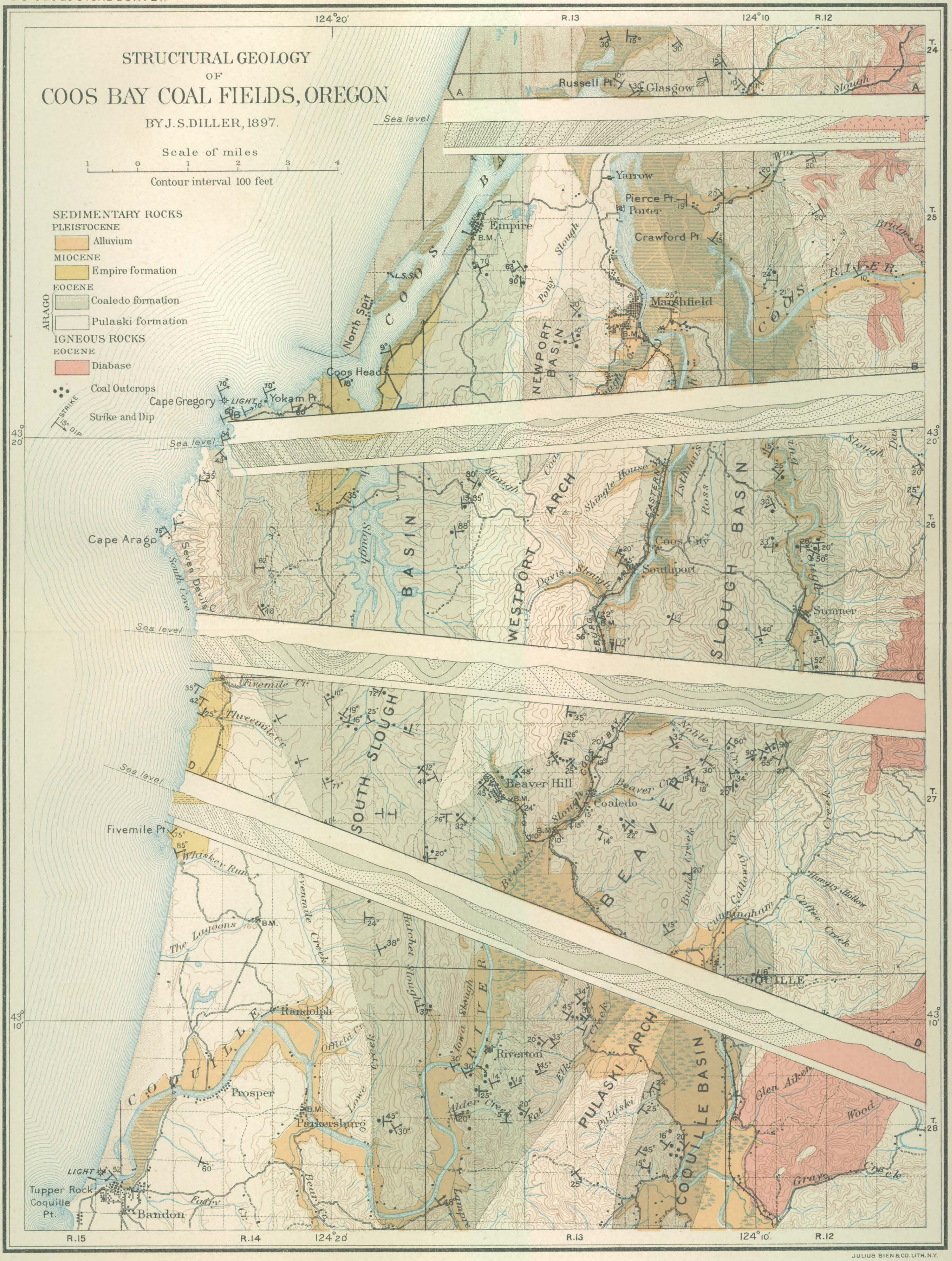


FIG. 28.—Section of Beaver Hill coal in Manning Gulch.

(4) The general structural relations are such as to show them to be the same bed of coal. The Newport Basin and the Beaver Slough Basin are separated by an arch of the sandstone below the Newport bed. It may be considered as practically certain that the Newport coal bed occurs near the bottom of both basins. It is the bed which is mined at Beaver Hill and Beaverton, where it is locally known as the Beaver Hill bed. It should be remembered that the Newport coal, Beaver Hill coal, and coal No. 1 on Dean & Co.'s property are all the same bed. The overlying coals are sometimes referred to by number with respect to the Beaver Hill.

The position of the coals at this place is somewhat variable, for the reason that the whole series to the north, having a strike nearly parallel to Isthmus Slough, here turns more westerly toward Beaver Hill. The position of No. 1 is, strike N. 52° E., dip 31° SE., and the top member, No. 6, strikes N. 50° E. and dips 25° SE. In the next gulch to the north, where a 400-foot tunnel has been run in upon No. 1, its strike along the tunnel varies from N. 10° E. to N. 30° W., but at the head of Manning Gulch, which reaches the slough near Kings Landing, the strike is N. 20° E., and is about normal. This is the most northern surface exposure of the Beaver Hill bed known within the Beaver Slough Basin. It doubtless extends much farther north, but has not been discovered upon the surface. Its section in Manning Gulch is given in fig. 28.



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Mr. C. H. Merchant, to whom I am indebted for many favors, has kindly furnished me a series of chemical analyses (6, 7, and 8, page 367) of the coal collected from the Beaver Hill bed on Dean & Co.'s property. The samples were in each case made up of fragments taken every few inches across the bench, so that the analyses of the coal in each bench represent much more fully than do ordinary analyses the chemical value of the coal. From the same source I have secured analyses 9 and 10 of the same bed in the eastern part of sec. 4, in Manning Gulch.

Beaver Hill until recently was the point of greatest activity on the Beaver Slough coal basin. I am much indebted to Mr. R. A. Graham, formerly the manager of the Beaver Hill Coal Company, and to Mr. L. A. Whereat, his civil engineer, for assistance while working in that region. The mine is on a branch of Beaver Slough, in sec. 17, only 1½ miles southwest of the locality where the section shown in fig. 27 is so well exposed. The exposures are few, but the prospecting in connection with the development of the Beaver Hill mine has brought to light the series shown in fig. 29. All of the members of the series shown in fig. 27 have not been discovered at Beaver Hill, and exposures are not such in this densely wooded region as to allow their relative position to be readily measured. The entire section of rocks immediately associated with the coal here appears to be about 550 feet, although this may be too high an estimate. It includes 15 feet of coal in five beds, ranging from 1 to 7 feet of coal each. The coal beds have been carefully measured, and sections of them are given in connection with the general section, fig. 29. At the bottom is an 18-inch coal, which is well exposed on the edge of the marsh nearly opposite the bunkers of the Beaver Hill mine. This small coal may represent the trace of coal reported below the Beaver Hill bed on Dean & Co.'s property, and also the trace of coal found in the 5-foot shale below the Newport bed at Newport. There can be no doubt as to its position with reference to the Beaver Hill bed at Beaver Hill, for both are exposed near together on the same side of the marsh.

None of the beds indicated in fig. 29 overlying the Beaver Hill bed are mined at Beaver Hill. Their outcrops occur within a mile southwest of the Beaver Hill mine, and their correlation with beds 3, 4, and 5 of the Dean & Co.'s coals (fig. 27) is probable.

The only coal mined at Beaver Hill is No. 1, and it is regarded as one of the best coals in the whole field. The Beaver Hill bed, as already indicated, is the same as the Newport bed. Pl. LII shows the settlement at the mine as seen from the trestle that spans the Caulfield branch of the marsh about Beaver Slough, while Pl. LIII represents the bunkers, and Pl. LIV the end of the rock tunnel leading into the Beaver Hill mine. An adit near by runs in upon the coal, and at a distance of 980 feet from the mouth an incline follows the coal, dipping southeast toward the basin. The incline has a length of 732 feet,

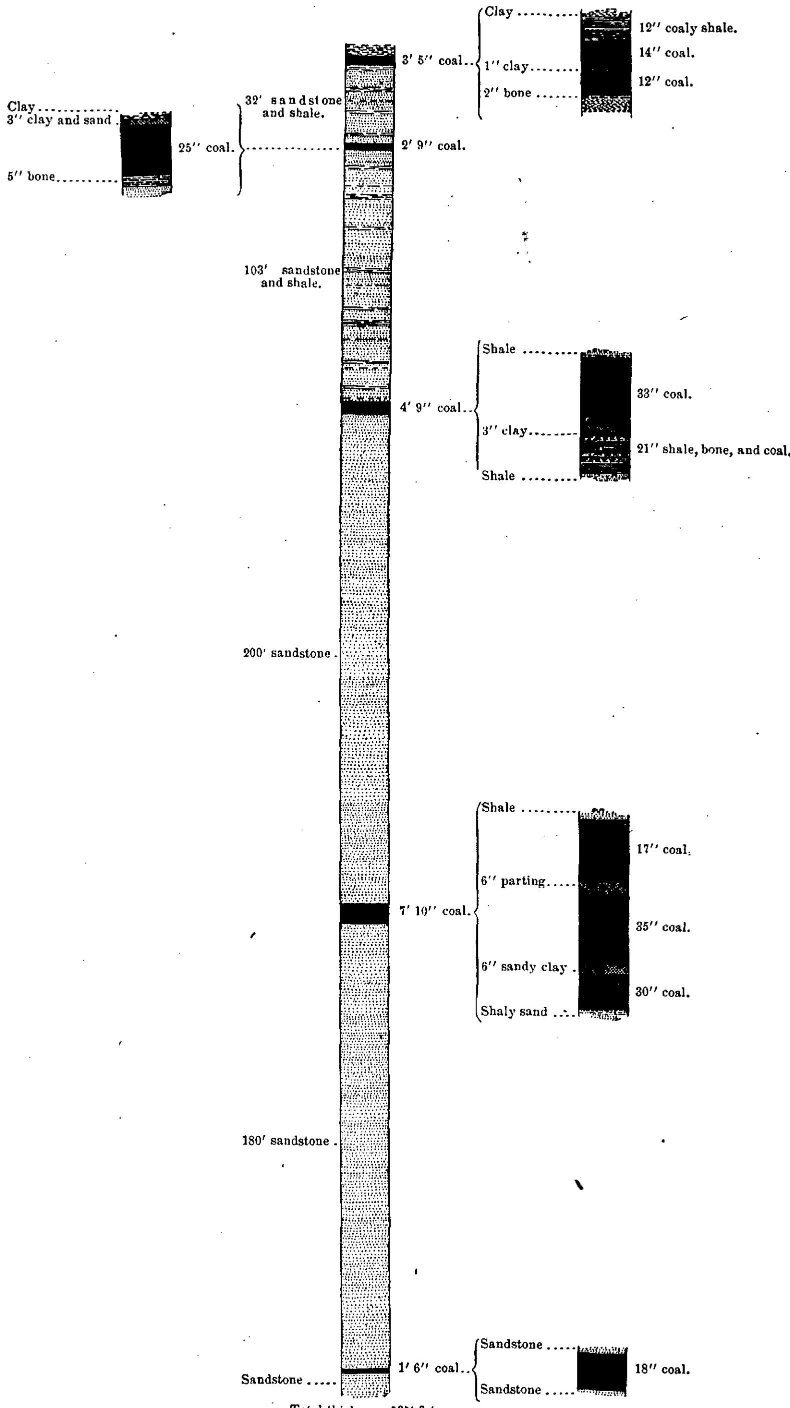
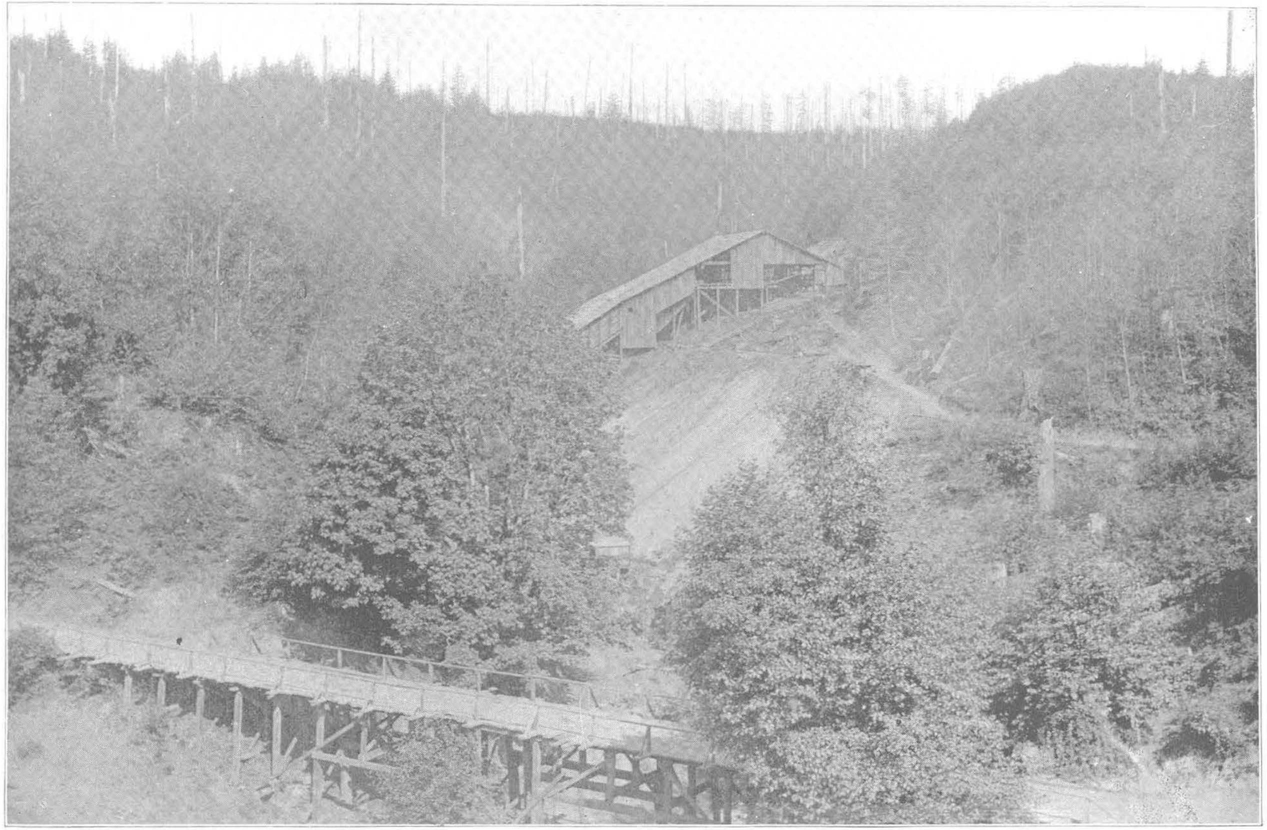


FIG. 29.—Section of coals and associated rocks at Beaver Hill.



BUNKERS AT NEWPORT MINE.

and reaches to a depth of 415 feet below sea level. From the incline there are two sets of gangways; one at 132 feet, another at 415 feet below sea level. The dip of the bed of coal near the surface is 45°, but decreases as the depth increases. In gangway No. 2 it is 44°. In the upper part of the chute, between the second and fourth gangways, it is 35°, and in the lower part of the chute it is only 31°, while along the fourth gangway, 415 feet below the surface, it averages about 27°. The associated rocks are rather soft, and as the pressure upon them rapidly increases with the depth, the pillaring and timbering of the mine are matters requiring much attention.

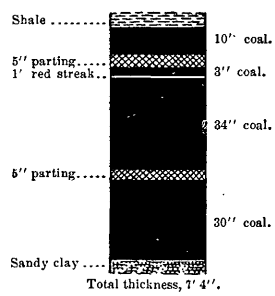


FIG. 30.—Section of Beaver Hill coal at end of No. 2 gangway.

There is comparatively little variation in the Beaver Hill bed as it appears in the mine. Fig. 30 represents it at a depth of 132 feet, and fig. 31 at a depth of 415 feet. At some points upon the last level gas appeared, so that safety lamps had to be used. The chemical composition of the coal mined at Beaver Hill is shown by analyses Nos. 11 and 12 in the list on page 367.

The gangways extending northeast from the incline encounter faults as they approach the Caulfield marsh. The faults produce so much disturbance that it is not economical to follow the coal through under the marsh to the hills beyond. Judging from the position of the Beaver Hill bed upon the northeast side of Caulfield marsh, according to Mr. Whereat's measurements, there must be a displacement of about 200 feet in this branch of the marsh, which leads up to Caulfield Gulch. Probably there are several faults, rather than one of so great a throw. On the northeast side of the Caulfield marsh a tunnel is run in upon the Beaver Hill bed for 1,000 feet, and in its course two faults were encountered, the first a normal fault of 20 feet with the downthrow on the northeast side, while succeeding that there was a jump up of 6 feet. Both these were quite near the marsh. After leaving the marsh by a considerable distance the faults seem to disappear. The association of ravines or sloughs and faults, both at Beaver Hill and Newport, strongly indicates that the presence of faults determines the places of the ravines.

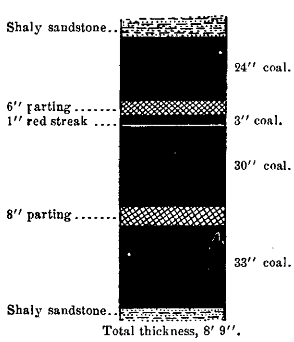


FIG. 31.—Section of Beaver Hill coal at end of No. 4 gangway.

Besides the ordinary normal faults already noted, in which the coal is completely cut off, there is near the end of the counter gangway, between gangways No. 2 and No. 4 of the Beaver Hill mine, an abrupt change in the attitude of the coal bed which does not break its continuity. A section of this occurrence, drawn in the line of the dip, is shown in fig. 32. From *a* in the counter gangway the coal extends 20 feet directly down to *b*, which is in a room extending up from gangway No. 4. The dip above the counter gangway, as already noted, is 35°, and below it is 31°, gradually decreasing to 27°. An abrupt change in the position of the bed, similar to that noted above, occurs also at Henryville, as represented in fig. 49.

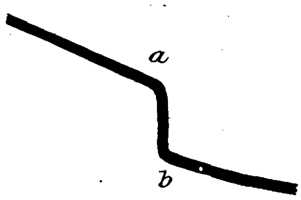


FIG. 32.—Section of displacement of coal in Beaver Hill mine between gangways No. 2 and No. 4.

As all of the readily available coal from the Beaver Hill incline has been removed, that portion of the mine, being badly squeezed, has been abandoned, and a new tunnel run in nearly 1,000 feet on the northeastern side of the marsh. Work has lately ceased at this point also.

In prospecting to determine the position of the coals nearer the axis of the Beaver Slough Basin, two drill holes were sunk near the border of the marsh; one about three-fourths of a mile, and the other 1½ miles, southeast of the mine. Both were close to the marsh, but upon opposite sides. The sections reported by Mr. Whereat are given below.

SECTION A.—*Record of drilling at a point 1,400 feet west and 210 feet north of corner of secs. 16, 17, 20, 21.*

	Feet.
Sandy clay, surface deposit	48
Coarse sand	3
Gray shale	15
Gray sandy shale	27
Gray sandstone	2
Gray sandy shale	84
Gray lime shale	11
Gray limestone and fossils	3
Gray lime shale	10
Dark-gray lime shale	15
Dark-gray shale	32
Gray soapstone	22
Gray shale	170
Gray shale and "nigger-heads"	14
Gray limestone	2
Gray shale	59
Conglomerate	11
Sandstone	48
Gray shale	34
Very coarse sandstone	5
Coarse sandstone and partings of coal	5
Sandstone and partings of coal	30
Total	650

BUNKERS OF NEWPORT AND BEAVER HILL MINES AT MARSHFIELD, OREGON.

SECTION B.—*Record of drilling at a point 1,500 feet south and 370 feet east of same corner.*

	Feet.
Yellow clay shale	14½
Blue shale	5½
Blue shale and fossils	20
Hard sandstone	1
Blue shale	1
Blue shale and fossils	24
Limestone and fossils	2
Blue shale	139
Sandstone	44
Conglomerate	30
Brown shale	4
Conglomerate	15
Sandstone; upper 27 feet very soft, with little or no core	65
Sandstone and sandy shale mixed	17
Sandy shale	81
Gray slate	62
Gray shale and fossils	15
Soft limestone	1
Hard, gray, fine-grained sandy shale	2
Total	543

The strata passed through are similar to those exposed along the railroad between Beaver Hill and the Junction, as well as along the main line from near Marshfield to Coquille.

Judging from the position of the coal in the Beaver Hill mine, it is probably at least 650 feet below the bottom of Section A and but little greater distance below Section B, because, although half a mile farther away from the mine, an arch of the strata brings it toward the surface. These sections show conclusively that overlying the group of coal beds shown in figs. 27 and 29, there is an extensive series of light-colored shales and sandstones, the upper part of the Coaledo formation, among which there are no coal beds of economic importance. These strata, so well exposed along the railroad and wagon road from Coquille to Beaver Hill and Marshfield, vary greatly in position, especially in the middle portion of the basin from Cedar Point to the divide, a mile beyond Coaledo. They have doubtless been thrown into small folds or wrinkles by being compressed within the arms of the larger basin. If the coals were near the surface in the basin they would be much affected by these wrinkles, but as they lie beneath a considerable thickness of beds, their position is, in all probability, less variable.

The central portion of the widest part of the Beaver Slough Basin lies near the Coquille between Beaver Slough and Cedar Point, and here probably the basin is deepest and contains a greater thickness of the Coaledo formation than exists anywhere else in the basin. While upon the northwest the dip at first is 45°, decreasing in a comparatively short distance to 26°, in the lower gangway of the Beaver Hill mine upon the southeast side at Cedar Point the surface dip is 30° in the opposite direction. If we accept 28° as the average dip upon the two sides of the basin, and regard the strata as continuing without change of inclination directly to the bottom of the basin, the basin would be about 7,000 feet deep. The regular and rapid decrease in the angle of the dip in the Beaver Hill mine shows that the rocks, long before reaching the middle of the basin, must be approximately horizontal. In fact, the bore holes sunk at the points already indicated give us information in this regard. At the one nearest the mine the inclination is from 12° to 20°, while at the latter the beds are reported as lying flat. Taking this decrease of dip into consideration, the basin must be much shallower than the figures given above would indicate. Making allowance for this rate of decrease, the depth of the basin is probably less than 2,000 feet. Some portion of that thickness is marsh deposit, which at Beaver Hill is certainly 50 feet deep and at Newport over 200 feet. Near the middle of the basin, under the wide marsh along the Coquille, it is likely to be much greater. The remainder of the thickness is of light-colored shales and sandstones, most of which come to the surface along the railroad between Beaver Hill and Cedar Point.

At Beaverton, a short distance southwest of the Beaver Hill mine, a new mine has recently been opened upon the Beaver Hill coal. Like Beaver Hill, it lies on the border of Beaver Slough, and is reached by a branch of the Coos Bay, Roseburg and Eastern Railroad. An adit has been run in the coal on the northeast side of the ravine and a slope upon the southwest side. Most of the coal is below sea level, although there may be much above. The slope is down about 700 feet, at an inclination of from 27° to 30°. Four gangways extend from it for a considerable distance on both sides, and the mine being thoroughly opened, the removal of coal has begun. The mine is favorably situated, and it is hoped that this effort will demonstrate the possibility of mining Coos Bay coal at a fair profit, notwithstanding the expense of lifting and pumping. The comparatively low price of Coos Bay coal in the market renders this a difficult problem, and the final outcome of Beaver Hill and Beaverton is watched with much interest.

North and west of Beaverton, in the same section (18), there is a series of coal exposures with strike ranging from N. 88° E. to N. 65° W., dipping in all cases southerly. The coal beds exposed are the Beaver Hill bed and those nearest it, and indicate that at this point the lower coals of the Beaver Hill and South Slough basins are continuous across the southern end of the Westport arch.

Southwest of the Beaver Hill and Beaverton mines, along the border of the Beaver Slough Basin, a remarkable change in the position of the coal beds is found in the western half of sec. 19. Crossing secs. 9, 17, 18, and into 19, the whole series of coal beds has a somewhat variable position, with an average strike approximately S. 45° W. and dip 24° to 45° SE. The strike becomes more southerly toward the

BEAVER HILL, OREGON.

southwest. The gangways at Beaverton, in the NE. $\frac{1}{4}$ of sec. 19, according to Mr. Whereat, run S. 31° W. Near the western border of sec. 19 the whole series quite abruptly swings around so as to strike S. 12° E. and dip 20° NE. This sudden change in strike is due to the fact that the arch of strata which bounds the Beaver Slough Basin upon the west, from East Marshfield to beyond Beaver Hill, here pitches to the southwest and runs out, allowing the coal beds to adjust themselves to the position of the strata in the South Slough Basin. The new strike of the beds points directly to Riverton, which lies close to the southern end of the basin. The section partially exposed near the western edge of sec. 19 is shown in fig. 33. The thickness of the rocks exposed, including the three lower coals, is about 336 feet. The upper coal may lie a hundred feet or more above the next lower one.

The lowest coal has three benches, and is regarded by miners and prospectors generally as the Beaver Hill

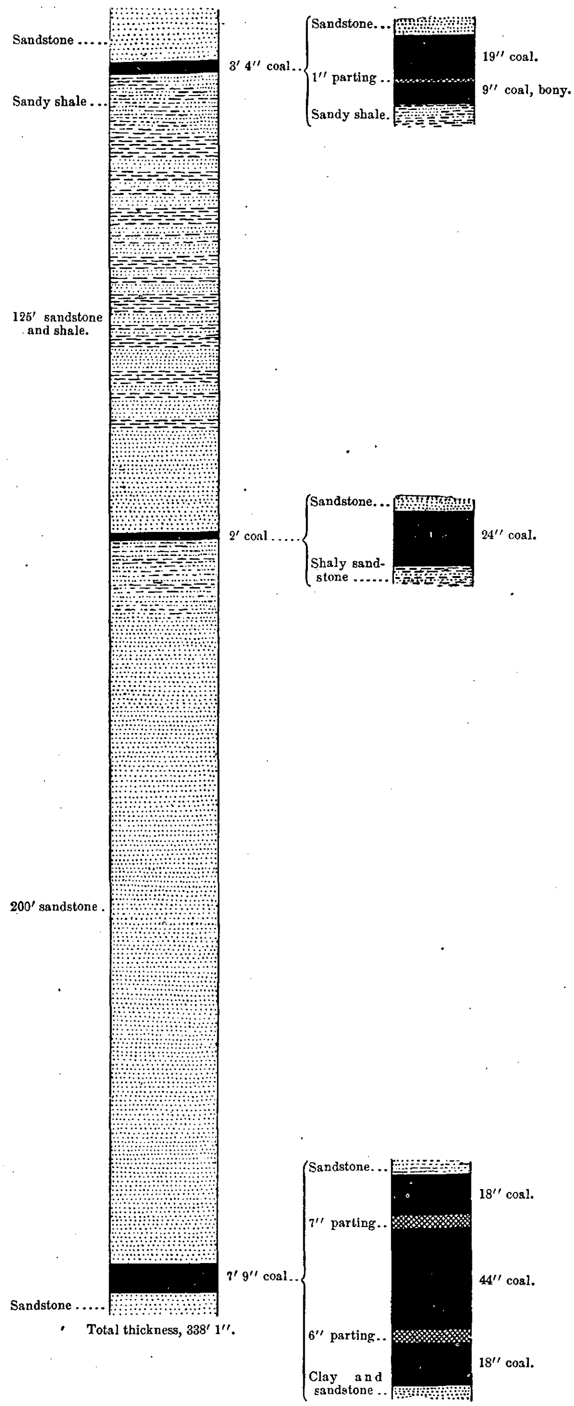


FIG. 33.—Section of coals and associated rocks near western edge of sec. 19, T. 27 S., R. 13 W.

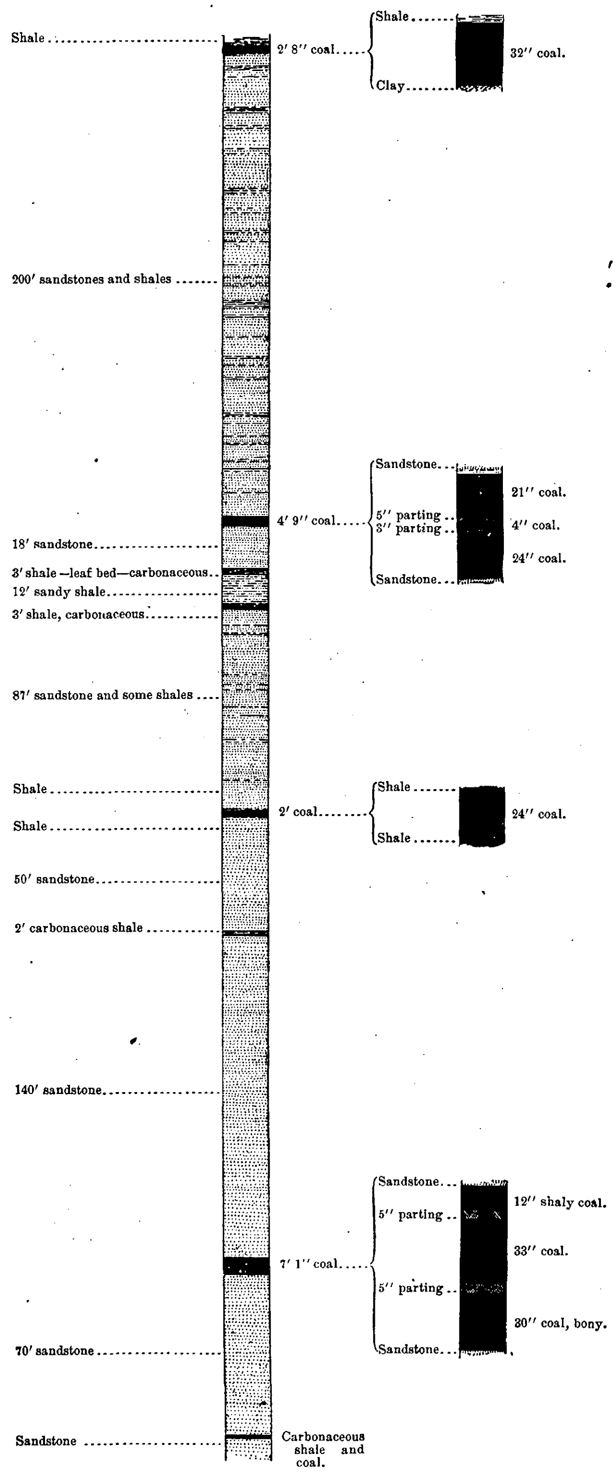


FIG. 34.—Section of coals and associated rocks at Riverton.

BUNKERS AND RAILROAD AT BEAVER HILL.

coal, although its bottom bench is smaller than is usually the case and the middle bench is considerably larger. Chemical analysis No. 13 in the list on p. 367 shows the composition of the coal at this point. About 200 feet above this there is a small bed having two exposures showing some variation in the coal. At some distance southeast of the other exposures, in sec. 30, is the Doyle outcrop, which has recently been opened for Mr. Graham. It resembles the Beaver Hill coal in some particulars, but in others differs widely. The middle bench is nearly 6 feet thick and contains considerable shale in its upper portion.

Near Riverton the coal beds cross the Coquille and enter the hills to the south, affording special facilities for economic mining and transportation. The coal can be readily run on short railroads by gravity to high bunkers on the river, where seagoing vessels may be loaded. On this account a larger number of mines have been opened here than at any other point in the coal field. The numerous prospects have exposed the section which is illustrated in fig. 34. For convenience of reference the four principal beds of coal may be designated, beginning next to the bottom, the Urquhart, Bunker, Timon, and Kight. Below the coal series is a thick mass of sandstone, which forms the bluffs for nearly 2 miles on the left bank of the river below Riverton. The same sandstone forms the prominent divide between Iowa and Hatchet sloughs, as well as the arch between Beaver and South sloughs. It is one of the most resistant of the rocks closely associated with the coal. At the top of this sandstone is the Urquhart coal, which has been opened by the river bank a short distance below Riverton, where the section shown in fig. 35 is exposed, and the specimen for analysis, No. 14 in the list on page 367, was obtained. The top coal is shaly, making a good roof, and is left up, but the middle and lower coals, with partings, are well exposed. The middle bench contains the best coal. The lower 2½ to 3 feet of the bottom bench is bony. Besides this opening there are three others farther south, approximately in the line of strike, and all may be upon the same bed, although there are differences which render the matter somewhat uncertain.

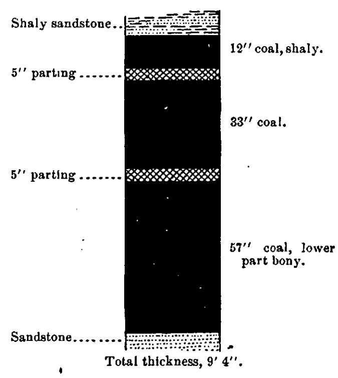


FIG. 35.—Section of Urquhart coal at Riverton.

The second opening is about one-fourth of a mile south of the river bank; the third is near Panter's, on the Alder Creek side of the divide, and the fourth is at Lyon & Co.'s mine. The distance from the first to the fourth is over a mile. Near Panter's, as shown in fig. 36, the top coal is missing. The sandstone rests directly upon what appears to be the middle coal, and the bottom bench is largely shale. At Lyon

& Co.'s mine, as shown in fig. 37, there are three benches again. The top one is slightly larger than the middle one, and the lower one is shaly. The coal of the middle bench in this mine has the composition shown in column numbered 15 in the list of analyses on p. 367.

The Lyon & Co. mine, which is not now in operation, is about 220 feet above the river, upon the prominent bluff down which, by cable and incline, the coal is transferred to bunkers by the river. Three tunnels run in on the coal, which dips a few degrees to the east. In the northern part of the mine there is an 8-foot fault, running nearly east and west, with the downthrow on the north. At the bottom of the lower parting a number of leaves have been found, but none of those collected were complete enough for identification.

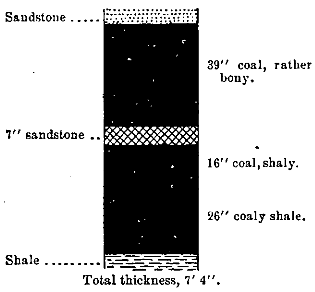


FIG. 36.—Section of Urquhart coal near Panter's.

The general structure of the Urquhart coal bed at once suggests that it is the same as that which is mined at Beaver Hill and at Newport. This suggestion is strengthened by other facts, especially the relation of the Urquhart coal to the other coals of the series. It is at the bottom of the group of coal beds, and is underlain not only by a thin seam of coaly shale like that at Newport and Beaver Hill, but also by a great mass of sandstone, which in the middle portion of the coal field marks the lower limit of the known workable coals. The character of the coal points in the same direction. At Newport the lower bench is considered the best coal, but at Beaver Hill the middle bench is regarded as best. At Beaver Hill the proportion of bony matter at the bottom of the lower bench is somewhat larger than at Newport and continues to increase toward the southwest, until in the Riverton region it becomes the principal part of the lower bench.

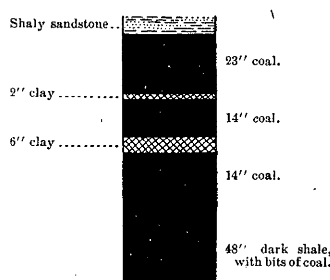
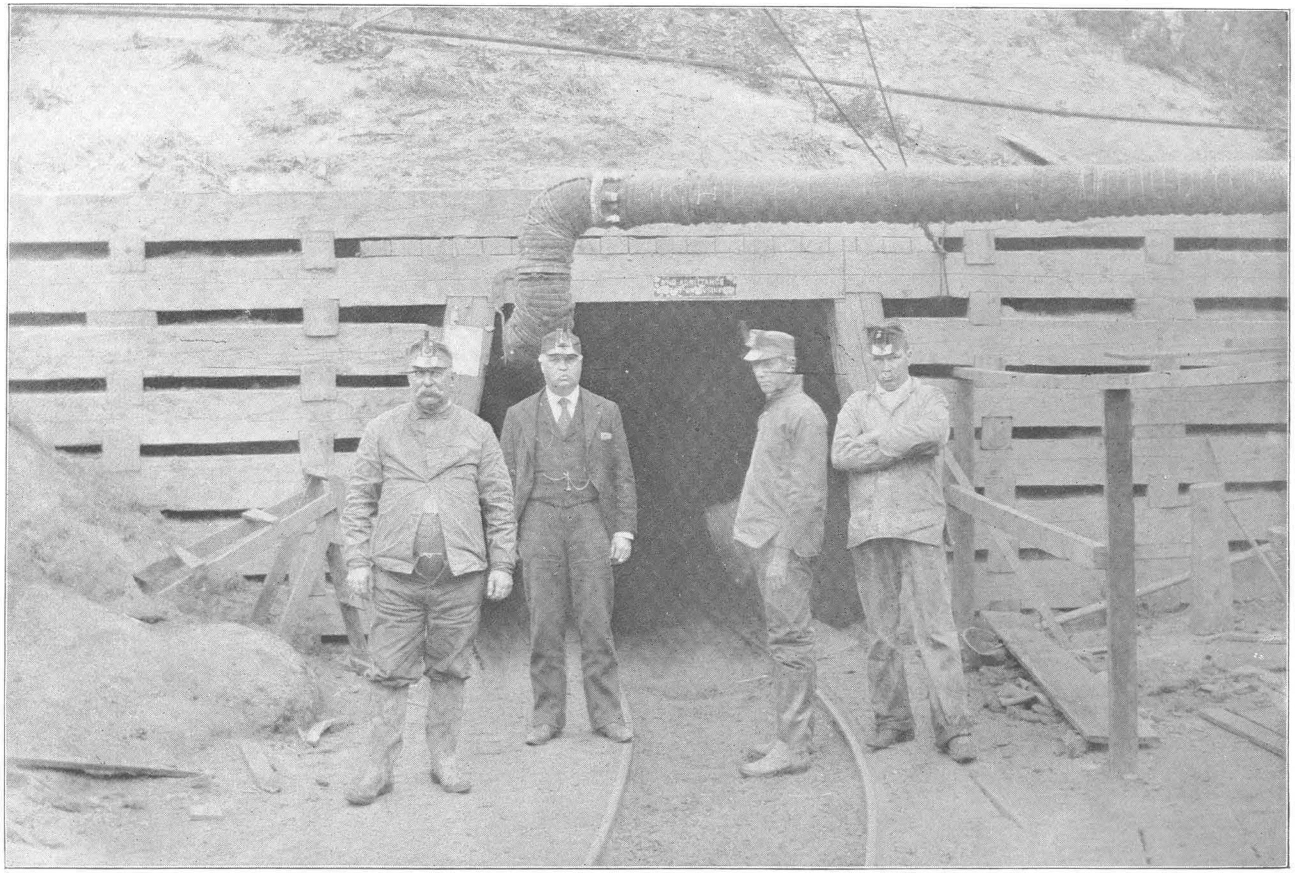


FIG. 37.—Section of Urquhart coal at Lyon & Co.'s mine.

Above the Urquhart bed about 200 feet is the bed which occurs in the ravine near the upper bunker of the Bandon Block Coal Company, and for this reason it has been called the Bunker coal. Two analyses of this coal have been made. No. 16 in the list of analyses on page 367 is from near the bunker and No. 17 is from a point a short distance farther south. The same bed appears to occur a mile southeast of Riverton on a branch of Alder Creek, where it has been opened by the Price Brothers, and the section shown in fig. 38 has been exposed. The thin coals at the top of the section were not looked for near the bunker. This bed is not mined at Riverton.



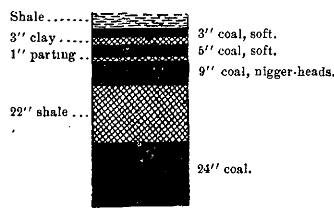
ENTRANCE TO BEAVER HILL MINE.

About 100 feet above the Bunker bed is a layer of carbonaceous shale 3 feet in thickness, which contains in its upper part numerous fossil leaves. Mr. F. H. Knowlton has examined these plants and identified, with more or less doubt, the following forms:

Magnolia lanceolata Lx.
Magnolia californica? Lx.
Laurus californica? Lx.
Sobolites californicus? Lx.
Rhamnus sp.
Juglans? sp.
Ficus? sp.

The leaves are nearly all fragmentary, but appear to be of species which have been found in the Auriferous gravels of California, and this is of interest for the reason that the leaves in this case are certainly of Eocene age.

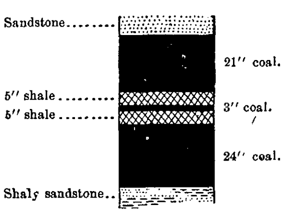
The Timon coal bed is 18 feet above the leaf bed, i. e., about 117 feet above the Bunker coal. It is the only coal now being actively worked. Its strike is S. 22° E. and its dip 10 to 13° NE., extending into the hills along the river beyond Riverton, so that a large body of coal lies above drainage and is conveniently situated for mining. Three mines have been located upon this bed within half a mile of the river by J. H. Timon, the Bandon Block Coal Company, and Joseph Ferrey. The roof is generally firm, so that the mines require but little timbering.



Total thickness, 5' 7".

FIG. 38.--Section of coal near southwest corner of section 17, on branch of Alder Creek.

The Timon mine is the oldest and has been worked more or less continuously for four years. By means of a rock tunnel the coal is reached from the under side, and a gangway then follows the coal, gently rising for drainage, to a total distance of about 1,000 feet. A section of the coal in Timon's mine is shown in fig. 39. The roof of the coal is generally sandstone, but occasionally shale containing a few brackish-water fossils, among which Dr. Dall recognizes a Macoma, is found. The shale may be slickensided. Where the slickensided shale occurs the coal becomes thinner.



Total thickness, 4' 10".

FIG. 39.—Section of Timon coal in Timon's mine, Riverton.

A short distance southeast of the Timon mine, at a somewhat greater elevation, Messrs. Loggie and Marsden were operating upon the same coal bed in the summer of 1897. The mine was closed in the early part of 1898, but has since been leased and reopened. Several entries were run in upon the coal at this point at different times, and discovered a small fault, which is not now visible. From the description furnished me by Mr. Marsden the strike of the fault is nearly north and south. It is a normal fault of about 7 feet, with a downthrow on the eastern side, and is close to a ravine separating the older and newer portions of the mine. The Riverton mines are not yet very extensively developed, but thus far few faults have been found.

The Timon coal has been found on a branch of Alder Creek, beyond the divide southeast of the mine operated by Loggie and Marsden. At this point the section is essentially the same as that shown in fig. 39.

The third mine upon the Timon coal is close to the river. Mr. Joseph Ferrey opened an incline near the outcrop of the coal and followed it down to a depth of about 100 feet, where he was temporarily stopped by water.

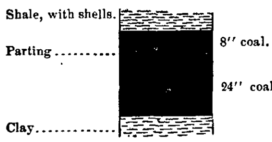


Fig. 40.—Section of Kight coal in Ferrey's mine at Riverton.

The Kight coal overlies the Timon coal by about 200 feet, and the two are separated chiefly by soft sandstones. It is the uppermost of the coals well exposed at Riverton, and has been mined chiefly by Mr. Ferrey, who ran an entry 500 feet upon the strike of the coal. Some water was encountered, but the mine drains itself. The bed contains 32 inches of coal, with a parting 8 inches from the top, as illustrated in fig. 40. The coal is much fractured perpendicular to the bedding, and at intervals is associated with pitch coal, which, on account of its interest, will be noted separately in the final portion of this paper (p. 368), where analyses of the coal and pitch coal are given. The occurrence of soft, shaly rocks above and below renders it necessary to timber the mine fully. The overlying shale is sometimes composed chiefly of brackish-water shells. The Ferrey mine on the Kight coal was operated successfully for some time, but as the mine proceeded the coal bent more to the east, becoming irregular, and was finally pinched out by an extensive landslide which reached the river at the northern edge at Riverton. The landslide covers many acres and fills the little valley that heads three-fourths of a mile southeast of the town. Kight's coal has been prospected on the surface near the head of this slide, and irregular portions of coal occur at several points in the slide. The road from Riverton to Fat Elk Creek crosses the lower part of the slide, where its irregular hummocky surface clearly tells the character of the material beneath. Tunnels have been run into it at several places, in prospecting for coal, but without encouraging results.

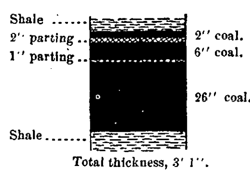


Fig. 41.—Section of Kight coal on branch of Alder Creek.

The Kight coal occurs south of the divide from Riverton on one of the branches of Alder Creek, where it has been opened by the Price Brothers. Fig. 41 shows a section of the coal at this point. While the lower coal of this bed appears as in the Ferrey mine, a small parting and coal are added at the top. However, there seems to be no reason to doubt that this is the Kight coal, because it holds the same relations to the Urquhart and Timon beds as does that at Riverton.

The Beaver Slough Basin ends a mile south of Riverton. On Alder Creek the Riverton coals have been found at the point where they turn around the southern end of the basin and start northeast along its eastern side. The Urquhart bed at Riverton strikes N. 30° W. On Alder Creek it strikes N. 80° W. The Timon bed, which at Riverton strikes N. 22° W., on Alder Creek strikes N. 80° W., and in a short distance to the east swings around to strike N. 40° E., with dip northwest instead of northeast, as in the other two cases. The southern end of the basin, where this marked change in the strike of the coals occurs, is near the southeast corner of sec. 17, and it is not profitable to prospect for workable coals farther southward within the coal field.

Not only the coal beds but also the large sandstones and other strata swing around the southern end of the basin, and their effect upon the topography of the region is clearly visible. The sandstone which underlies the Urquhart coal turns in the prominent hills of sec. 20 and passes into the Fat Elk country. The same feature is indicated by the hills northeast of Riverton, which curve to the river at Strangs Landing.

The eastern side of the Beaver Basin south of the Coquille is fairly well exposed in the ravines along the steep hills south of Strangs Landing and on the western branches of Fat Elk Creek farther southwest. The exposures are not continuous, but they are so related that the sections they afford may be made out quite completely, as illustrated in fig. 42. The number of coal beds exposed is larger than at Riverton, and their relation to the Riverton coals is a matter of importance. The five coals indicated in fig. 42 overlie a massive sandstone, which forms the prominent spur west of Fat Elk Creek in sec. 10. The coal next above this sandstone appears to be one of Peterson's, exposed near the line between secs. 9 and 16. This coal was not well exposed, but had the appearance of a good-sized bed, and the quality of the coal, as indicated by its analysis, No. 18 in the table (p. 367), is good. The next three above this are exposed in the ravine at Gabelers, and for convenience the whole group of coals lying above the sandstone may be referred to as the Gabeler coals. The top coal of the Gabeler group is Strang's. It is exposed near the schoolhouse two-thirds of a mile south of Strangs Landing. On the western branches of Fat Elk Creek a number of coals are poorly exposed, but in such positions as to suggest that they are the Gabeler coals. None of the coals of this section can be positively identified with the Riverton coals, although it is certain from structural relations that they must be at essentially the same horizon. None of the coals in the Fat Elk Creek section are being mined. The only ones which have been fully opened are the two uppermost. Strang's coal (*e* in fig. 42) has a total thickness of over 15 feet, with

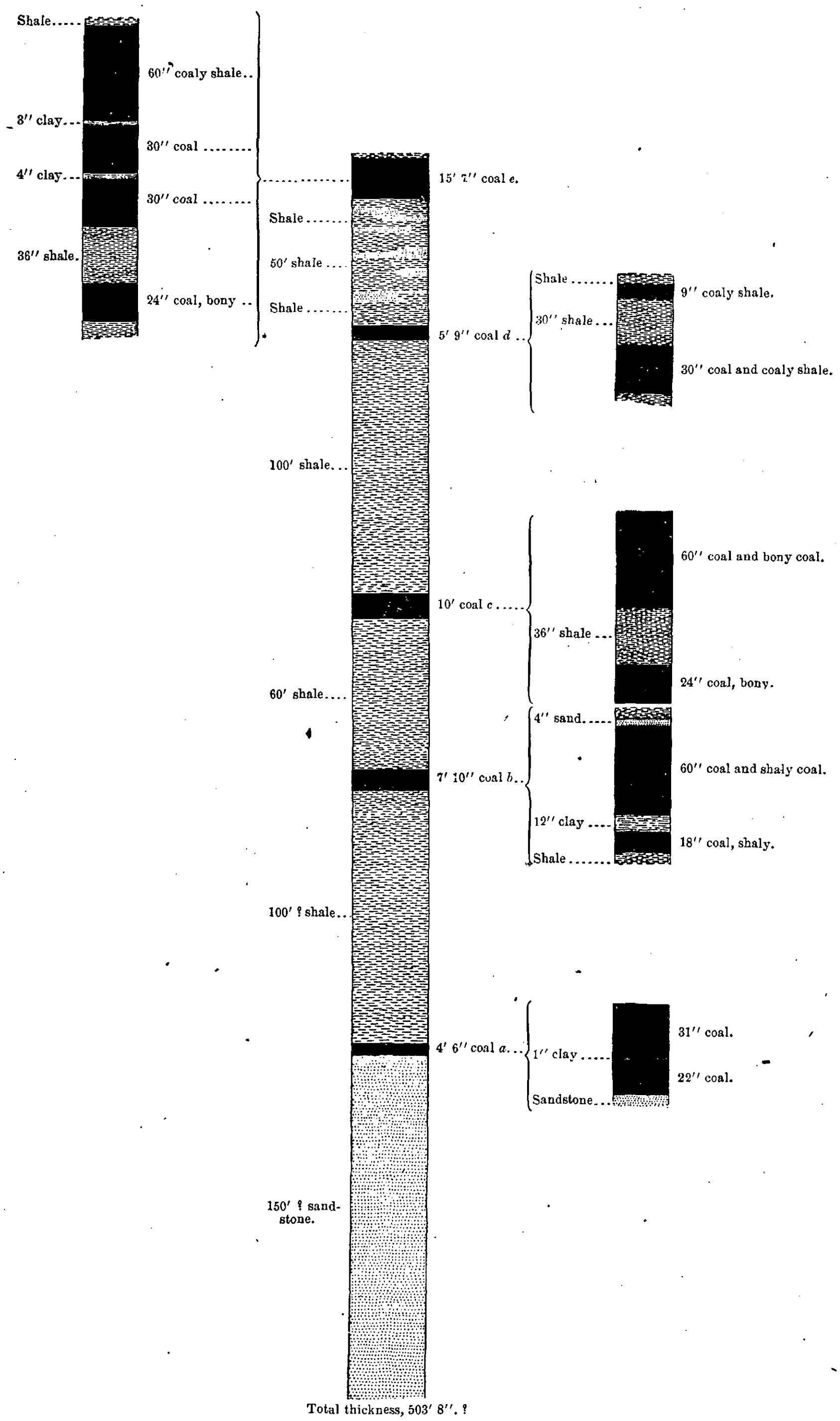


FIG. 42.—Section of coals and associated rocks in Fat Elk Creek region.

numerous partings, as represented in the detailed section of the right-hand column. It contains much shaly matter, which seriously affects its quality. Parker's bed (*d* in fig. 42), as well as the other two coals (*b* and *c*) below it, are exposed in the same ravine leading west from Gabelers, and contain too much shaly matter and bone in proportion to the good coal to promise profitable mining. On account of the quality of Peterson's coal, at the bottom of the section, it is worthy of exploitation, and if found sufficiently large for mining would yield a considerable mass of coal under the hill to the southwest.

Northeast of the Fat Elk Creek country, along the side of the Beaver Basin, the first feature to attract our attention is Cedar Point, the bold spur which reaches the north side of the river 2 miles west of Coquille. This point is composed of sandstones and shales whose position suggests that they are a continuation of the heavy sandstone which lies in the bend of Fat Elk Creek, $1\frac{1}{4}$ miles to the southwest. At the eastern base of Cedar Point, near the railroad, is the coal represented in fig. 43, and above the sandstone on the west side of the point, near McQuiggs, is a coal of much the same character. Over 2 feet of coal could be seen at McQuiggs, and it is said to be 3 feet in thickness. The whole group of Gabeler coals must cross the country just west of Cedar Point, but they have not yet been discovered. Lying below the Cedar Point sandstone, a short distance from the horizon of the Cedar Point coal already referred to, but a little farther northeast, are two other exposures of coal; one in sec. 35, of little importance, and another in sec. 25, affording the illustration in fig. 44. Its strike is N. 10° E. and its dip 20° NW. Both these coals lie along the western side of the Pulaski arch, by which, as noted later, they are separated from the coals of the Coquille Basin.

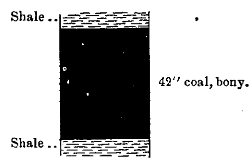


FIG. 43.—Section of Cedar Point coal.

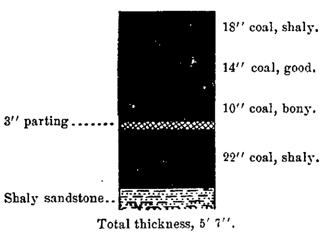


FIG. 44.—Section of coal near Budd Creek, 2 miles north of Coquille, in section 25.

It will be noticed that upon the map there is shown a rather prominent ridge which extends first northeast from Cedar Point and then curves westward toward Coaledo. It is formed of the Cedar Point sandstone, and appears to end between the forks of Beaver Creek. This crescent-shaped ridge marks the eastern limit of the wide portion of the Beaver Basin. The rocks at Cedar Point dip northwest, but the position of the rocks swings with the curvature of the ridge, and near the north end they dip to the southwest. At this point, near the corner of secs. 14, 15, 22, and 23, were the old "Utter mines," long since inoperative. The coals in which the mines were located overlie the Cedar Point sandstone. A section of the coals at the "Utter mines," now owned by the Beaver Creek Mining Company, is shown in fig. 45, which contains not only the general section but detailed sections of the coal beds. These coals correspond in a general way to the Gabeler coals above the heavy sandstone in the Fat Elk country, and a comparison shows a considerable degree of resemblance. Only two of the coals, *b* and *c* of the section, have been mined. Chemical analysis No. 19 in the list on p. 367, shows the composition of the coal in the upper bench of bed *b*, which has been most extensively developed and is still worked. The position of the strata at this point is of special interest. They strike N. 60° W., and dip 20° SW. This strike, if continued, would reach the western edge of the basin at a bend in sec. 9, T. 27 S., R. 13 W.

The arch of which the coal and associated rocks at the "Utter mines" show one side extends almost directly across the Beaver Slough Basin and separates it into two portions: a short, wide portion lying between Coaledo and Riverton, and a long, narrow portion extending from Coaledo northward between Isthmus and Catching sloughs to Glasgow.

The coals of the Beaver Creek Mining Company are essentially the same as those of the Dean & Co. property in sec. 11, with which we began the study of the Beaver Slough Basin. A comparison of the sections in figs. 27 and 45 does not show a very striking similarity. The two sections are only about 2 miles apart across the basin, and furnish evidence of much greater variation in the coals in that direction than parallel to the length of the basin. The Newport bed, which appears in both basins with the same features, is recognizable for a distance of 15 miles north and south along the central portion of the field, but east and west it is so variable as not to be clearly recognized at a distance of only a few miles. The same is true to a less extent, as will be seen later, of the Southport and several other beds; and this would be expected, for the swamps in which the coal originated were long north and south, but narrow east and west, which is the direction from which the sediments were carried into the swamp. The variations in the coal are due chiefly to changes in the number and size of the partings and the amount of fine sediment in the coal itself, rendering it shaly or bony. In general, the quantity of good coal is largest near the center of the field, and although the thickness of the coal beds may increase toward the sides of the field, the quantity of good coal decreases, by reason of the admixture with it of fine mud and sand.

The position of the coals at the "Utter mines," so widely at variance with that of the coal group at any other point in the Beaver Basin, long since attracted attention and puzzled the prospectors of that region. It is due to an irregular arch of the strata in the valley of Beaver Creek east of Coaledo. The strike of the strata before reaching Coaledo apparently swings around to the north, so that the coals dip westward, forming a narrow syncline or basin with those on Dean & Co.'s property. The strata about Coaledo are much disturbed.

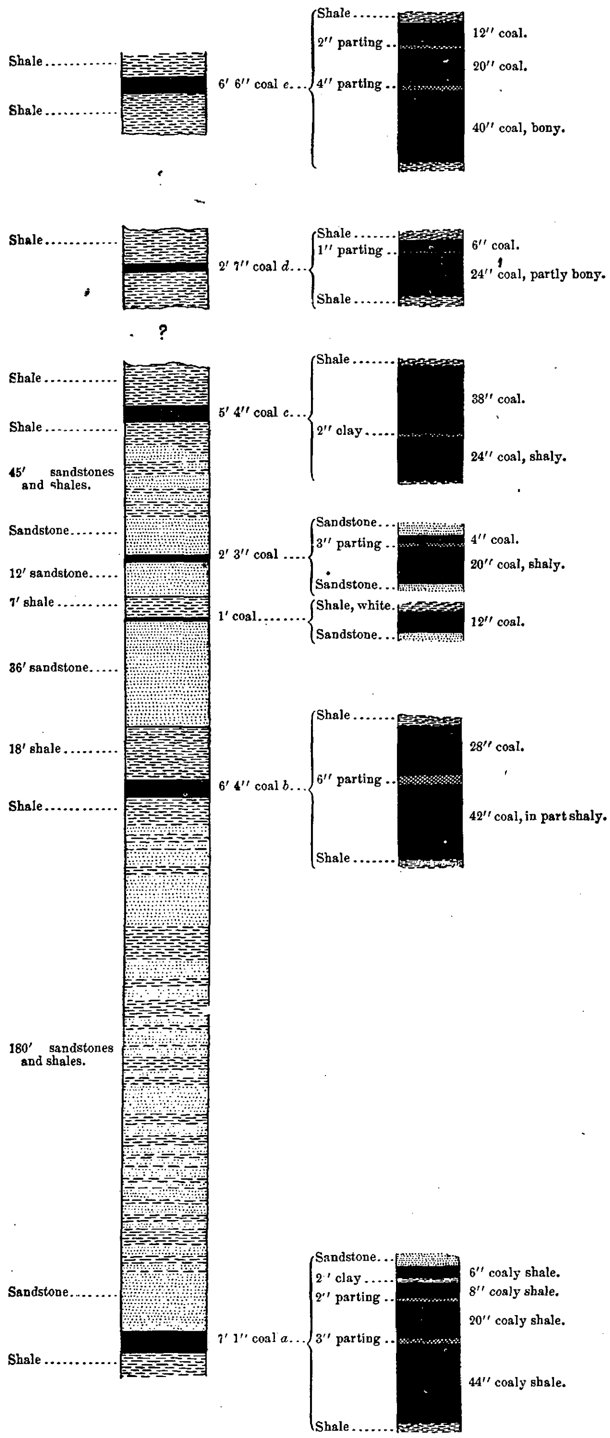


FIG. 45.—Section of coals and associated rocks at Beaver Creek mine (Utter mines), three-fourths of a mile southeast of Coaledo.

They have various strikes and dips, due in part to the wrinkling of the strata in the basin, and possibly in part to faulting which may extend along Beaver Slough.

In the valley of Noble Creek, about one-fourth mile south of the corner on the line between secs. 11 and 12, a coal occurs having the section given in fig. 46. This coal strikes N. 60° E. and dips 32° NW. It is of interest here in marking the eastern limit of the Beaver coal basin, extending north and widening out above the head of Isthmus Slough. A short distance to the southeast, near the line between secs. 12 and 13, there are three coal beds, all of which dip to the southeast. They are represented by fig. 47, and are separated from the one represented in fig. 46 by an arch of the strata, across which the coal once extended. The lowest coal in fig. 47 appears to be the same as that of fig. 46. Chemical analyses have been made of three of these coals, numbered 20, 21, and 22 in the table of analyses on page 367. Mr. William Sharp, who has done much prospecting in the Coos Bay region, has opened this coal by several tunnels on both sides of the divide between Noble and Beaver creeks. The bed appears to be the same as the lower bed which has been worked at the "Utter mines," and there may be underlying it a still larger bed, having a greater amount of inferior coal. Above it are two beds, and possibly more in the little basin lying east of the arch a short distance, near the divide at the head of Noble Creek, which borders the coal field upon the east. The strata are much disturbed, varying greatly in strike and dip, and frequently standing at angles of from 60° to 90°. Close to the eastern border of the field the deep cut by Noble Creek across the strike of the coal-bearing beds affords the best opportunity found in that region to examine the coal beds. The strata are much folded, and the same bed may be repeated a number of times along the stream. Mr. Frank Batter, who has prospected the northern part of the coal field quite fully and prepared a map showing the location of many of the coal outcrops, reports a series of about twenty beds of coal here. The apparently large number of coals is at least in part due to repetition, and the disturbed condition of the strata has resulted in large measure from the upheaval east of Coaledo. Nowhere else along the eastern border of the coal field have the strata been so generally disturbed.

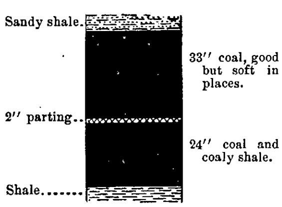


FIG. 46.—Section of coal one-fourth of a mile south of section corner, on line between secs. 11 and 12, T. 27 S., R. 13 W.

The Beaver Slough Basin north of the head of Beaver Slough has been found a much less satisfactory part of the coal field for investigation. Exposures are comparatively few and isolated. In very few cases are even two beds of coal exposed near enough together to afford an opportunity to determine their relations.

From the Dean property, where the section of fig. 27 was measured, the coals extend northeast along the western border of the Beaver Basin. Near the head of Manning Gulch, in sec. 4, the Newport bed as shown in fig. 28 occurs, but north of that point it has not with certainty been recognized upon the surface.

At Henryville, along the eastern bank of Isthmus Slough, in sec. 34, T. 26, R. 13, there were once extensive mining operations and several coals were discovered, but none are now open to investigation. The works consist of an incline run down upon the coal, but not quite in the line of its dip, for 1,750 feet. The coal being of poor quality, a better bed was sought by sinking a shaft at the mouth of the incline to

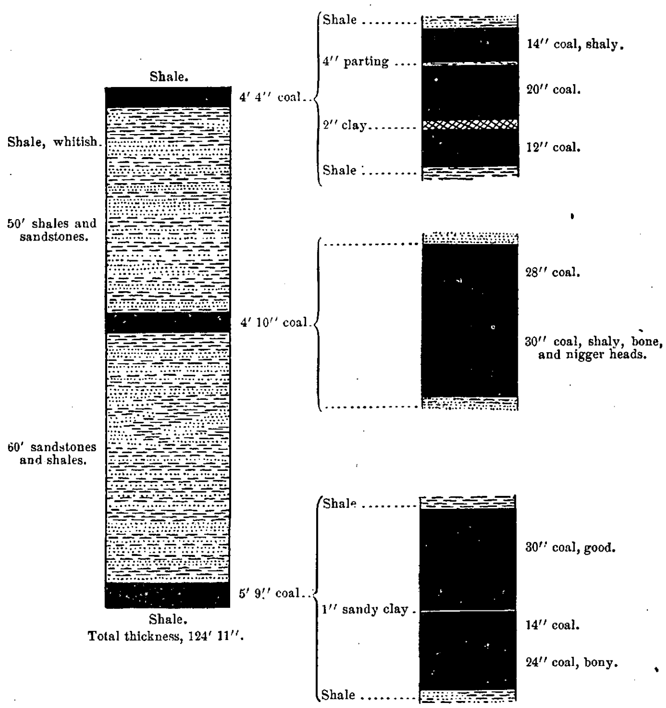


FIG. 47.—Section of coals and associated rocks 2½ miles northeast of Coaledo, near eastern line of secs. 12 and 13, T. 27 S., R. 13 W.

the depth of 375 feet, and from this point a boring is said to have been made 180 feet farther. Several additional beds of coal were thus found, and some coal was removed from them by means of the shaft. A section of the workings and the coals discovered below the surface, as furnished me by Mr. M. J. Bowron, is given in fig. 48. The mine has long since been closed and there are no exposures of the coal now accessible. The top bed, No. 1, in which the incline was opened, is a large one, but contains little coal of value as compared with the amount of waste material necessary to be removed to obtain it. The coal is reported upon good authority to be about 9 feet in thickness and has the character of what is called the "Big Dirty vein," like the top bed at Dean's (fig. 27, p. 329) and Beaver Creek (fig. 45, p. 347). Numerous small irregularities and faults in the bed were encountered in sinking the incline; but one reported to me by Mr. William Campbell, who had immediate charge of the work, is unusual and recalls an occurrence at Beaver Hill represented in fig. 32 (p. 334). The feature at Henryville is represented in fig. 49. At *a* the coal became nearly vertical, but the incline was continued and crossed the fault at *b* to *c*, where the coal was found

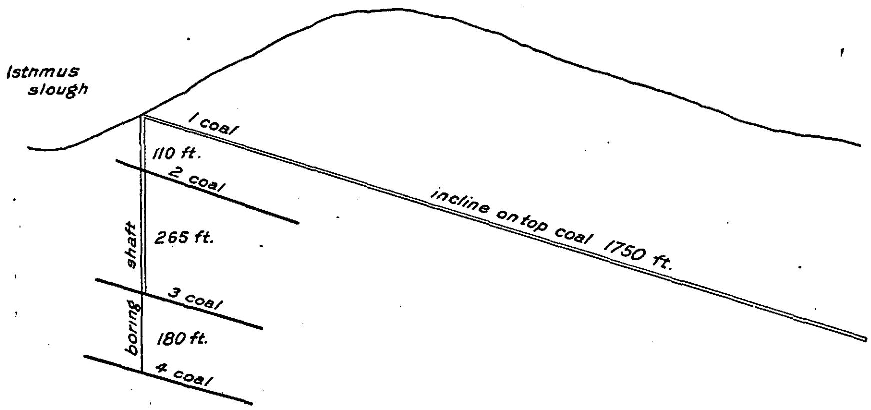


FIG. 48.—Section of mine and coals at Henryville.

again with an increased dip. At *b* the coal was found 16 feet above the incline.

Coal No. 2 in the shaft, 110 feet below the surface, is said to contain 3 feet 6 inches of clean coal without partings. Coal No. 3 appears 265 feet below No. 2 in the shaft, with a reported thickness of 6 feet 4 inches. It contains a 3-inch clay parting 2 feet 4 inches from the top. This bed

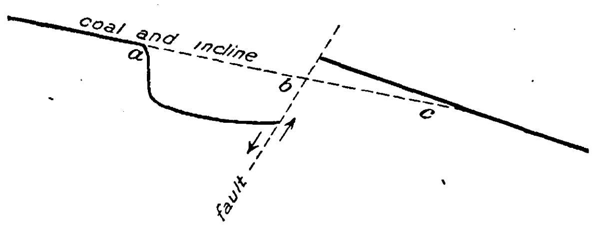


FIG. 49.—Section of displacement of coal on Henryville incline.

is regarded by Mr. Campbell and others who saw it as the Newport bed. The still lower bed, reported by Mr. Bowron to be 5 feet 8 inches in thickness, may represent a bed lower than the Newport, but this does not seem probable, for the bed below the Newport, so far as known, is always small. The thickness of the section, as calculated from these measurements, is much less than that determined at Dean's.

One mile northeast of Henryville, near the corner of secs. 25, 26, 35, and 36, a tunnel and an incline have been run in upon a gently dipping coal whose section is represented in fig. 50. The strata were found to be much broken. Their position in the middle of the basin, as already

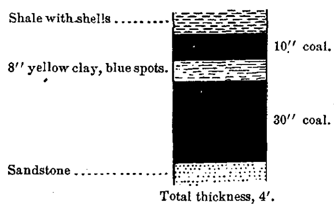


FIG. 50.—Section of coal 1 mile northeast of Henryville.

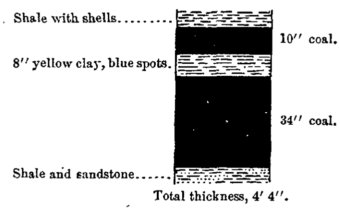


FIG. 51.—Section of Catching's coal, 1 mile south of Sumner.

pointed out, is much more variable than that near the sides. The analysis of coal from this bed is numbered 23 in the list of analyses given on p. 367.

The same coal as that represented in fig. 50 occurs over 2 miles farther eastward along the border of the coal field, near Mr. Catching's, a mile south of Sumner. It is illustrated by fig. 51. The character of the coal, as well as the fossils and the peculiar layer of yellow clay with blue spots between the two benches of coal, is the same in both cases and there can be but little doubt that they are the same bed. In every respect save one the two beds are alike. The lower bench of coal at Catching's is a little larger than at the other locality.

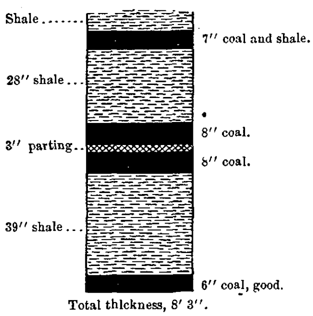


FIG. 52.—Section of Boone's coal, 1 mile southwest of Sumner.

A mile southwest of Sumner a bed of coal occurs near Mr. Boone's, where the section given in fig. 52 was obtained. It lies well in from the side of the basin, which is here about 5 miles in width, and strikes N. 70° E., instead of nearly north and south, as is most frequently the case with the coals near the border of the basin.

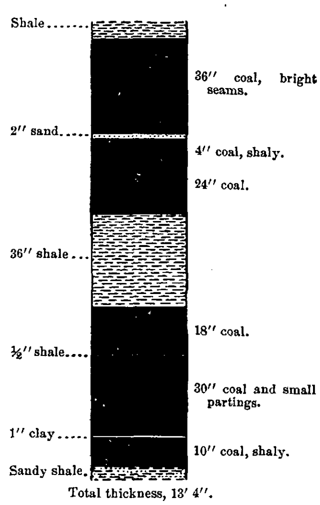


FIG. 53.—Section of Wilson's coal, 1 mile southeast of Sumner.

About a mile southeast of Sumner, near Mr. Wilson's, is another large bed showing a section illustrated in fig. 53. These two exposures indicate the character of the change which usually takes place in the coal as it approaches the side of the basin. The differences, as in the case just noted, are not always marked, but generally the coals become larger, and they do so most frequently at the expense of quality. The amount of mud and sand intermingled with the coal and interstratified with it increases with nearness to the shore of the swamp.

Proceeding northward, in the further examination of the Beaver Slough Basin, we will take up first the western side, along Isthmus Slough, and then the eastern side, near Catching Slough and the eastern border of the bay.

Some traces of coal have been found upon the lower part of Davis Slough, near where the Newport bed might be expected to cross, but no workable coal has thus far been opened. However, at Southport, a mile farther north, coal has been mined. The Southport mine was opened in 1875, and by a railroad half a mile in length the coal was carried to wharves on the slough. Several tunnels, one of which was nearly 600 feet in length, were run in to the north upon the coal, whose strike is N. 20° E. and dip 15° SE. The entries are now caved in, so that the mine can not be examined under ground, but the coal is exposed at the mouth of the upper tunnel, and affords the section shown in fig. 54. A chemical analysis of the coal at this point is numbered 24 in the list of analyses (p. 367). At the mouth of the tunnel the parting between the benches is not distinct, but becomes so in the mine. This mine was once considered of great promise, but was in operation for only about ten years. The bed mined at this point is generally known as the Southport, and its relation to the other beds, especially the Newport, is to a considerable extent a matter of conjecture. The occurrence of a bed supposed to be the Southport in the shaft at Henryville, about 250 feet above the supposed Newport bed, tends to show that the Southport overlies the Newport. Better evidence, however, is afforded by the fact that the Southport bed, although outcropping only a few miles southeast of Newport, is not found in the Newport Basin. Its absence can be satisfactorily explained only upon the supposition that it overlies the Newport bed by more than 100 feet.

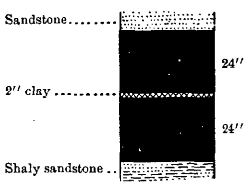


FIG. 54.—Section of coal at Southport mine.

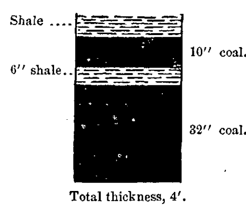


FIG. 55.—Section of coal at Caledonia mine.

A short distance north of the mouth of Shingle House Slough, in the SE. ¼ sec. 11, T. 26, R. 13, the Caledonia mine was operated for a short time, about 1888. The coal strikes N. 2° W. and dips 10° NE. Four tunnels were run in upon it and considerable coal was mined. Fig. 55 shows a section of the coal at the Caledonia mine. According to Mr. C. Sneddon, a hole was drilled in that neighborhood which penetrated three beds of coal—one bed a foot in thickness near the surface, another 20 inches thick 30 feet below the surface, and at a depth of 60 feet the Caledonia bed was found. The Caledonia coal resembles the Southport somewhat, but not very closely. However, on account of the fact that it occurs just about in line of the strike of the Southport coal, the two are regarded as most likely the same bed. In the NE. $\frac{1}{4}$ of sec. 2, T. 26, R. 13, a 3-foot vein occurs which appears to be the Caledonia. The Newport bed has been much sought for in that region, but thus far without success.

Several coals have been opened upon the east side of Isthmus Slough, near its mouth; one at the Bay City Mills and another half a mile farther south, near Archer's. In both cases the strike is nearly north and south, and the dip 5° to 15° E. Mr. Gammill has recently made a boring at this locality and discovered another vein about 4 feet in thickness. All of these veins must lie above the Caledonia, which crops out some distance westward upon the western side of the slough.

Of the openings just referred to, the one farthest south, near Mr. Archer's, affords the exposure illustrated in fig. 56. The coal crops out upon a moderate slope about 100 feet above tide level in the adjoining slough, thus giving ample opportunity for handling, storing, and shipping it.

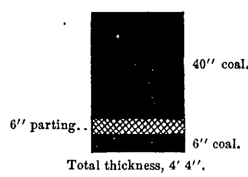


Fig. 56.—Section of Archer's coal, 2 miles southeast of Marshfield.

The Westport arch separates the Newport Basin on the west from the Beaver Slough Basin on the east, and is composed chiefly of the sandstones of the Westport formation. The arch culminates in Westport Hill, which stands out prominently at the head of Coalbank Slough. North of Westport Hill the arch forms the principal part of the ridge lying between Coalbank and Isthmus sloughs. To the north it narrows and runs under Coos Bay. So also the western side of the Beaver Slough Basin lying a long Isthmus Slough runs under the bay and is lost to view. The eastern side, however, lying along Catching Slough, continues northward along the eastern shore of the bay to North Slough, and is occasionally well exposed.

On the eastern side of Beaver Slough near Sumner, to which place it has already been traced, the first coals to be noted have been recently exposed by a landslide in sec. 19, T. 26, R. 12, near Master's, 2 miles northwest of Sumner, where the section given in fig. 57 was observed, chiefly by Mr. Frank Batter. The coals strike nearly north and south, and dip westerly 20° to 30° toward the middle of the basin lying between this point and Coos City. One or more of these same coals, having a corresponding position, occurs farther northward, near Esterbeck's and Cavanaugh's.

Directly east of Master's exposure, nearly a mile upon the eastern side of Catching Slough, are three outcrops of coal whose positions vary greatly, with prevailing strike nearly east and west and dip to the north. These coals lie close to the eastern border of the field. The largest bed is 5 feet in thickness, with five partings, and dips eastward away from the coals shown in fig. 57 and the basin to which they belong.

Besides the coals already mentioned, a few others have been noted along Catching Slough, but none of them have been well opened excepting one at Norton's, upon the east bank a mile north of the mouth

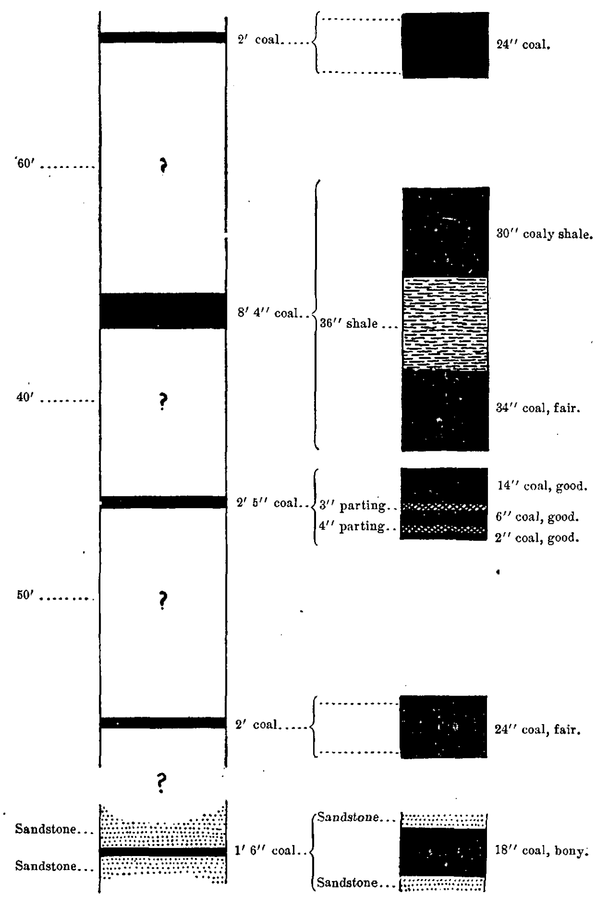


FIG. 57.—Section of Master's coals, 2 miles northwest of Sumner.

of Stock Slough. A section of Norton's coal is given in fig. 46 and an analysis is numbered 25 in the list (p. 367). A few tons of Norton's coal have been removed, and its quality has been highly commended. It yields a "fair" coke, and thus far is the only coking coal known in the Coos Bay coal field. It lies close to the slough, but hardly far enough above it to afford sufficient fall for convenient handling. The coal is nearly flat, or dips gently to the southeast, and it appears to be somewhat broken by small faults. While considerable coal may be removed from this place, the large number of partings, the disturbed condition of the strata, and the nearness to the eastern border of the coal field are conditions which suggest a rather small limit for the coal that is economically available. Upon the western side of Catching Slough, opposite Norton's, the sandstone of the hills dips westward into the basin, which, instead of narrowing to the northward, holds its width and plunges into the bay. The eastern side, however, is well exposed here and there along the shore, beginning near the Creamery, 3 miles directly east of Marshfield, in secs. 29 and 30, T. 25, R. 12.

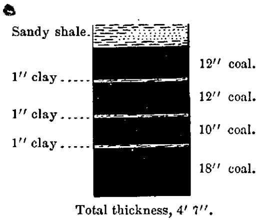


FIG. 58.—Section of Norton's coal on Catching Slough, 3½ miles southeast of Marshfield.

At Mr. Worth's house, and in the ravine close by, are exposures of what appear to be the same coal (fig. 59), which is especially remarkable for the large number of partings it contains. Near Smith's, in the same region, the coal represented in fig. 60 occurs at a horizon several hundred feet below the coal at Worth's. Coal is exposed at a number of places near the eastern shore of the bay between the Creamery and Kentuck Slough, but mining has not been attempted. On the point between Kentuck and Haynes sloughs two beds of coal have been found a mile east of Glasgow, and openings have been made to mine them both. The upper one is known as the Hardy coal and the lower one as the Steva coal, and their sections are given in fig. 61. These beds, having about 180 feet of sandstone between them, have been traced from near one slough across the divide to the other. The strike near Kentuck Slough is nearly north and south, dipping to the west under the bay, but farther northward the coals make a decided swing toward the ocean, indicating approach to the northern end of the basin.

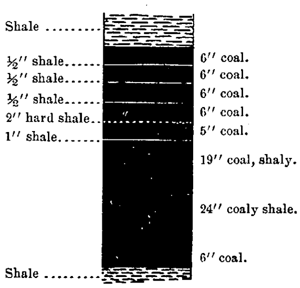


FIG. 59.—Section of Worth's coal near Coos River Creamery.

The divide rises to a height of over 500 feet and contains a considerable body of coal which is conveniently situated for mining and transportation.

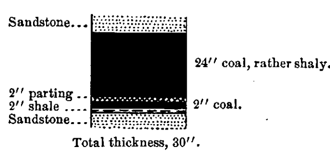


FIG. 60.—Section of Smith's coal near Coos River Creamery.

The mine on the Hardy coal was opened in 1871 upon the south side of the divide in sec. 1, a short distance northeast of Jordan Point. It was operated by a rock tunnel, over 800 feet in length, run through fossiliferous rocks overlying the coal and a gangway of over 400 feet in length upon the coal. The coal, although somewhat irregular in its course, was not affected by faults as far as the gangway extended. The coal is reported by

Mr. W. A. Goodyear,[1] who examined the mine when in operation, to be rather soft and to air-slack badly. The mine closed about 1873.

Mining began upon the Steva vein about 1891. It was opened upon the Kentuck side of the divide, a short distance north of the township corner, by a tunnel 450 feet in length. Only the lower three benches

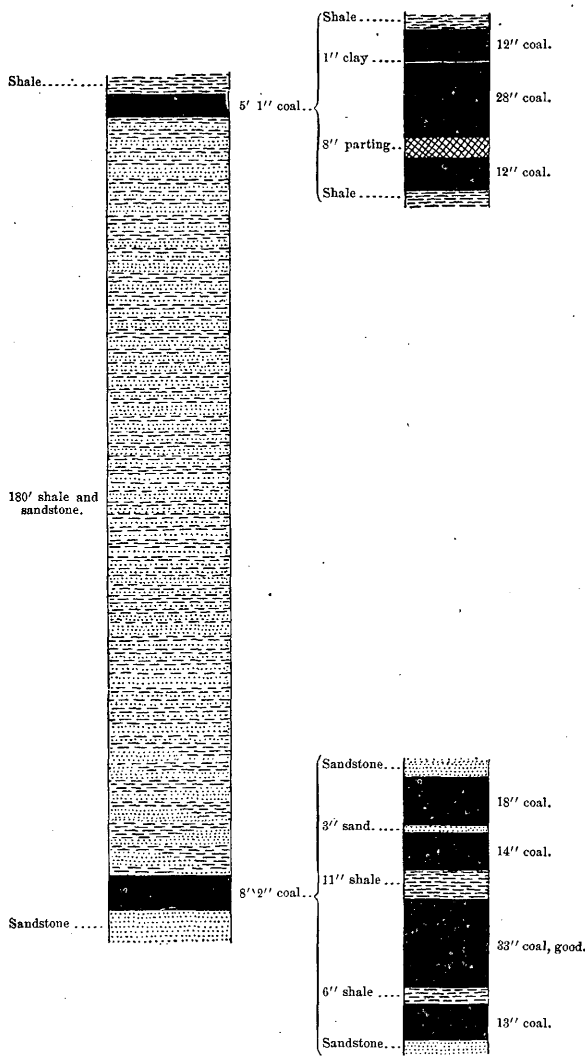


FIG. 61.—Section of Hardy and Steva coals near Glasgow.

were mined, and about 150 tons of coal were taken out. Analysis No. 26 in the list of analyses (p. 367) shows its composition. This coal has not been traced quite to Kentuck Slough. The material near the slough has slid and concealed it.

[1] Coal mines of the Western Coast, 1887, p. 93.

In the rock tunnel of the Hardy mine fossils are abundant, and among them is found *Cardita planicosta*, one of the most characteristic Eocene forms. This occurrence clearly demonstrates that the strata of the Coos Bay coal field—i. e., the Coaledo formation—are of Eocene age.

Much search has been made for other coals in that region, but no important ones have yet been found. Near Glasgow a boring was made to the depth of 70 feet, passing through two little coal beds, 6 inches or less in thickness, in the strata overlying the Hardy coal. Traces of coal have been found in the southern part of sec. 25 in such position as to indicate that the beds lie below the Steva coal, but the existence of an important bed in that position is a matter of doubt.

It has been asserted that the Newport and Hardy coals are the same bed, but this is hardly probable, since the Steva bed lies beneath the Hardy, and there is no indication of an important bed within a few hundred feet below the Newport. It is much more likely that the Steva bed is the equivalent of the Newport. It lies near the border of the field and would be expected to contain a much larger amount of sediment, of whose increase in the northern portion of the Newport bed there is a suggestion at the South Marshfield mine (illustrated in fig. 25), 5 miles from Glasgow.

The northern end of the Beaver Slough Basin is not so well exposed as the southern end, near Riverton, and yet the curvature of the Hardy and Steva coals clearly indicates an approach to the northern end. This is interrupted, however, by the occurrence of the Steva bed, just beyond the limits of the map, on the point between Haynes and North sloughs, where its strike is N. 6° W. and its dip 30° SW., making a considerable angle with that already noted. Fig. 62 shows a section of the bed at this point. The coals are somewhat larger than in the mine. Farther northward the coal-bearing rocks pass beneath the dune sands of the coast. The coals reported at intervals along the coast farther north probably have no direct connection with the coal basins of Coos Bay.

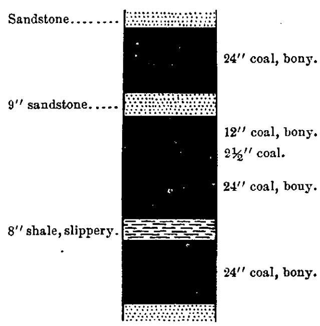


FIG. 62.—Section of coal in section 34, on point between North and Haynes sloughs.

SOUTH SLOUGH BASIN.

South Slough Basin has the South Slough for its central topographic feature and lies to the west of the Newport and Beaver Slough basins, from which it is separated by the Westport arch. Except at the southern end, the limits of the South Slough drainage mark out approximately the outline of the basin. The coal exposed at several localities near Empire, as well as that farther southwest in secs. 8, 17, and 18, T. 26 S., R. 13 W., and sec. 1, T. 27 S., R. 14 W., belong to the eastern arm of the basin. In sec. 2 the coals turn and extend northwest, cropping out at several points on Big Creek and reaching the coast between Miner's Creek and Big Creek.

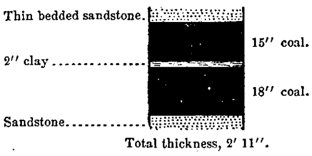


FIG. 63.—Section of coal near summit on the Empire trail, in NE. ¼ sec. 29, T. 25 S., R. 13 W.

Near the summit on the Empire trail, a mile west of Pony Slough, several coals are exposed. Surface openings show the section of fig. 63. One coal stands at an angle of over 60°, and another near by, a larger bed but of poor quality, stands vertical.

About a mile south of Empire, on the Cammon road, three coal beds are reported, 3, 5, and 6 feet, respectively, in thickness. They are poorly exposed by several small tunnels and shafts which are nearly closed, so that the reported measurements could not be verified. The coals lie close together, and several exposures may be upon the same bed. One bed shows 18 inches of coal above and 20 inches below a 6-inch parting of gray sand, and closely resembles the coal a mile to the east of Empire on the Marshfield trail. The coal dips eastward at an angle of 70° and can not be mined to advantage. Coal was early discovered here, and one of the first cargoes was shipped from this vicinity.

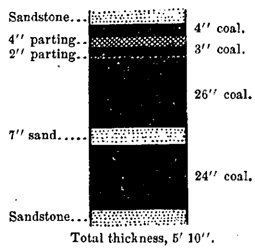


FIG. 64.—Section of coal near Oldlands, sec. 8, T. 26 S., R. 13 W.

The coals at the two localities just noted, on the trail and on the Cammon road, although a mile apart, may be of the same group. They dip toward each other steeply, as if forming a narrow but deep syncline. The layer of sand covering the region and the high inclination of the beds do not encourage prospectors, for there is scarcely any probability that paying coal will be found in that part of the basin.

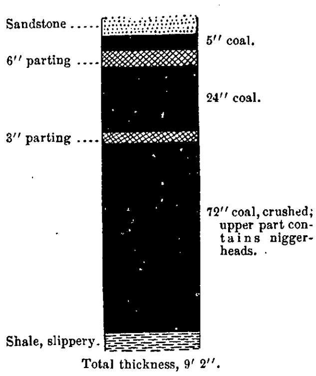


FIG. 65.—Section of coal opened by Mr. Monroe, near line between secs. 17 and 18, T. 26 S., R. 13 W.

Pony Slough lies close to the sharp arch that separates the Newport and South Slough basins. Upon the eastern border of the South Slough Basin no more coal has been opened north of sec. 8, T. 26 S., R. 13 W. Near Mr. Oldland's, in sec. 8, a bed crops out, and farther southwest the same bed has been recently opened by Mr. Monroe. Near Oldland's the coal afforded the section shown in fig. 64, and it probably extends northward through sec. 5. It has a dip of 55° NW. Its structure, size, and position all tend to indicate that it is the Newport bed which comes out to the surface along the border of the Newport Basin three-fourths of a mile to the east. At that point, however, there does not appear a clear parting in the upper bench as at Oldland's, but of the three benches the upper is said to be the most variable at Newport.

Where opened by Mr. Monroe, near the line between secs. 17 and 18, the bed is larger, but stands at a higher angle (70°), dipping to the west, and is more crushed, especially the lower part, which is much thickened. Fig. 65 shows the section at this point. Farther south in the same gulch a mass of much crushed coal has been opened, and it probably belongs to the same bed. South of the Bandon road, in secs. 18 and 19, Mr. Monroe has opened several other coals striking nearly north and south and dipping to the east at angles ranging from 15° to 88°.

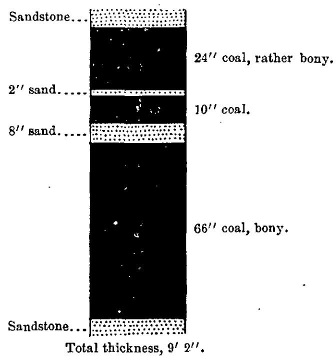


FIG. 66.—Section of coal in southwest part of sec. 31, T. 26 S., R. 13 W.

Proceeding southwestward along the eastern side of the South Slough Basin in the southwest part of sec. 31, T. 26 S., R. 13 W., the coal illustrated in fig. 66 was observed. It is a large bed, made up of three benches, like the Newport bed, but their relative size and the quality of the coal is different. The strike of the bed is N. 20° W. and the dip 52° NE. toward the side of the basin, and it is possible that there is a narrow syncline here, as farther south along the township line in 27, between ranges 13 and 14. In the adjoining portions of secs. 13 and 18 it is well shown by the dips of coal recognized upon both sides.

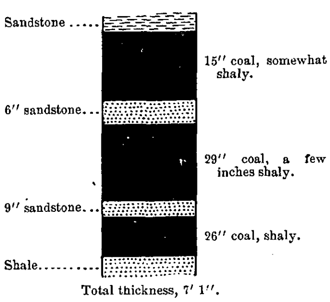


FIG. 67.—Section of coal in southwest part of sec. 2, T. 27 S., R. 14 W.

In sec. 1, T. 27 S., R. 14 W., there are a number of coal outcrops with a uniform strike of N. 20° E. and steep dip to the northwest (53° to 72°), the biggest bed having the highest inclination. This bed is not faced up at sufficient depth to show it free from surface modifications. It appears to have a thickness of 6 feet 2 inches, with three benches resembling the Newport, but is generally soft and muddy.

In the southwestern part of sec. 2 of the same township there are several fine outcrops faced up for Captain Parker and lately prospected extensively for Mr. J. D. Spreckels by W. S. Chandler, from whom I have received much information concerning recent openings. Two exposures are shown in figs. 67 and 68, and their striking resemblance to the Newport bed is at once apparent. They are less than half a mile apart, and near the main line of strike, which curves to the northwestward. One strikes N. 80° W. and dips 18° NE., and the other strikes N. 66° W. and dips 19° NE. Near the southeast corner of sec. 2 the strike is N. 70° E. and the dip 25° NW. All these openings are on the same bed and mark the point where the coal swings across the basin by a small transverse arch and turns northwest along its western side. The quality of the coal, judged from its physical appearance as well as its analysis (No. 27, p. 367), is very good. It outcrops in such a position as to allow sufficient fall for handling and delivery at tide level without obstruction. Its gentle slope is convenient for mining, and a large body of coal lies in the hills to the northwest along the strike, which curves to the north until it is about N. 30° W. This strike carries the coal into the head of Big Creek, where several other outcrops have been opened. The promise found in the exposures of coal in the southern part of sec. 2, however, is greatly limited by the position of the coals in adjacent sections. Near the line between secs. 2 and 3 the Newport coal, as well as the one overlying it, dips easterly at a high angle, showing that the gentle dips do not extend far to the northwest. To the southwest, in sec. 10, high dips prevail, as also to the eastward in sec. 1, where the dip ranges from 53° to 70°. It is probable, therefore, that the area promising the most favorable conditions for mining in the southwest part of sec. 2 is less than a square mile in extent.

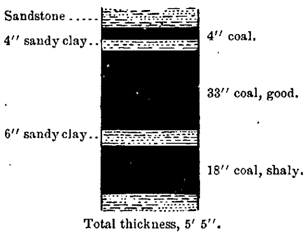


FIG. 68.—Section of coal in west part of sec. 2, T. 27 S., R. 14 W.

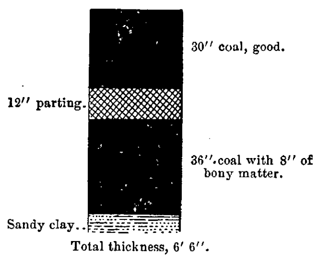


FIG. 69.—Section of coal at Aiken's cabin in western part of sec. 18, T. 27 S., R. 13 W.

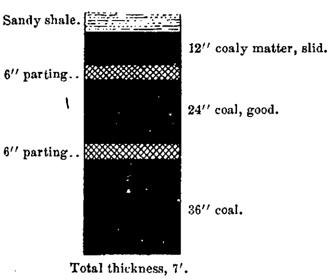


FIG. 70.—Section of coal in eastern part of sec. 14, T. 27 S., R. 13 W.

Directly west of Beaver Hill, near the western line of sec. 18, at Aiken's cabin, a bed of coal occurs having the section given in fig. 69. The coal is not so opened as to show the presence or absence of any more coal at the top. It dips apparently about 40° W. The coal looks very much like that of Beaver Hill, from which it is separated by a narrow ridge made by the Westport arch, around the end of which the coal appears to swing to the Beaverton mine. An analysis of this coal is numbered 28 in the list of analyses given on p. 367.

There is but little doubt that this bed is the same as that mined at Beaver Hill and Beaverton, and the doubt is lessened by exposures of the same coal farther westward, where the upper bench appears.

In the eastern part of sec. 13, about one-fourth mile directly west of Aiken's cabin, the same coal appears as in fig. 70, and has a dip of 12° SE., forming a shallow syncline with that of Aiken's cabin. Farther westward, in sec. 13, the same bed again appears as in fig. 71, with a strike N. 20° W. and dip 33° SW. to a small basin lying beyond. Exposures are extremely meager in that region, and the nearer the approach to the coast the thicker becomes the covering of superficial deposits, so that prospecting is rendered more difficult. The extent of the basin is unknown, but can not be very great, although it may occupy a part of secs. 11, 12, 13, and 14, T. 27 S., R. 14 W. It may be considered a southern extension of the South Slough Basin, from the main portion of which it is separated by a low cross arch in the northern parts of secs. 11 and 12. To the southeast it swings around the end of the Westport arch and is connected with the Beaver Slough Basin.

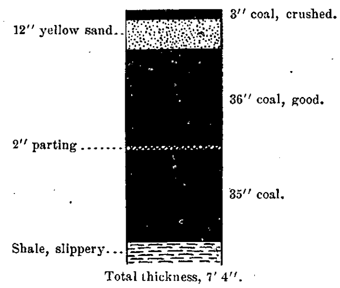


FIG. 71.—Section of coal in southwest part of sec. 13, T. 27 S., R. 14 W.

Farther southward, in the eastern part of sec. 26, Captain Parker some years ago opened a bed, of which fig. 72 represents a section. The coal is cut by one of the branches of Sevenmile Creek, in a ravine 125 feet deep. About 25 feet above the bottom of the ravine a curved tunnel runs southwesterly upon the coal for 100 feet. Some of the coal is rather soft and earthy and is somewhat crushed, but much of it is of good quality, as shown by analysis No. 29 (p. 367).

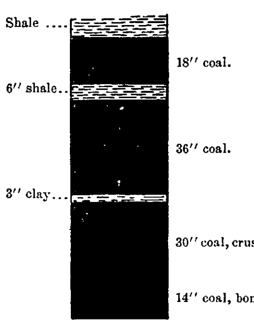


FIG. 72.—Section of coal on Sevenmile Creek, in eastern part of sec. 26, T. 27 S., R. 14 W.

This coal was extensively prospected last year by different parties under the direction of R. A. Graham and W. S. Chandler. It is generally known as the Sevenmile or Big coal, since it has a larger amount of coal than any other bed in the Coos Bay coal field. From Parker's opening, in sec. 26, it has been traced northward across secs. 23, 14, 10, and 4, T. 27, R. 14, to the vicinity of Fivemile Creek. Its dip is eastward, and generally at a high angle, sometimes even vertical. To the south it has been traced across the NE. ¼, sec. 35, and the SW. ¼, sec. 36, into the ridge which forms the divide west of Hatchet Slough, and its dip to the east does not exceed 40°.

Although the amount of coal in this bed is large, it frequently varies, is usually soft, and contains a number of clay partings. The roof and floor are shale, sometimes soft and slippery, rendering mining difficult, and it is doubtful whether this coal can be profitably mined.

At first this coal was regarded as the probable equivalent of the Newport coal, but later investigations tend to show that it lies far below the Newport bed. These beds occur nearest together in sec. 10, T. 27, R. 14, where their outcrops are about a mile apart, and each has a dip of 80° E. On this basis, if the beds are not faulted, about 5,000 feet of strata lie between them. If it is so far below the Newport coal and widely developed it may underlie the whole of the Westport arch. It has not been definitely recognized in any other part of the coal field beyond that already noted, although it is probable that it may yet be positively identified farther south.

Near the northern line of sec. 1, T. 28, R. 14, a 10-inch coal between shales and a slide containing 4 or 5 feet of coal were found in a branch of Hatchet Slough. The slide came down from near the summit to the westward. In the SE. $\frac{1}{4}$, sec. 1, several exposures of a 2-foot bony coal were found with a 6-inch parting of sand near the middle, but nothing that appears to be equivalent to the Big vein was seen at this point.

Farther southwest, nearly 2 miles east of Parkersburg, in sec. 24, T. 28, R. 14 W., several coals were observed, one 3 feet 10 inches in thickness and another 2 feet. In both the coal was much weathered and either soft or bony. The exposures were too poor to afford a completely reliable impression of the character of the coal. Traces of these coals have been found south of the Coquille River, a short distance west of Lamprey Creek, where Mr. Timon has recently opened a bed exposing 6 feet 5 inches of coal with four partings ranging from 1 to 10 inches in thickness. It is probable that this bed is the equivalent of the Seven-mile coal. It lies far below the Urquhart, which appears to be the equivalent of the Newport bed.

Returning now to the northern portion of the South Slough Basin, its coals may be traced along the northwest border of the basin into the drainage of Big Creek, where five beds of coal have been found in sandstones and shales having a thickness of not over 300 feet. The largest bed, which lies at the top, has 4 feet 11 inches of coal, with two partings from 3 to 6 inches thick. The quality of the coal is generally poor. The other four beds of coal range from 8 to 15 inches thick. The largest bed, at the top of the series, has been opened at several points, but does not promise profitable mining. Analysis 30 in the list, page 367, is of Big Creek coal. The strike of the coal is N. 30° W. and the dip 48° NE. If continued in this direction it would reach the coast near the mouth of Big Creek, half a mile south of the light-house at Cape Gregory. The sea cliffs bordering the beach south of the light-house toward Cape Arago, as well as east toward Coos Head, afford especially good and continuous exposures of the rocks of that region. If beds of coal occurred they would most likely be well exposed. None, however, are seen excepting one at Yokam Point, where a coal 1 foot 10 inches in thickness occurs regularly interstratified with the sandstones and shales, having a strike N. 15° W. and a dip 70° NE. The bluff is rugged, and the coal can be reached only by means of a ladder or rope. Although not promising for mining, some of the coal has been used to good effect at the light-house for winter fuel. The adjacent sandstones immediately overlying the coal are full of marine shells, among which *Cardita planicosta* occurs; so that in this case, as east of Glasgow, the coal is certainly of Eocene age. The structural as well as paleontological relations of the coal-bearing beds show that they are equivalent to those so well exposed along the coast at Yokam Point and westward to near the mouth of Big Creek. As already stated, only one coal reaches the coast; the others have run out before reaching this point. This is the place where the original swamp merged into the sea. The coal beds and brackish-water strata are here represented by purely marine sediments of the same age.

COQUILLE BASIN.

Having considered the Newport, the Beaver Slough, and the South Slough basins, there yet remains the Coquille Basin. It embraces the coals extending from the town of Coquille a little west of south, by Harlocker Hill, to the upper portion of Hall Creek. The southern portion of the basin extends about 4 miles beyond the southern limit of the map, Pls. XLVIII and XLIX. The complete outline of this basin and of all the other basins in the Coos Bay coal field will be shown in the Coos Bay folio of the Geologic Atlas of the United States.

The coals of this little basin are best exposed along the river 4 miles south of Coquille at Harlocker Hill, where they have been recently well opened by prospectors. A generalized section of the coals in the vicinity of Harlocker Hill is shown in fig. 73, and in the same figure detailed sections of the coal beds are given. All of the coals, except the two upper ones, crop out on the steep slope facing the river. Another coal is said to occur at the bottom of the section, but as it is exposed only at low water it could not be examined. The four lower ones marked in the section are well exposed along a steep ravine a short distance above the road, and have been opened by Mr. A. J. Smith. The second is largest, but the quality of the material is not so good. The third and fourth beds from the bottom have been opened by tunnels and some coal has been removed. Preparations were in progress to open a mine here. The two coals noted at the top of the section are exposed a short distance north of Harlocker Hill near Mr. Figg's place. All of these coals dip from 16° to 20° NW. Southwest of Harlocker Hill, in the western branches of the ravine leading up from the old logging camp, the strata including the coal dip to the

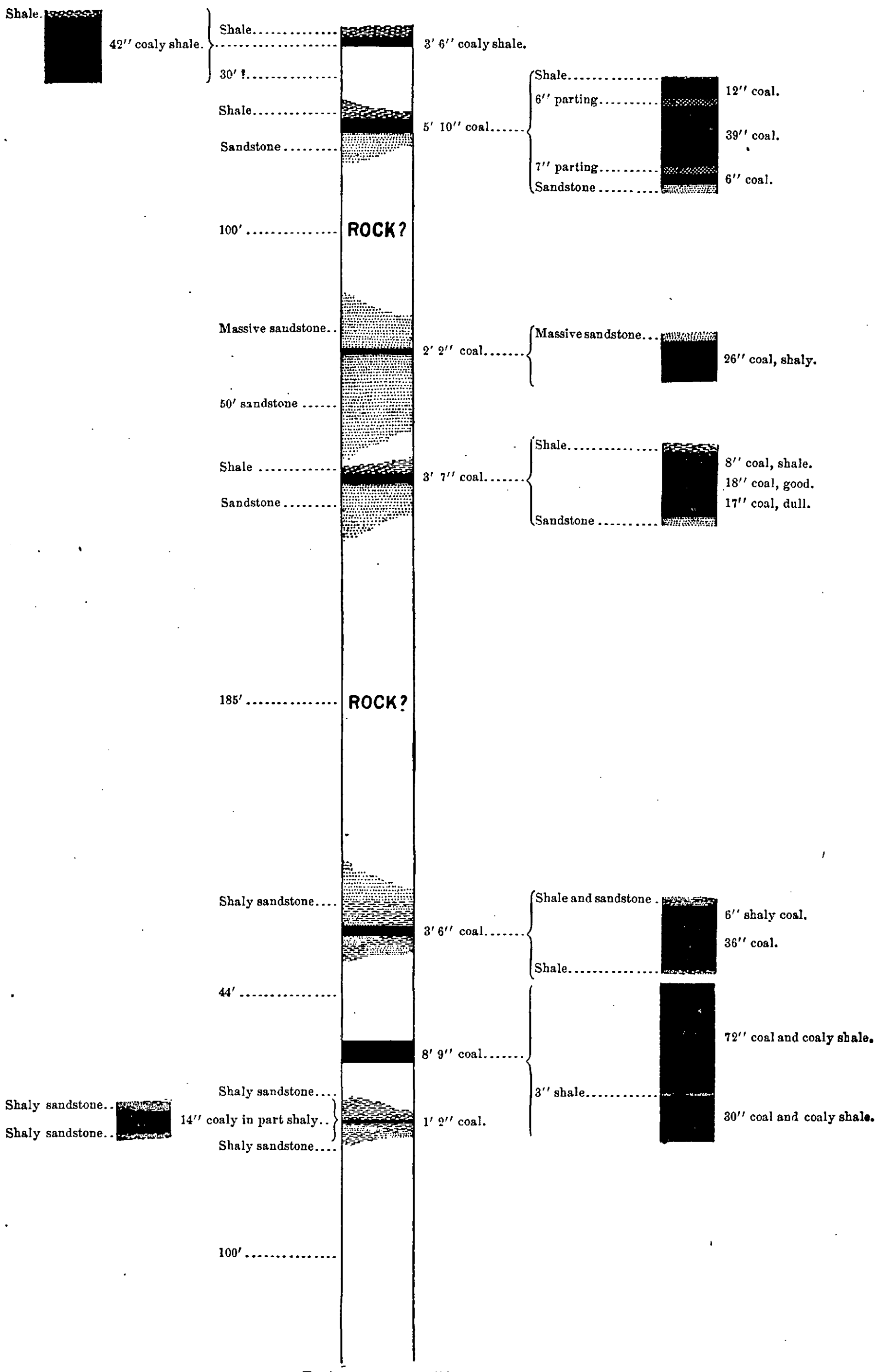


FIG. 73.—Section of coals and associated rocks in the vicinity of Harlocker Hill, 4 miles south of Coquille.

southeast—i. e., toward the beds of Harlocker Hill—and with them form a syncline or basin. Southeastern dips are exposed also near the road at Pulaski Creek, and all the coals which run into the ground at Harlocker Hill come out again to the surface within a few miles to the west. If these coals prove to be worth mining and the basin is not too deep to drain itself, they can be most economically mined from the end. The middle of the basin is about half a mile northwest of the river front of Harlocker Hill. The coals crop out on the southeastern slope of Harlocker Hill at an altitude of 200 feet or less above the

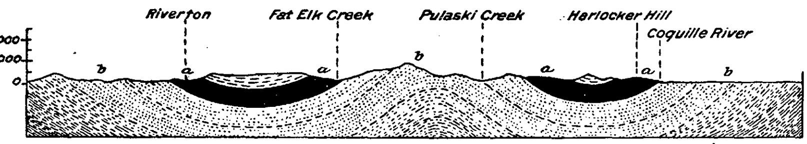


FIG. 74.—Section from Harlocker Hill to Riverton, across Coquille basin, Pulaski arch, and Beaver Slough Basin.

river, with an average inclination of 10° NW. If that inclination continues northwest to near the middle of the basin the coals at that point must lie at least several hundred feet below the level of the river. Only about a square mile of the basin remains above drainage at this point. To the north it has been washed away by the Coquille and to the south by the Fishtrap.

The relation of the Coquille Basin at Harlocker Hill to the lower end of the Beaver Slough Basin at Riverton may be seen in fig. 74. On the right is the Harlocker Basin, the dark band representing the coal-bearing bed, and on the left is the Beaver Slough Basin at Riverton. The two are separated by an arch near the head of Pulaski Creek, which for convenience may be called the Pulaski arch. Although numerous outcrops of coal are known west of Fat Elk Creek and east of Pulaski Creek, none are known in the intermediate region. The reason is that the Pulaski arch brings up strata of the Pulaski formation which lie below the coal.

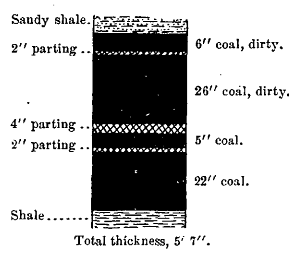


FIG. 75.—Section of coal near Lilly's, 1 mile southwest of Arago.

It is the Pulaski arch which separates the Coquille and Beaver Slough basins farther north. The irregular arch on Beaver Creek may possibly be connected with the northern end of the Pulaski arch.

The coal basin extending south from Harlocker Hill contains several coal beds about Lilly's, a mile southwest of Arago. They occur in the bold hills facing eastward, and, like the coals prospected on Harlocker Hill, dip to the west. Fig. 75 illustrates the largest coal of the three outcrops examined. Although it is certainly one of the group of coals occurring at Harlocker Hill, its exact equivalents can not be identified with a high degree of probability. The coal next the top one of the

Harlocker series exposed in the ravine a short distance southwest of Figg's place is most like it.

From Lilly's the coals extend to Halls Creek, where, at Lundy's place, two exposures occur, one showing 2 feet of coal and the other nearly 7 feet, including a good-sized "nigger-head" and some bony material. The two exposures are only about 250 yards apart and may be the same bed. If so, the thickening of the bed is only local. Farther up the creek coal has been reported near the northeast corner of sec. 16, but is not now exposed. This marks the southern limit of the Coos Bay coal field.

North of Harlocker Hill, coal is next found near Coquille, where a few openings have been made and a hundred tons or so removed. Fig.

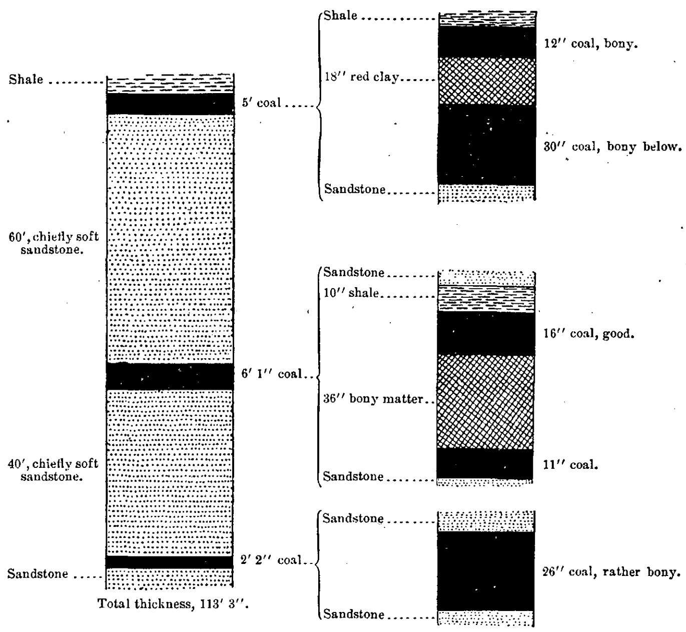


FIG. 76.—Section of coals and associated rocks at Coquille.

76 shows a section of the coals exposed. The distances between them have not been fully measured. The top coal lies nearly flat, and Mr. Burrows has run a tunnel into it for several hundred feet. The other coals exposed in a ravine northeast of the town have been opened by Mr. Wilson. Upon the middle bed an incline has been run 125 feet. At first the slope was 20° to the south, but the coal flattened out and became wrinkled and the tunnel meandering. Upon the lower coal a tunnel was run to the northwest and an incline to the east to the length of 120 feet, on a slope of 16°. The position of the strata is very irregular, a feature which may be due, at least in part, to the large mass of diabase a short distance to the southeast. These are the most northern exposures of coal known in the Coquille Basin.

The Coquille Basin, extending from a mile north of Coquille to the upper portion of Halls Creek, has a length of about 8 miles and a width of nearly a mile. Its area is approximately 8 square miles. The only part within it of considerable promise is at Harlocker Hill, and even here the readily available mass is limited to but little over a square mile.

ANALYSES OF COOS BAY COALS.

No.	Moisture at 105° C. 1 hour.	Rapid heating.		Ash.	Sulphur.	Physical properties of coke.	Analyst.
		Volatile matter.	Fixed carbon.				
1	9.78	42.57	44.19	3.46	0.91	Sooty, partly coherent	Peter Fireman.
2	11.94	41.48	37.85	8.73	1.32	Sooty, non coherent	Do.
3	15.45	41.55	34.95	8.05	2.55	Will not coke	Thomas Price.
4	17.27	44.15	32.40	6.18	1.37	do	Do.
5	9.66	43.50	35.02	11.82	3.08	do	George Steiger.
6	14.84	32.60	50.21	2.35	......		Henry G. Hanks.
7	14.78	35.20	40.25	9.77	......		Do.
8	10.05	41.55	44.50	2.90	......	Does not coke	Thomas Price.
9	15.49	35.87	44.59	4.05	......		Henry G. Hanks.
10	16.30	33.46	42.67	7.57	......		Do.
11	10.42	42.21	43.18	4.19	0.69	Sooty, very slightly coherent.	Peter Fireman.
12	9.56	49.85	35.98	4.61	0.94	Does not coke	George Steiger.
13	9.54	42.37	43.90	4.19	1.85	do	Do.
14	13.9	35.7	45.4	5.00	......		C. A. Luckhardt & Co.
15	10.30	55.37	26.50	7.83	0.38	Does not coke	George Steiger.
16	10.43	66.71	13.23	9.63	0.37	do	Do.
17	8.10	38.95	43.18	9.77	4.28	do	Do.
18	10.59	50.05	33.89	5.47	0.56	Will not coke	Do.
19	9.58	44.66	40.06	5.20	1.12	do	Do.
20	11.65	66.18	17.31	4.86	0.59	do	Do.
21	11.30	41.04	43.63	4.03	2.10	do	Do.
22	11.54	49.13	33.76	5.57	0.49	do	Do.
23	12.06	60.92	16.23	10.79	4.38	do	Do.
24	7.94	41.91	46.95	3.20	0.28	do	Do.
25	10.27	45.69	42.74	1.30	0.94	Coke fair	Do.
26	11.03	44.97	31.99	12.01	2.01	Will not coke	Do.
27	9.00	44.92	41.74	4.34	1.97	do	Do.
28	8.53	42.52	44.43	4.52	0.82	do	Do.
29	6.88	48.69	32.05	12.38	1.50	do	Do.
30	10.03	53.63	29.70	6.64	3.06	do	Do.
31	.79	48.90	36.58	13.73	6.25	Coke good	Do.
32	14.24	55.60	22.64	7.52	0.32		

In all the analyses of this table made by Mr. Steiger the volatile matter was determined by heating seven minutes over a Bunsen burner flame 18 centimeters high, the crucible being placed 8 centimeters above the burner. The results are given in the columns under rapid heating.

Localities of coals of which analyses are given in the table.

1. Newport mine, sec. 9, T. 26 S., R. 12 W. Shows distinct woody structure.
2. Newport mine, sec. 9, T. 26 S., R. 12 W.
3. Newport mine, upper bench.
4. Newport mine, lower bench.
5. South Marshfield mine, middle bench.

6. Beaver Hill coal, middle bench, Garden Gulch, Dean & Co.'s property, sec. 9, T. 27 S., R. 13 W., from C. H. Merchant.
7. Beaver Hill coal, lower bench, Garden Gulch, Dean & Co.'s property, sec. 9, T. 27 S., R. 13 W., from C. H. Merchant.
8. Beaver Hill coal, middle bench, Dean & Co.'s property, eastern part of sec. 9, T. 27 S., R. 13 W., from C. H. Merchant.
9. Beaver Hill coal, middle bench, eastern part of sec. 4, T. 27 S., R. 13 W., from C. H. Merchant.
10. Beaver Hill coal, lower bench, eastern part of sec. 4, T. 27 S., R. 13 W., from C. H. Merchant.
11. Beaver Hill coal, Beaver Hill mine, sec. 17, T. 27 S., R. 13 W.
12. Beaver Hill coal, Beaver Hill mine, sec. 17, T. 27 S., R. 13 W. Middle bench 300 feet beneath surface.
13. Beaver Hill coal (?), near western line of sec. 19, T. 27 S., R. 13 W.
14. Urquhart's coal, by river, one-half mile southwest of Riverton.
15. Lyon & Co.'s mine, middle bench, 1½ miles south of Riverton.
16. Bunker coal, 28-inch bed, near Bunker, of Bandon Block Coal Company, at Riverton.
17. Bunker coal, Urquhart's opening on 24-inch bed, one-half mile south of locality 16.
18. Peterson's coal, near the line between secs. 9 and 16, T. 28 S., R. 13 W.
19. Beaver Creek mines (Utter mines), 1 mile southeast of Coaledo, coal of Upper Bench B.
20. Top bench of lower coal shown in section represented by fig. 47, 2½ miles northeast of Coaledo, near eastern line of secs. 12 and 13, T. 27 S., R. 13 W.
21. Middle coal. Shown in fig. 47.
22. Top coal. Shown in fig. 47.
23. Coal, 1½ miles northeast of Henryville, sec. 26, T. 27 S., R. 13 W
24. Southport coal, 5 miles south of Marshfield.
25. Norton's coal, on Catching Slough, sec. 5, T. 26, R. 12.
26. Steva coal, 5 miles northeast of Marshfield.
27. Near South Slough, sec. 2, T. 27 S., R. 14 W.
28. Coal at Aikens Cabin, near western line of sec. 18, T. 27 S., R. 13 W.
29. Parker's coal, on Seven Mile Creek, sec. 26, T. 27 S., R. 14 W.
30. Near Dr. Cook's, sec. 28, T. 26 S., R. 14 W.
31. Coal reported from Shasta Costa Creek, near Rogue River.
32. Reservoir coal, near Marshfield.

PITCH COAL OF THE COOS BAY COAL FIELD.

Associated with the coal that is mined at several points in the Coos Bay coal field is a coaly substance generally known in that region as "pitch coal." It was observed and samples were collected at two localities—Ferrey's mine, at Riverton, and the Newport mine, at Libby—but it has been reported from other places. These two occurrences are about 13 miles apart and associated with different beds of coal in different basins. In Ferrey's mine my attention was first called to it by Mr. William Sharp. The coal is so crushed that its relation to the pitch coal could not be clearly made out, but the pitch coal appears to occur as irregular masses, veins, or partings in the coal, varying from 2 inches to 3 feet in thickness.

The principal occurrence is in the Newport mine, where it is not uncommon. The best specimens I have were sent me by Mr. P. Hennessey, the superintendent of the mine, who collected them from a small vertical "seam" which passes directly through both benches of coal as well as the mining and cap rock. The "seam," or rather vein, is about 2 inches in diameter, with well-marked sides sharply defined against the coal and associated rock. Its mode of occurrence is therefore in strong contrast with that of the lignite, and suggests that it is related to asphalt rather than coal, for the latter very frequently occurs in fissures.

The pitch coal has a dark-brown color with brown streak and lighter brown powder. It is rather soft and very brittle, with irregular, angular fracture. One of its common physical features is a foliated structure, by reason of which it splits into small, thin plates. This structure in the best specimen at hand is perpendicular to the walls of the vein. It readily ignites from a match, melts with strong intumescence, and yields a very smoky flame. This easy ignition, fusion, and combustion again suggests that pitch coal is related rather to asphalt than to coal. It is evident that if the pitch coal is an asphalt it belongs to a group of compounds of which petroleum is a member, and may be more closely related to petroleum than to coal in origin. To discover more fully the chemical nature of the pitch coal and its relation to the Newport coal, samples of both were referred to Prof. William C. Day for special chemical investigation, and his report follows. His investigation shows conclusively that the pitch coal is an asphalt, and that its origin is independent of that of the coal with which it is associated.

The occurrence of asphalt in the oil regions of California is not uncommon, and its genetic relation is a matter of much interest. Prof. I. C. White, State geologist of West Virginia, who is one of the highest authorities in this country on coal, oil, and gas, calls my attention to a deposit of grahamite in Ritchie County, West Virginia, described by Professor William M. Fontaine[1] and lately by himself.[2] It fills a fissure 3 feet wide, and was once extensively mined for use in manufacturing gas. The elementary composition of this West Virginia asphalt as given by Fontaine and that of the pitch coal as reported by Day are shown in the accompanying table, where they are seen to be quite closely related:

Composition of asphalt from West Virginia (1) *and Oregon*(2).

	Carbon.	Hydrogen.	Oxygen.	Ash.	Nitrogen.	Sulphur.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	76.45	7.83	13.46	2.26	Trace.	Trace.
2	72.17	7.90	14.61	4.30	0.58	0.52

The special interest growing out of this similarity is to be found in Professor White's theory of the origin of the West Virginia asphalt. He says, in a letter to me dated February 14, 1898:

It is simply the residuum of petroleum. The fissure extends down through underlying oil sands, and when the crack was opened petroleum oozed up and the tarry matters in solution finally plugged up the exit, just as they will do in an oil well if not interfered with by the torpedo man. The fissure has been traced for over a mile and runs about N. 13° W., being at right angles to the great "Volcano" anticline which extends through that region, and the upthrust of the latter evidently caused the rent.

[1] Am. Jour. Sci., 3d series, Vol. VI, 1873, pp. 409-416.
[2] Bull. Geol. Soc. Am., Vol. X.

The proof of the correctness of Professor White's view is found in the fact that "a great deposit of petroleum has lately been developed in the immediate vicinity of the fissure and 1,800 feet under the surface." While the presence of pitch coal in Oregon contains interesting suggestions with reference to the occurrence of petroleum, too little is yet known of the facts to warrant any predictions.

THE COAL AND PITCH COAL OF THE NEWPORT MINE.

By WILLIAM C. DAY.

The questions at issue are: First, is the pitch coal a variety of asphaltum? Second, was it derived in any way from the coal or is its origin different from that of the coal? And, if the latter, is not the presence of material of the nature of petroleum or allied substance indicated as the original mother substance from which the pitch coal was formed?

Briefly stated, my conclusions are that the pitch coal is a variety of asphaltum, and that it has not been formed from the coal alone with which it is associated, although vegetable material similar to that which yields coal may have formed some of the original material which, by a process of distillation, was converted into the pitch coal. From the nitrogenous bodies which I have found in the pitch coal I judge that animal matter has been in part, if not entirely, the source of the pitch coal. In short, the pitch coal has in all likelihood been formed in the same general way as other asphalts in California which are believed to have been the result of the distillation of animal and vegetable remains in presence of hot water or steam. This is the view entertained by Prof. S. F. Peckham, who has studied the petroleums and asphalts of California in much greater detail than any other investigator. Peckham's views are summed up in the following quotation from a paper by him on the Nature and origin of petroleum:[1]

> The circumstances of my life have brought me into personal contact with deposits of bitumen over a very wide area and under such conditions as have afforded me very unusual opportunities for a careful study of all the phenomena attending the appearance of bitumen at the surface of the earth, the result of which has been to confirm the opinion that I have heretofore expressed—that, in the majority of instances, bitumens, from natural gas to asphaltum, are, where we now find them, distillates.

I believe, then, fully that the pitch coal and the associated coal are perfectly independent of each other and are of entirely different origin, the pitch coal being formed by methods ascribed to the asphalts, while the coal is formed from wood, according to the generally accepted views of the formation of coal.

There are various theories in regard to the origin of petroleum, natural gas, and the asphalts, but it is not necessary to discuss these

[1] Proc. Am. Philos. Soc., Vol. XXXVI, No. 154, p. 111.

theories here, the questions being, rather, whether the pitch coal is an asphalt, and whether it could have been formed in situ from the coal.

The facts considered in drawing conclusions include analytical data pertaining to the pitch coal and the coal, results of experiments upon the distillation products of both, comparisons with similar products obtained by the distillation of gilsonite, and finally the action of a number of solvents which are customarily employed in investigations and analyses of the asphalts generally.

ANALYTICAL DATA PERTAINING TO PITCH COAL AND ASSOCIATED COAL OF THE NEWPORT MINE.

ELEMENTARY ANALYSIS (SPECIMENS DRIED AT 105° C. FOR 2 HOURS).

	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Ash.	Oxygen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pitch coal	72.17	7.90	0.58	0.52	4.30	14.61
Coal	58.54	5.03	1.13	0.82	6.38	29.23

DETERMINATIONS OF MOISTURE, VOLATILE MATTER, FIXED CARBON, AND ASH.[1]

	Moisture at 105° C., 1 hour.	Volatile matter.	Fixed carbon.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Pitch coal	2.24	83.69	11.41	2.66
Coal	10.71	44.48	39.02	5.79

[1] The percentage of ash in the asphalt varies somewhat from one sample to another; different samples also vary slightly in color when powdered. The ash of the coal appears to be constant in all samples so far as examined.

Three analyses made by W. F. Hillebrand are inserted here for comparison:

No.	Moisture at 105° C., 1 hour.	Moisture over H_2SO_4 in vacuo, 48 hours.	Volatile combustible, less moisture, in vacuo.	Fixed carbon, less ash.	Ash.	Sulphur.	Phosphorus.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent*
1	2.00	2.01	83.88	12.06	2.05	0.62	0.002
2	2.08	2.02	82.91	10.45	4.62	1.00	0.006
3	11.22	12.92	44.31	36.77	6.00	1.96	1.31

The coke of the pitch coals (1 and 2) was in hard, black lumps, adhering to the crucible, while that of the coal (3) was loose sandy. The ash of both pitch-coals and coal was nearly white.

No. 1 is pitch coal from Newport mine.

No. 2 is pitch coal from Ferrey's mine at Riverton.

No. 3 is coal from Ferrey's mine at Riverton.

DETERMINATIONS OF SILICA, IRON, AND ALUMINA IN ASH.

	Silica SiO_2.	Ferric oxide Fe_2O_3.	Alumina Al_2O_3.
	Per cent.	*Per cent.*	*Per cent.*
Pitch coal	33.39	4.26	7.72
Coal	16.92	11.53	11.79

DETERMINATIONS OF SOLUBILITY IN CARBON BISULPHIDE, ORDINARY ETHER AND PETROLEUM ETHER.

	Carbon bisulphide.		Ordinary ether.		Petroleum ether.	
	Insoluble.	Soluble.	Insoluble.	Soluble.	Insoluble.	Soluble.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pitch coal	36.45	63.55	34.21	65.79	89.34	10.66
Coal	Nearly all.	Trace.	Nearly all.	Trace.	All.	None.

CONSIDERATION OF ANALYTICAL RESULTS.

An inspection of the figures obtained as the result of elementary analysis of pitch coal and coal shows marked differences in the percentages of carbon and of oxygen, the pitch coal being much higher in carbon and lower in oxygen than the coal. The percentages of ash do not differ greatly in the two, but, as is evident from the analyses of the two ashes, there is very marked difference in their composition as well as in their appearance.

In the quantity of moisture given off at 105° C. a much larger proportion is evident for the coal than for the pitch coal, while under strong heat the latter gives off a much higher percentage of volatile matter than the former.

The figures of the elementary analysis of pitch coal do not resemble those of the analysis of any one of 65 different coals considered in Dana's Mineralogy, pages 756–758, edition of 1868. Comparing the same figures with those of asphalt analyses, however, they do agree fairly well with those of asphalt from Auvergne, which are as follows (see Dana, p. 752):

	C.	H.	O.	N.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Asphalt	77.64	7.86	8.35	1.02	5.13
Pitch coal	72.17	7.90	14.61	0.50	4.30

Most of the recorded analyses of asphalts are open to question, and there is much need of revision.

The figures for the Oregon coal agree fairly well with those of a brown coal from Meissen, Saxony (Dana, p. 758, analysis No. 54), as follows:

	C.	H.	O.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Meissen coal	58.90	5.36	21.63	7.50
Oregon coal	58.54	5.03	29.23	6.38

I have been unable to find any analysis of an asphalt which bears any resemblance to the analysis of the coal just given; the percentages of carbon in asphalts are always much higher than 58.

When I first observed the ashes of the pitch coal and the coal, I was much impressed with their different color and the presence in the pitch-coal ash of sharp, angular particles which were entirely absent in the ash from the coal. The color of the pitch-coal ash was nearly white, while that of the coal ash was brown, indicating a larger percentage of oxide of iron. These observations led me to make determinations of silica, iron, and aluminum in the two ashes. Comparing the results obtained, it is evident that the percentage of silica in the pitch coal (33.69) is just about twice the amount present in the coal (16.92); on the other hand, the figures for the combined oxides of iron and aluminum in the coal ash are about twice those obtained for the pitch-coal ash. The two materials, then, so far as ash can serve to indicate, are not of the same origin, since we should hardly expect such marked difference in mineral constituents if the pitch coal had been formed from the coal or from the woody matter which seems to have given rise to the coal. I am inclined to give considerable weight to the evidence furnished by this comparison of the two ashes.

ACTION OF SOLVENTS UPON THE TWO MATERIALS.

A most marked difference appears between pitch coal and the associated coal when we consider the action of the solvents carbon disulphide, ether, and petroleum ether or naphtha.

The coal, as would be expected, is almost entirely insoluble in the liquids named, while the pitch coal dissolves to a greater or less extent in all three, 63.55 per cent being soluble in carbon disulphide, 65.79 per cent in ether, and 10.66 per cent in petroleum ether. In short, so far as the action of solvents is concerned, the pitch coal acts like an asphalt, while the coal shows no such conduct.

PRODUCTS OF DRY DISTILLATION.

A quantity of pitch coal was placed in a hard-glass retort and heated. It very soon melted, forming a thick, black liquid, which promptly gave off moisture, accompanied by a dense white smoke. Soon afterwards, oil was noticed condensing in the upper part of the retort and running back to the heated liquid. The dripping of oil into the receiver soon began. it was at first dark and turbid looking and mixed with a small amount of moisture. After a time the color became lighter and took on a greenish cast; later still, and toward the end of the distillation, it became dark red and so viscous that it would hardly flow.

The general conduct of pitch coal in distilling is very similar to that of gilsonite under the same treatment, except that "foaming" takes place in distilling gilsonite, while pitch coal shows very little tendency to foam in distillation, which is regular and uniform throughout. The odor of the oil from pitch coal is of the same character as, but not identical with, that from gilsonite. As in the case of gilsonite, ammonia was quite freely evolved toward the end of the distillation, as shown by strong odor and immediate action upon wet litmus paper. The distilled oil was next subjected to distillation with steam; i. e., it was put into a flask with water, and the latter was boiled, and the steam and volatile oil were condensed in an ordinary Liebig's condenser.

The oil thus volatilized came over with the steam as a yellowish-green oil floating on the surface of the condensed water. After a time the oil becomes darker in color. The volatilization of oil with steam after a time comes to a definite and rather abrupt end, leaving undistilled a dark, rather viscous, and tarry liquid of disagreeable odor floating on the water in the distilling flask.

The conduct of this oil in distilling with steam is identical with that of oil from gilsonite when similarly distilled with steam, except that the odors are different enough to distinguish one kind from the other, although they are of the same character.

On shaking the oil, volatile with steam, with dilute sulphuric acid, the latter acquires, on settling off, a flesh-colored tint, showing that something has been dissolved; neutralization of this acid with an alkali (potassium hydroxide solution) gives at once a light, nearly white precipitate, which is again readily soluble in dilute acid. This conduct again is exactly like that which distillate from gilsonite shows. This action of dilute acids upon asphalt oil or petroleum was first noticed, so far as I know, by Prof. S. F. Peckham[1] in connection with the California petroleum. He has shown that the crude petroleums of California contain esters made up of basic oils in combination with an exceedingly viscous, feebly acid, tar. When the crude oils are treated with dilute acid, this acid radical forms a hydrate which produces with the other constituents of the petroleum an emulsion from which the aqueous acid solution of the basic oils is separated with much difficulty. He also claims that the basic oils belong to the pyridine and quinoline series. Peckham's description of the conduct of California petroleum

[1] Am. Jour. Sci., 3d series, Vol. XLVIII, p. 250.

fits very perfectly, indeed, my experience with gilsonite from Utah and the pitch coal now in hand. Similarity in origin is therefore suggested, although of course it can not be regarded as proved.

A quantity of the Oregon coal was also subjected to heat in a retort in the same manner as the pitch coal. The conduct of the coal was most decidedly different; there was no melting or even apparent softening; moisture was promptly and quite freely given off, but the only distillate obtained was a very small quantity of thick, black coal tar, such as is usually obtained in greater or less degree from the destructive distillation of various kinds of coal, as in the manufacture of illuminating gas. Most of the volatile matter given off appeared to be gaseous and uncondensable. There was too small a quantity of this distilled tar to do anything further with it.

In regard to the question whether asphalts are ever formed directly from woody material, as coal is, there is little, if any, reliable evidence. In this connection the following quotation from a paper by Professor Peckham[1] is of interest:

One hundred miles due north of this coast [i. e., between Point Conception and Ventura, California], on the other side of the Coast Ranges, I have examined some of the most extensive veins of asphaltum yet discovered. They have been traced across the country continuously for miles and have been mined to a depth of more than 300 feet. In chemical composition the asphaltum bears a specific relation to the petroleums of Ventura County. They both contain the esters of the pyridine bases. These asphaltum veins lie on one side of and irregularly parallel with a stratum of sandstone, which, like all of the strata of that region, stands nearly vertical. Along this sandstone stratum bitumen exudes for a long distance. Against it, and on the other side of it, rests a bed of infusorial earth at least 1,000 feet in thickness, in some places saturated with bitumen, but for the most part clean and white. These formations extend across the country, parallel for miles with the general trend of the Coast Ranges. Enormous springs of maltha, issuing therefrom at intervals, have produced at several points flood plains of asphaltum that fill the small valleys like a glacier, many feet in depth and square miles in extent. The maltha is invariably accompanied with water, and at several points there are evidences that at some period in the past history of those outflows the springs that are now cold have been gigantic hot springs of silicated water similar to those that I believe produced the famous Pitch Lake of Trinidad.

I went to Trinidad prepared to find abundant evidence of the direct conversion of wood into bitumen, as described by Wall and Sawkins. I saw nothing of the kind, nor could I find anyone else who had. A superstition among the natives ascribes to the black mangrove the power of secreting bitumen. This shrub grows with its roots in sea water and often covered with oysters. The movement of the tide, the most nearly eternal phenomenon in nature, bears the bitumen that rises from the bottom of the sea against the oyster shells, and their jagged edges gather the floating particles. The entire deposit of pitch, both within and without the lake, contains on an average 10 per cent of partially decayed vegetation, and also an amount, difficult to estimate, of branches, trunks, and stumps of trees, some of the latter of enormous size, much larger than any now standing in the vicinity. I did not see the outcrop of the lignite bed to the south of the lake, that dips at an angle that would send it under the lake, as described by Manross, but I was told by one who had seen it that this lignite bed, 12 feet in thickness, contained branches, trunks, and stumps of trees

[1] Proc. Am. Philos. Soc., Vol. XXXVI, No. 154, pp. 110, 111.

that were in exactly the same condition as those found in the pitch—that is, they were still wood, not having been changed into lignite and therefore not capable of being distilled by hot silicated water into pitch.

From this quotation it would appear that the formation of any of the bitumens, including asphaltum, is due to *an act of distillation* upon one or another kind of organic matter, although it appears to be unessential whether this matter be animal or vegetable.

From a consideration of all that I have been able to learn, there appears to be no case of transformation of woody matter into asphalt by any such gradual transforming process as ultimately converts wood into coal, and consequently there is no reason for the admission of any such hypothesis in the case of the coal and pitch coal under consideration.

SUMMARY.

The evidence accumulated in the investigation shows conclusively that the pitch coal is an asphalt showing none of the characteristics of coal, the chief points being fusibility, manner of burning, action of solvents, peculiarities in distillation, similarity of distillate to the distillates of bodies unquestionably classified as asphalts, and the separation of pyridine and quinoline bases, which seem to be rather characteristic of California and other Western bitumens.

The properties of the coal, on the other hand, are those of true coal, and the difference between the ashes of the two are such as to furnish strong argument against common origin.

THE TITANIFEROUS IRON ORES OF THE ADIRONDACKS

BY

JAMES FURMAN KEMP

CONTENTS.

ILLUSTRATIONS.

TITANIFEROUS IRON ORES OF THE ADIRONDACKS.

By James Furman Kemp.

INTRODUCTION.

It is well known to geologists that some igneous rocks exhibit great uniformity in mineralogical composition and structure over wide areas of outcrop, and that others are extremely variable. As a rule, the acidic types are especially marked by the former characteristic, and to such a degree that granites and rhyolites often display a monotonous regularity throughout hundreds of square miles. The basic rocks, on the other hand, are prone to vary, even within restricted areas, and among them the gabbro group is preeminent in this tendency to change. This predisposition is well brought out by the wide contrasts in mineralogical composition which are found in the members of the gabbro group. The anorthosites at the one extreme are nearly pure feldspar; the gabbros proper have augite, plagioclase, and magnetite, often with olivine; the norites have hypersthene replacing the augite of the last named; the pyroxenites are nearly pure pyroxene, and the peridotites have olivine and pyroxene together. And yet in many great gabbro areas, such as the Adirondacks or the Cortlandt series near Peekskill, New York, these types grade, one into the other, so insensibly that only microscopical determinations serve to distinguish them.

A moment's reflection will make it evident that this tendency to vary, or, in other words, the tendency of some minerals to aggregate to the exclusion of others, may lead to the production of important bodies of iron ore. If a normal gabbro containing labradorite, pyroxene, olivine, and magnetite in the proportions of say 3:3:1:1, becomes gradually enriched with magnetite almost to the exclusion of the other components, a change takes place that is entirely analogous to the familiar passage of a normal gabbro into a pyroxenite or an anorthosite, but it is one that is less frequent and of a lower order of magnitude, because magnetite is a less abundant component than is either the pyroxene or the feldspar. The development of bodies of magnetite in this way is nevertheless well known in several parts of the world, and it is the purpose of the present paper to describe several that have been discovered in the Adirondacks.

It should be emphasized that the extremely basic portions of the magma, which have yielded the large bodies of ore, have been developed while the rock mass was still, at least in large part, a molten fluid, and the rearrangements have been essentially magmatic. The chemical and physical laws which underlie the rearrangements are obscure, and as time goes by artificial experiment may be needed to elucidate and demonstrate them. They are not without significant parallels, however, in the experience of the metallurgist with slags and mattes.

The bodies of magnetite that occur in igneous rocks in the manner above outlined are practically always titaniferous, although in varying degree. They constitute a type of ore deposit that is singularly uniform the world over. The wall rock is gabbro or some member of the gabbro group in nearly all the known occurrences, the two exceptions being nepheline-syenite at Alno, in northern Sweden, and basic nepheline rocks in São Paulo, Brazil. The gabbros may, however, be greatly metamorphosed and may be represented by hornblende-schists or hornblende-gneisses, but even then inference as to their original gabbroic character is well founded, and careful microscopical investigation may be confidently expected to demonstrate it. When the igneous rock is not dynamically metamorphosed or squeezed, the ore forms large irregular bodies in it. In one place or another all intermediate grades of richness, from pure ore to barren rock, are known. If the wall rock has been squeezed and rendered gneissic or schistose, the ore masses have been dragged out into lenses. At Cumberland Hill, Rhode Island, all the visible portion of an intruded boss or stock contains the disseminated magnetite, and the entire mass, rather than a specially enriched portion of it, must be considered to be ore. Bosses and dikes of similar character are known in Sweden and Norway, and there, as well as elsewhere, the ores are so essentially of the nature of rocks that they have in several instances received special rock names. Thus, in 1876, A. Sjögren[1] called the ore at Taberg, in Sweden, magnetite-olivinite, because it consists of olivine and magnetite, although it shades out on the edges into an olivine-gabbro or hyperite. M. E. Wadsworth,[2] in 1884, gave the name "cumberlandite" to the very similar rock or ore from Iron-mine Hill, Cumberland, Rhode Island, where, as just stated, a peridotite knob or boss is so enriched with magnetite as to have attracted attention as a source of iron for the last century and a half. In more recent years J. H. L. Vogt[3] has employed "ilmenitite" as a rock name for the Scandinavian ores that are practically ilmenite; and "ilmenite-gabbro," "ilmenite-norite," "ilmenite-enstatitite," for those that still have considerable amounts of the minerals of the corresponding rocks. For a Swedish variety with much spinel

[1] On the iron-ore deposit at Taberg, in Småland, Sweden: Geol. Föreningens Stockholm, Förhandl., Vol. III, 1876, pp. 42-62. Neues Jahrbuch, 1876, p. 434.

[2] Lithological Studies, 1884, p. 80.

[3] Om dannelse af jernmalmforekomster: Norwegian Geological Survey, 1892, pp. 14-29, 130-133. Zeitschr. für praktische Geologie, January, 1893, p. 6, and especially the summary, p. 9.

Hj. Sjogren[1] has suggested the name "magnetite-spinellite," and O. A. Derby[2] has applied "jacupirangite" to the basic developments of nepheline rocks in Brazil that practically become titaniferous ores. All these names, whether desirable additions to petrography or not, emphasize the fact that the several observers viewed the ores as essentially rocks rather than minerals, and as forming local phases of what was elsewhere an ordinary igneous intrusion.

CHEMICAL COMPOSITION OF TITANIFEROUS MAGNETITE AND OF ILMENITE, CONSIDERED AS MINERALS.

The titaniferous iron ores have been generally regarded as mechanical mixtures of ilmenite (menaccanite) and magnetite, and the belief has been quite general in the past that magnetic concentration would remove the magnetite and leave behind the inert ilmenite. Yet it is a belief that will lead only to disappointment.

The relations of ilmenite and magnetite in the ores are obscure, for difficulties always lie in the way of the sharp discrimination between two opaque minerals of similar appearance when mingled in involved aggregates. There is also a lack of agreement among mineralogists as to the way in which the formula for ilmenite should be written. According to one conception ilmenite is theoretically FeO,TiO_2, and is a metatitanate of iron, which would correspond to FeO 46.75 (or Fe 36.36), and TiO_2 53.25. This composition has been approximated in one or two cases,[3] but as a rule the iron obtained by analysis is much too high for the formula, and in some instances the TiO_2 has also exceeded the theoretical value. The alternative conceptions have therefore been suggested that the formula should be written $FeO,TiO_2+nFe_2O_3$ (Rammelsberg), or $(FeTi)_2O_3$ (Rose). The latter receives some theoretical support from the fact that ilmenite has been thought to crystallize in isomorphous forms with hematite (Fe_2O_3) and corundum (Al_2O_3). It is opposed by the undoubted presence of FeO in the mineral, as determined by analysis, and by the demonstrated replacement of the FeO up to as much as 13 per cent with MgO. Furthermore, recent careful analytical work[4] has failed to prove the existence of Ti_2O_3 in the ilmenite, although this oxide has been artificially produced. Doubt has even been cast on the presence of Fe_2O_3.

The supposed isomorphism of ilmenite and the sesquioxides of iron and aluminum has been combated by Axel Hamberg,[5] who states that

[1] En ny jernmalmtype, representerad af Routivara malmberg: Geol. Föreningens Stockholm Förhandl., January, 1893, Vol. XV, pp. 55-63.

[2] Magnetite ore districts of Jacupiranga and Ipanema, Brazil: Am. Jour. Sci., 3d series, Vol. XLI, April, 1891, p. 311.

[3] The variety crichtonite from St. Cristophe yielded Marignac: TiO_2 52.27, FeO 46.53, Fe_2O_3 1.20. A specimen from the Ingelsberg afforded Rammelsberg TiO_2 53.03, FeO 38.30, Fe_2O_3 2.66, MnO 4.30, MgO 1.65.

[4] Th. Koenig and O. von der Pfordten, Untersuchungen über das Titan; Zur Constitution des Titaneisens: Ber. Deutsch. Chem. Gesell., Berlin, Vol. XXII, 1889, pp. 1488-1494, 2070.

[5] Bemerkungen über die Titaneisen-Eisenglanzgruppe: Geol. Föreningens Stockholm, Förhandl., Vol. XII, p. 567.

hematite and corundum are hemihedral-rhombohedral in crystallization, whereas ilmenite, like pyrophanite and katapleite, are tetartohedral-rhombohedral. Hamberg therefore supports FeO,TiO_2 as the theoretical formula. Much doubt may be said to still hang over the true method of writing it, but $FeO,TiO_2+nFe_2O_3$, the one suggested by Rammelsberg, is generally used. Mechanical mixtures of ilmenite with magnetite or hematite might be thought of as possible but elusive causes of the variability in composition. The absence of the two last named in any sample under investigation would be a difficult thing to demonstrate on account of the opacity of all the minerals concerned, but when well-developed crystals which have grown upon the walls of vugs and cavities are analyzed there seems no reason to think that either of these foreign minerals could be involved. In crystallizations of irregular outline from igneous magmas the case is different and the conditions are much more favorable to the production of mixtures.

On the other hand, magnetite (Fe_3O_4), or, better, FeO,Fe_2O_3, is also known to contain very considerable percentages of TiO_2 while still preserving its isometric crystallization. The famous case of the octahedrons from Meiches, in the Vogelsberg, which were analyzed many years ago by A. Knop,[1] is familiar to all mineralogists. Knop obtained Fe_2O_3 21.75, FeO 51.29, TiO_2 24.95, MnO 1.75. This is a difficult analysis for which to write a formula except by the assumption of the presence of Ti_2O_3. Other magnetites with titanium are well-known. O. A. Derby has mentioned to the writer natural lodestone from Brazil with 20 per cent TiO_2.

All students of the microscopical structure and mineralogy of rocks are familiar with the frequent occurrence of titaniferous magnetite or ilmenite—it is not often that they can be discriminated—in the more basic igneous rocks. The presence of titanium is indicated by the alteration of the opaque, iron-bearing mineral around its borders and along cracks to the white product known as leucoxene, a variety of titanite; but unless crystal outlines of isometric or rhombohedral character can be detected, or unless the peculiar triangular striæ of ilmenite are present, the exact identity of the original is in doubt. It might almost be said that the iron-ore mineral of diabases and gabbros is invariably titaniferous, were it not that in a few tested cases no titanium has been found.

The improbability of eliminating the titanium by magnetic concentration is evident from the above general considerations; and in practice this treatment is likely to raise the percentages of both titanium and iron in the concentrates, because the olivine, hornblende, pyroxene, and other silicates pass into the tailings.

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[1] Annalen Chem. und Pharm., Vol. CXXIII, p. 348.

CHEMICAL COMPOSITION OF THE TITANIFEROUS ORES.

GENERAL REMARKS AND ANALYSES.

The titaniferous ores, in distinction from the individual minerals, ilmenite and magnetite, vary greatly in composition. The titanic acid may be only a few per cent, or it may reach as high as 50, in which case the available iron is of course extremely low. In ordinary furnace practice 1 per cent or less of titanic acid makes no essential difference in the reactions of smelting, but as the quantity increases difficulties appear, unless the composition of the slag is correspondingly changed. Although small traces of titanium can be detected in almost all the magnetites in the old crystalline gneisses, ores are not usually described as titaniferous unless 3 per cent or more of titanic acid is present. From this minimum all percentages are recorded up to 50 and more, but the usual range of those that have been utilized or seriously considered in this country lies below 20 per cent. Ores with nearly 40 per cent have been treated in England. When, however, the titanic acid goes beyond 20 per cent it reduces the percentage of available iron to such a degree that the consumption of fuel per ton of pig produced is prohibitive.

The accompanying table of twenty-one analyses will give a fair idea of the range in titanic acid of a series representing both American and foreign mines. The analyses are arranged in the order of decreasing TiO_2. In a few instances additional determinations will be found in the footnotes.

Analyses of a series of American and foreign ores, showing range in titanic acid.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
	Ekersund, Norway.	Bay St. Paul, Quebec.	Norway.	Ekersund, Norway.	Chugwater Creek, Wyo.	Sandford Bed, N. Y.	Cheney Bed, N. Y.	Split Rock, N. Y.	Norway.	Grape Creek, Colo.	Greensboro, N. C.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
TiO_2	41.75	40.00	39.20	34.50	23.49	19.52	15.77	15.66	15.10	14.00	13.74
FeO	31.01	29.57	30.00	27.00	17.96	70.80	55.64	27.95	58.07	70.50	79.14
Fe_2O_3	22.11	20.35	18.59	29.00	45.03			15.85			
SiO_2	0.60	1.91	5.70	....	0.76	1.39	9.79	17.90	19.90	8.60	0.52
Al_2O_3	....	4.00	2.89	....	3.98	4.00	7.12	10.23	2.61	4.00	4.50
MnO	0.28	None.	0.60	....	1.42	....	....	Trace.	0.14	....	0.64
CaO	0.55	1.00	....	2.00	1.11	....	8.89	2.86	2.11	1.60	0.72
MgO	3.15	3.17	2.80	4.07	1.56	....	3.00	6.04	1.88	2.30	0.54
P_2O_5	0.015	....	....	1.268	Trace.	....	....	0.04	....	....	None.
S	Trace.	....	....	0.287	1.44	0.028	1.00	0.14	0.19	....	None.
Cr_2O_3	....	....	....	....	2.45	....	....	0.51	....	....	....
V_2O_5	....	....	....	....	....	....	....	0.55	....	....	....
Cu	....	....	....	....	....	....	....	....	....	....	....
H_2O	....	....	....	....	....	....	....	1.33	....	....	....
Total.	99.95	100.00	99.78	98.13	99.20	95.738	101.21	99.05	100.00	101.00	99.80
Fe	40.08	37.25	36.67	41.30	45.49	51.20	40.33	32.82	42.04	49.35	57.30
P	0.0065	None.	....	0.553	Trace.	0.022	....	0.017	....	....	None.
S	Trace.	None.	....	0.287	1.44	0.028	1.00	0.14	0.19	....	None.

Analyses of a series of American and foreign ores, showing range in titanic acid—Cont'd.

	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.
	Millpond Pit, Essex County, N. Y.	Lincoln Pond, Essex County, N. Y.	Mayhew Range, Minn.	Greensboro, N. C.	Church Mine, N. J.	Cumberland, R. I.	Cumberland, R. I.	Norway.	Taberg, Sweden.	Greensboro, N. C.
	Per cent.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per cent.*
TiO_2	13.38	12.31	12.09	12.08	10.52	9.99	9.35	7.10	6.30	4.95
FeO }	82.37	27.92	80.78	79.78	69.40	44.88	....	53.73	43.45	30.28
Fe_2O_3 }		30.68								54.42
SiO_2	3.67	11.73	2.02	0.75	7.92	22.87	....	28.10	21.25	3.25
Al_2O_3	1.50	6.46	2.68	4.62	4.36	10.64	....	1.70	5.55	4.81
MnO	....	....	....	0.28	0.19	2.05	....	0.48	0.40	....
CaO	Little.	3.95	....	0.13	0.46	0.65	....	3.55	1.65	0.24
MgO	0.50	3.35	....	2.04	2.52	5.67	....	3.98	18.30	....
P_2O_5	0.017	0.82	0.03	....	0.02	....	....	0.77	0.127	None.
S	0.068	0.04	....	....	1.46	....	....	0.59	0.013	Trace?
Cr_2O_3	....	....	2.40	0.32	....	....	....	....	....	....
V_2O_5	....	0.04	....	Trace.	....	....	....	....	Present	....
Cu	....	....	....	....	....	....	....	....	0.02	....
H_2O	....	0.64	....	....	0.49	3.05	....	....	2.60	1.66
Total	101.505	97.94	99.90	100.00	96.94	99.80	....	100.00	99.66	99.61
Fe	59.56	44.19	58.48	57.77	50.60	32.50	32.80	38.89	31.45	60.60
P	0.007	0.36	0.013	....	0.008	....	0.026	0.336	0.055	None.
S	0.068	0.04	....	....	1.46	....	0.057	0.59	0.013	Trace?

1 and 4. Quoted by J. H. L. Vogt, in Om dannelse af jernmalmforekomster (On the formation of iron ores): Norwegian Geological Survey, 1892, p. 26. The analyses are taken from a paper by Dr. A. Tamm, Analyses of iron ores, 1871–1890: Geol. Föreningens in Stockholm, Förhandl., Vol. II. 4 is a general sample. The FeO and Fe_2O_3 were separately determined.

2. Bay St. Paul, on the lower St. Lawrence. Analysis by Frederick Penny, Geol. Survey Canada, 1873–74, p. 227.

3. Analysis of an ore smelted in 1869 at Norton, England. W. M. Bowron, The practical metallurgy of the titaniferous ores: Trans. Am. Inst. Min. Eng., Vol. IX, 1882, p. 160.

4. See under 1.

5. Chugwater Creek, Wyoming, the locality now called Iron Mountain. Analysis by J. P. Carson for F. V. Hayden, U. S. Geol. Survey of Wyoming and Adjacent Territories, 1870, p. 14. Carson also determined ZnO 0.47. He gives the manganese as Mn_3O_4. Other analyses will be found in U. S. Geol. Survey of the Fortieth Parallel, Vol. II, p. 14.

6, 7, and 12. These, based on samples from the vicinity of Lake Sandford, in the Adirondacks, are analyses of ores used by A. J. Rossi in an experimental campaign with a small blast furnace, The smelting of titaniferous ores: The Iron Age, February 6 and 20, 1896.

7. See under 6.

8 and 13. Samples gathered by the writer near Elizabethtown and Westport, New York, and analyzed by W. F. Hillebrand for this paper.

9 and 19. Working analyses of ores smelted in Norway. David Forbes, On the composition and metallurgy of some Norwegian titaniferous ores: Chemical News, December 11, 1868. They are also cited in Bowron's paper mentioned under No. 3.

10. Grape Creek, near Rosita, Colorado. Quoted by B. T. Putnam from a report by M. Chaper. See Tenth Census, Vol. XV, 1885, p. 475.

11, 15, and 21. Rockingham County, North Carolina. J. P. Lesley, Titaniferous iron-ore belt near Greensboro, North Carolina: Proc. Am. Philos. Soc., June 16, 1871, Vol. XII, pp. 154–156. The samples came from the McCristen plantation. 11 is by A. F. Fesquet; 0.64 MnO=0.69 Mn_2O_3. 15 is by F. A. Genth. 21 is by J. B. Britton, slightly recast so as to make the oxides conform to the formulas here used. 3.25 SiO_2 is given as insoluble matter.

12. See under 6.

13. See under 8.

14. From the Mayhew Range, near Mayhew or Iron Lake, northeastern Minnesota. Analysis by R. S. Robertson, Minn. Geol. Survey, Bull. VI, p. 141.

15. See under 11.

16. Church mine, near Bethlehem, New Jersey. Analysis by J. B. Britton, cited by R. W. Raymond, Trans. Am. Inst. Min. Eng., Vol. XXI, p. 275. Also 2.69 organic matter. Analyses of a series of samples by Isidor Walz gave: TiO_2 15.05, 13.30, 12.36, 14.45, 9.83, 12.19, 10.37, 9.82, 12.02. One determination of phosphorus was 0.007.

17 and 18. Cumberland Hill, Rhode Island. No. 17 is given by R. H. Thurston as an average of several analyses. It is cited by M. E. Wadsworth, Mem. Mus. Comp. Zool., Harvard Coll., Vol. VII, p. 185. Also ZnO 0.20. (Compare footnote No. 5.) No. 18 is by Capt. John Pitman, U. S. A., for Tenth Census, Vol. XV, p. 567. Other analyses are cited by M. E. Wadsworth, Bull. Am. Iron and Steel Assoc., November 20, 1889, p. 314.

19. See under 9.

20. Taberg, Sweden. J. H. L. Vogt, Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata: Zeitschr. für praktische Geologie, p. 9, January, 1893. The analysis is an early one by Lindquist and has been cited by many writers.

21. See under 11.

A critical survey of the analyses brings out the fact that the FeO varies directly and the Fe_2O_3 inversely with the TiO_2, a relationship that will be later shown more in detail for the Adirondack ores. The explanation lies in the probable increase of the magnetite molecule with the decrease of TiO_2. At the same time, when both titanium and iron become low and the earthy bases enter, the presence of the ferromagnesian silicates is indicated, and their entrance would mean a relative increase in FeO over Fe_2O_3 without regard to the TiO_2.

METALLIC IRON.

Considered as ores of iron the analyses show these varieties to be of moderate or low percentages. They compare favorably with our eastern brown hematites and fossil ores, and have about the same ranges in metallic iron. Only in Nos. 12 and 21 do they approach the Lake Superior hematites or the richer eastern magnetites. Nos. 11, 14, and 15 are quite high, but Nos. 8, 17, 18, and 20 present the low values in iron which are characteristic of unroasted carbonates and clay ironstones.

SILICA, ALUMINA, LIME, AND MAGNESIA.

When in considerable amounts, silica, alumina, lime, and magnesia indicate the presence of the rock-making silicates and are essentially fortuitous, except, perhaps the last named and alumina. As already stated, magnesia is known to enter into some ilmenites, and it is possible that a part of the magnesia and alumina may be combined in spinels. Microscopical green spinels are rather plentiful in the included labradorites of the Sandford bed in the Adirondacks. It is interesting in this connection to note that as recently as 1893 W. Petterson[1] and Hj. Sjogren,[2] in papers independently prepared but simultaneously issued, established a new variety of titaniferous ore body—that is, a mixture of ilmenite and titaniferous magnetite, with hercynite or

[1] Om Routivara jernmalmsfält i Norrbottenslän (On the Routivara iron-ore district in Norrbottensland): Geol. Föreningens Stockholm, Förhandl., Vol. XV, 1893, pp. 45–54.

[2] En ny jernmalmstyp, representerad af Routivara malmberg (A new iron-ore type represented on the Routivara ore hill): Idem, p. 55. See, also, idem, pp. 140–143, for further notes.

pleonaste. Somewhat similar aggregates have been known for years to exist in Westchester County, New York, and in North Carolina. The former ore attained some prominence, first as an aluminous magnetite and later as a supposed emery,[1] while the latter was called emery ore by Genth,[2] although he failed to record the exact locality. The American ores are much lower in titanium than the Swedish, but are higher in alumina. Their spinel is obviously an iron-alumina variety.

CHROMIC OXIDE.

It is possible that chromic oxide, which is generally present in titaniferous ores, although rarely determined, may also enter into some form of spinel. The ore richest in chromium, so far as known to the writer, is that from Chugwater Creek, Wyoming, No. 5, with 2.45 Cr_2O_2. The Mayhew sample, No. 14, with 2.40 Cr_2O_3, is very near it. Albert B. Leeds,[3] in 1876, announced the presence of as much as 1 per cent Cr_2O_3 in the menaccanite of the Adirondack labradorite rocks, and it may be said that at least traces of chromium are almost invariably present in titaniferous ores.

MANGANESE.

Manganese is a common, if not invariable, ingredient, and, as expressed in terms of the protoxide, ranges from a maximum of 2.05 per cent in the Cumberland, Rhode Island, ore, No. 17, down to a mere trace. In the Cumberland instance it may be present in the ferromagnesian silicates, which are abundant in the ore, but its higher values in the table are not always accompanied by increase in silica, as would be the case were it present in the ferromagnesian silicates alone.

[1] J. P. Kimball, Am. Chemist, Vol. IV, 1874, p. 321; Trans. Am. Inst. Min. Eng., Vol. IX, 1880, p. 19. G. H. Williams, Am. Jour. Sci., 3d series, Vol. XXXIII, February, 1887, p. 194.

The following analyses of samples from Routivara, Sweden, Westchester County, New York, and North Carolina may be of interest:

	Routivara.	Westchester.	Westchester.	North Carolina.	North Carolina.
TiO_2	14.25	3.88	3.52	0.78	2.42
FeO	34.58	21.14	18.49	....	....
Fe_2O_3	33.43	25.86	28.21	....	....
SiO_2	4.08	1.13	1.04	1.39	0.98
Al_2O_3	6.40	45.58	36.46	52.24	44.86
Cr_2O_3	0.20	....	....	0.30	Trace.
MnO	0.45	....	....	....	....
CaO	0.65	....	....	0.84	0.91
MgO	3.89	....	....	0.68	3.27
P_2O_5	0.016	0.16	0.09	....	....
Fe	50.29	34.54	34.13	30.97	33.52

Additional analyses of the Westchester ore will be found in Kimball's second paper, and in Williams's paper, p. 197.

[2] F. A. Genth, Bull. 1, North Carolina Geol. Survey, p. 66.

[3] Notes on the lithology of the Adirondacks; Thirtieth Ann. Rept. New York State Mus. Nat. Hist., 1876, p. 79; concluding paragraph of paper. Reprinted in Am. Chemist, March, 1897.

NICKEL AND COBALT.

Nickel and cobalt have been proved to exist in appreciable amounts in a number of the titaniferous ores of Ontario by F. J. Pope, recently of the Kingston School of Mines, and later one of the writer's students. A pyritous magnetite gave Ni 1.2132, Co 0.1067. The surrounding gabbro yielded Ni 0.0768, Co 0.0277. A sample with only a trace of pyrite (pyrrhotite?) afforded Ni 0.1187, Co 0.0787. The gabbro forming ing the walls yielded Ni 0.0563, Co 0.0214. Another ore contained Ni 0.1127, Co 0.0413. In samples gathered by Bailey Willis from the Dannemora mine, Rockingham County, North Carolina, for the Tenth Census, NiS 0.01, CoS 0.03 were reported.[1] It is probable that in this case the metals were in pyrrhotite, as the ore had 0.089 S.

These two metals have been seldom looked for in analyses of titaniferous magnetites, but from the well-known association of nickel and cobalt with gabbros, their presence is perfectly natural, and, indeed, to be expected. At the same time they and other minor ingredients, such as chromium and vanadium, may exercise an important influence on the resulting iron and steel. Copper has been found in the Taberg ore (0.02 per cent) and zinc both at Cumberland, Rhode Island (ZnO 0.2 per cent), and Chugwater Creek, Wyoming (ZnO 0.47 per cent).

PHOSPHORUS AND SULPHUR.

The two minor components which have, as a rule, excited the most interest are phosphorus and sulphur. The impression is widespread that titaniferous ores are prevailingly low in both these elements. The statement is often, although not invariably, true. Some occurrences are very free from both, as shown by analyses 1, 6, 9, 11, 12, 18, and 21. Nos. 5 and 16 are low in phosphorus but high in sulphur, whereas the relations of the two in No. 4 are reversed, both, however, being high. In No. 13 the phosphorus exceeds the sulphur and is quite high. Low phosphorus is indeed the rule in titaniferous ores, but it is not so invariable a rule as to be trusted. In the Adirondack ores the sulphur is present in pyrrhotite, and the same is probably true elsewhere. It would appear that in the magmatic rearrangements that led to the segregation of the ores, the phosphoric acid was largely eliminated, despite the fact that usually in igneous rocks the ever-present apatite belongs in the same group of minerals and forms at much the same stage as the iron ores.

VANADIC OXIDE.

One of the most characteristic features of titaniferous ores is the presence of vanadic oxide in small amounts, and one can only regret that it has not oftener been determined. Being one of the rarer ele-

[1] Tenth Census, Vol. XV, p. 310.

ments, it has seldom been sought for, and yet enough determinations have been made to make it characteristic of this type of ore body. The amount is usually less than half of 1 per cent, or about 5 to 10 pounds of vanadic acid to the ton. Analyses of Adirondack ores made for this paper by W. F. Hillebrand and later cited (p. 395) indicate its presence in almost every instance. Vanadium, it is interesting to remark, was first discovered in pig iron made from the titaniferous ores of Taberg, Sweden. In connection with its identification in the ore of the Church mine, in western New Jersey (No. 16 of preceding table), Isidor Walz[1] in 1876 made determinations of a considerable number of iron ores, especially magnetites. He found vanadium in upward of twenty, but it is noticeable, when his results are critically studied, that the titaniferous varieties are the only ones that yield more than traces. The analyses here quoted embrace the richest determinations:

Analyses of iron ores showing presence of vanadium, by Isidor Walz.

	Church mine.				Mine near Church mine.	North Crosby, Canada.	Magnetic sand, Long Island.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	14.45	12.19	9.82	13.30	12.02		
P_2O_5	0.007			Trace.	0.158		
V_2O_5	0.31	0.38	0.36	0.41	0.13	0.31	0.10
S	0.435						
Fe	55.02			54.04			

When Walz's analyses were reported some attempts were made to recover the vanadium from the Church mine ore on a commercial scale, but they did not prove successful.[2] At Iglamala, Sweden,[3] where the ores are similar to those at Taberg, 0.40 per cent V_2O_5 has been determined.

CARBON.

A most remarkable feature of several of the Adirondack samples is the presence of small but weighable amounts of carbon which is not present as carbonic acid nor in any easily oxidizable form. It was rec-

[1] On the general occurrence of vanadium in American magnetites, Am. Chemist, June, 1876, p. 453. Further notes on the distribution and uses of vanadium, without reference to iron ores, will be found in the Eng. and Min. Jour., April 23, 1887, p. 291; June 8, 1889, p. 519. W. F. Hillebrand gives the results of many determinations of vanadium in rocks in Am. Jour. Sci., Sept, 1898, p. 209, and concludes that it is chiefly present in the basic igneous varieties. Sixty-four determinations were made in different samples. A forthcoming thesis for Ph. D. by F. J. Pope, at Columbia University, will treat of the chemical composition of the titaniferous ores of Ontario in detail and will include a discussion of methods of determining vanadium. See also in this connection, A. A. Hayes, Proc. Am. Acad. Arts and Sciences, Vol. X, 1875, p. 294.

[2] R. W. Raymond, Trans. Am. Inst. Min. Eng., Vol. XXI, 1892, p. 275.

[3] J. H. L. Vogt, Zeitschr. für prakt. Geologie, January, 1893.

ognized by the searching analysis of W. F. Hillebrand. In the ore of the Lincoln Pond mine there is 0.05 per cent C, and traces were found in the ores from Oak Hill, Tunnel Mountain, and Split Rock. Dr. Hillebrand speaks of it as follows:

I have taken considerable pains to make certain of the presence of carbon in the ores, and I think it is there beyond a doubt. Its amount is small, but after the extraction of the greater portion of the ore with HCl, collection of the residue on asbestos and ignition of the same, in an appropriate manner, CO_2 is given off in very perceptible amount, as shown by the heavy precipitate given by it in baryta water. The amount found in the ore not treated by HCl (after deduction of the CO_2 of carbonates) seems to be somewhat more than that found in the residue from the HCl extract.

Hillebrand inferred the presence of graphite, rather than infiltrated carbonaceous matter, and regarded the difference in weight as determined before and after the extraction with HCl as of slight moment, because the absolute differences were so small. The writer has examined some of the residues that were caught on the asbestos filter with high powers under the microscope, and finds fragments of pyroxene, hornblende, garnet, feldspar, and a few black, opaque grains that might be graphite, although if a little ilmenite had resisted the action of the HCl it might furnish the grains, so far as one can tell. No other black, opaque mineral would be likely to be caught at this point in the analysis.

It is significant to note in this connection that in the complete analysis of the Dannemora ore from North Carolina Captain Pitman[1] found 0.06 C in addition to 0.07 CO_2, and that J. B. Britton reported 2.69 per cent organic matter (!) in the ore of the Church mine, New Jersey.[2]

The presence of carbon in an ore of igneous origin suggests interesting analogies with the diamond-bearing peridotites of South Africa. L. De Launay, in his contribution Les Diamants du Cap, states that rich rock contains only 1 part diamond to 3,000,000 to 36,000,000 parts of rock, or about 0.00003 to 0.000003 per cent C, amounts which make the carbon of the titaniferous ores seem large. The diamonds are now generally considered original crystallizations from the igneous magma. Any occurrence of carbon, aside from carbonates, in an igneous rock, is manifestly of extreme interest. The samples in question were taken from the abandoned dumps of mines that had been closed for some years, but so far as observation goes in indicating probabilities they were free from vegetable matter. If carbon can be demonstrated in an igneous rock, or in any aberrant, magmatic derivative of it, the presence of metallic iron, which has been shown in not a few basic intrusives, can be accounted for on a simple chemical basis.

[1] Tenth Census, Vol. XV, p. 310.
[2] As quoted by R. W. Raymond, Trans. Am. Inst. Min. Eng., Vol. XXI, p. 275.

ALKALIES AND CHLORINE.

In the complete analysis of the ores by Hillebrand a few tenths of 1 per cent of alkalies were met, soda predominating. They are due to small included bits of feldspar, for such can be identified in thin sections. Small amounts of chlorine and fluorine were also detected, which were derived from apatite. In the Oak Hill sample,[1] however, with only 0.14 P_2O_5, 0.42 Cl was determined. As suggested by Hillebrand, this is doubtless derived from some form of scapolite. Scapolite has been not infrequently noted by the writer as derived from the feldspars of the Adirondack gabbros, although it has not been microscopically detected in this particular sample.

CHART TO ILLUSTRATE THE COMPOSITION GRAPHICALLY.

In order to illustrate the relations of the several components of the ores to one another, a series of curves or broken lines has been plotted, based on the available analyses of Adirondack samples, and some quite striking things have been brought out (see Pl. LV). The analyses have been limited to this locality for various reasons. The ores are all in a related series of rocks, and therefore supply a better connected series. But the most important consideration has been the fact that no other analyses give all the desired data. FeO and Fe_2O_3 are seldom determined separately, and often where given separately it is because enough FeO has been calculated to form $FeOTiO_2$ with the TiO_2, all the remaining iron being stated as Fe_2O_3. It is, however, quite evident that some of the FeO is present necessarily in magnetite (FeO, Fe_2O_3), and that this method is inaccurate. As regards the rarer oxides, Cr_2O_3 and V_2O_5, data are rare, and almost unattainable when FeO and Fe_2O_3 are also demanded. The lines are plotted from the following eleven analyses, all by W. F. Hillebrand, except Nos. 4, 6, 8, and 11, which have been kindly supplied by Mr. George W. Maynard,[2] who made them some years ago, while professor in the Rensselaer Polytechnic Institute at Troy, New York. They lack the Cr_2O_3 and V_2O_5, and sometimes the P_2O_5 and S, but otherwise can be utilized.

In the chart the abscissas are the actual percentages in metallic iron, they being the most available common term. It makes comparatively slight difference what is selected for the abscissas, provided the practice is uniform for all the analyses. The oxides are then plotted, the molecular ratios, as obtained by dividing the percentages by the molecular weight, being used for ordinates. On account of the small amounts of S, P_2O_5, Cr_2O_3, and V_2O_5 present, a different and much larger scale had to be used for them, but they are placed vertically over the larger ingredients of the same analyses in the lower broken lines.

[1] Not given in the preceding table, but cited later on.

[2] Some of these have already been published. Geo. W. Maynard, The iron ores of Lake Champlain: Jour. British Iron and Steel Inst., Vol. I, 1874.

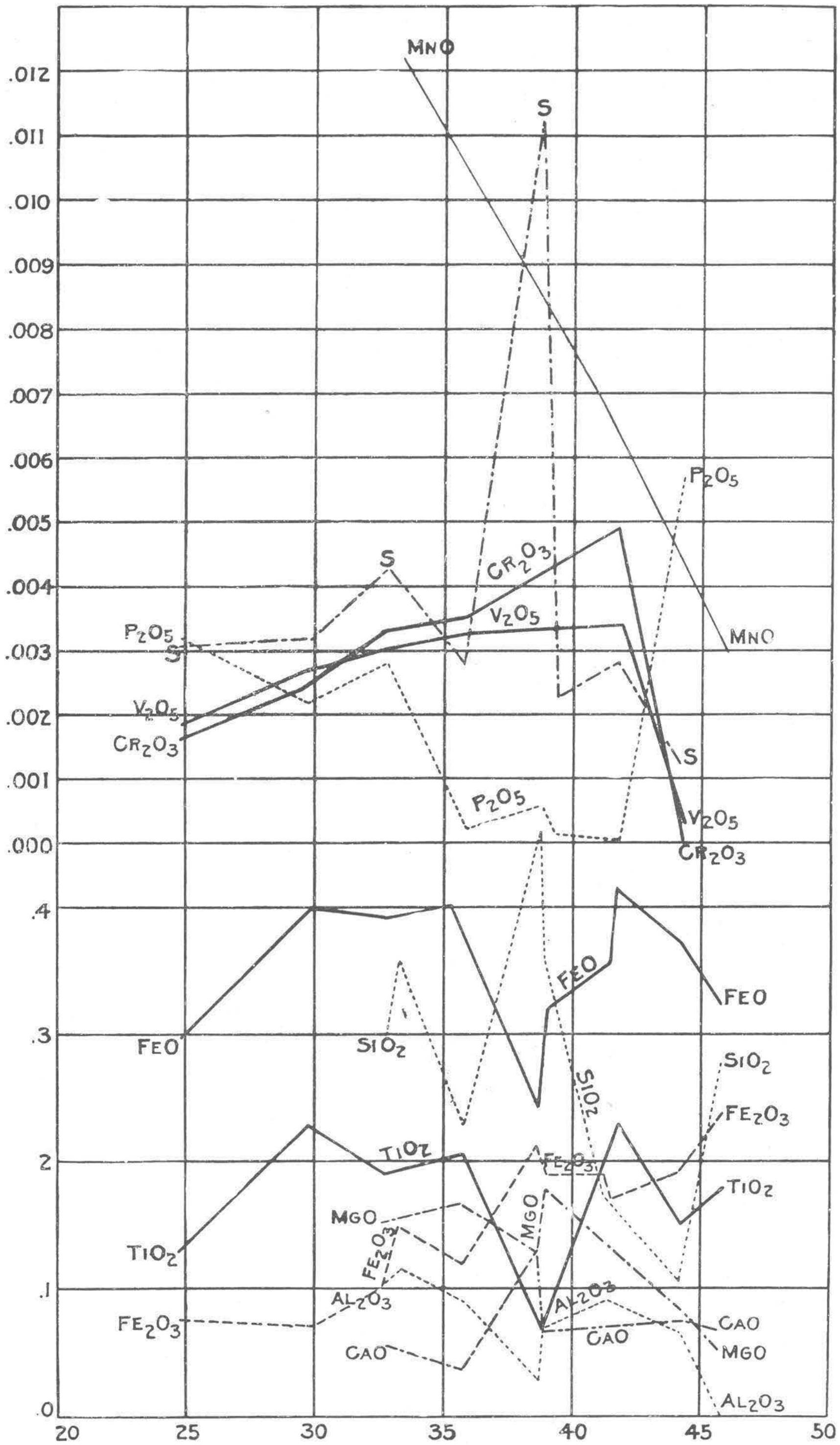


DIAGRAM ILLUSTRATING THE CHEMICAL COMPOSITION OF ADIRONDACK IRON ORES.

Analyses of ores from the Adirondacks.

	1.	2.	3.	4.	5.	6.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	24.65	29.87	32.82	33.36	35.99	38.68
Fe_2O_3	11.52	11.16	15.85	23.77	20.35	34.13
FeO	21.34	28.35	27.94	21.24	28.82	17.33
TiO_2	10.55	13.07	15.66	13.15	16.45	6.01
SiO_2	Not det.	Not det.	17.90	21.64	13.35	27.16
Al_2O_3	Not det.	Not det.	10.23	11.86	8.78	2.86
CaO	Not det.	Not det.	2.86	Not det.	2.15	7.08
MgO	Not det.	Not det.	6.04	Not det.	6.63	5.28
Cr_2O_3	0.25	0.37	0.51	Not det.	0.55	Not det.
MnO	Not det.	Not det.	Not det.	0.87	Not det.	Not det.
V_2O_5	0.34	0.50	0.55	Not det.	0.61	Not det.
P_2O_5	0.46	0.32	0.04	Not det.	0.02	0.09
S	0.10	0.10	0.14	Not det.	0.09	0.36

	7.	8.	9.	10.	11.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	38.98	41.43	41.57	44.19	45.93
Fe_2O_3	30.34	30.36	26.30	30.68	38.43
FeO	22.81	25.46	29.78	27.92	23.40
TiO_2	5.21	16.37	18.82	12.31	14.70
SiO_2	21.42	10.26	Not det.	12.42	16.46
Al_2O_3	7.03	9.35	Not det.	6.46	0.34
CaO	3.59	Not det.	Not det.	3.95	3.54
MgO	6.92	Not det.	Not det.	3.35	2.13
Cr_2O_3	None.	Not det.	0.75	None.	Not det.
MnO	Not det.	0.47	Not det.	Not det.	0.23
V_2O_5	Not det.	Not det.	0.62	0.04	Not det.
P_2O_5	0.14	Not det.	Trace.	0.82	Net det.
S	0.04	Not det.	0.06	0.04	Not det.

1. Tunnel Mountain, Elizabethtown. Foot of mountain.
2. Little Pond, Elizabethtown. South pit.
3. Split Rock mine, Westport.
4. Kingdom mines, Elizabethtown. Probably the same as Tunnel Mountain, summit.
5. Tunnel Mountain, summit, Elizabethtown.
6. Norway mine, Westport.
7. Oak Hill, Elizabethtown.
8. Iron Mountain, Elizabethtown. Propably the same as Oak Hill.
9. Little Pond, Elizabethtown. North pit.
10. Lincoln Pond, Elizabethtown.
11. Split Rock, Westport.

The striking sympathy of the lines of FeO and TiO_2 is at once apparent, as they are almost exactly parallel, except in the last analysis. This is a confirmation of the assumption that the molecule FeO, TiO_2

is present, and that it is the source of the titanium in the ores. The Fe_2O_3 line is antagonistic to both the FeO and the TiO_2. It varies inversely with them, and to that extent it supports the assumption that the TiO_2 is present in the molecule $FeO,TiO_2 + m\ Fe_2O_3$; for, if this were true, equal masses being assumed, the more Fe_2O_3 the less relatively of FeO,TiO_2 could be present; whereas, if the Fe_2O_3 were all in magnetite (FeO,Fe_2O_3), the FeO line should show a tendency to vary more in sympathy with it. The Al_2O_3 is markedly sympathetic with the MgO, and strongly suggests the presence of spinel, while the CaO is curiously antagonistic to both, but especially to the MgO, with which it varies inversely. The SiO_2 and the CaO are sympathetic, but the former shows great variation. The SiO_2 is strikingly antagonistic to the FeO and TiO_2.

Among the lesser ingredients the Cr_2O_3 and the V_2O_5 are extremely sympathetic, as they always vary in the same sense if not absolutely in the same degree. It is an interesting question in just what molecules these elements are present. Vanadium in nature is usually combined with lead or copper. Copper is known in some titaniferous ores, but, to the writer's knowledge, no lead has ever been reported. Vanadinite being isomorphous with apatite, and vanadic acid corresponding thus to phosphoric acid, we should infer that the V_2O_5 replaces some of the P_2O_5 in the apatite assumed to be present, and the antagonistic behavior of the P_2O_5 line gives some confirmation of it. Assuming a fairly constant amount of apatite, the two should vary inversely, but with variable apatite some sympathy might be expected. A search through the recorded analyses of apatites, however, has failed to reveal mention of even a trace of vanadium, although phosphoric acid enters vanadinite in considerable amounts. The assumed relations of vanadic and phosphoric oxides throw no light on the sympathy of the former for chromic oxide.

The sulphur shows no recognizable relations with the other lesser ingredients, but it is somewhat sympathetic with the SiO_2. The determinations of MnO have been too fragmentary to admit of comment. The three available approximate a straight line. It is to be regretted that additional complete analyses were not at hand, so that the table could be extended.

In connection with the presence of these elements in the ores, the associations brought out by the well-known tabulation of the elements in accordance with the "periodic law" are striking. Practically all those recorded in the analyses, except oxygen, belong in series 3 and 4, viz: In series 3, Na, Mg, Al, Si, P, S, and Cl; in series 4, K, Ca(Sc), Ti, V, Cr, Mn, Fe, Ni, Co. Copper and zinc are the only ones left out. It is well appreciated by the writer that analogous chemical properties are indicated much more strongly by the vertical groups in the periodic law than the horizontal series, and yet the comprehensive collection of all those concerned in the ores in the two horizontal series is striking, even if its significance can not be detected. Scandium, the rare element in series 4, has never been recognized in them. An abbreviated reproduction of this portion of the table will make the matter clearer. The table is taken from Roscoe and Morley's Dictionary of Chemistry.

Series.	Groups.							
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
3	Na, 23	Mg, 24	Al, 27	Si, 28	P, 31	S, 32	Cl, 35.5	Fe, 56; Ni, 58.6
4	K, 39	Ca, 40	Sc, 44	Ti, 48	V, 51	Cr, 52	Mn, 55	Co, 59; (Cu, 63)

GEOGRAPHICAL DISTRIBUTION OF THE TITANIFEROUS IRON ORES IN THE ADIRONDACKS.

So far as known, the titaniferous iron ores of the Adirondacks are limited to Essex County. They are most numerous in the townships of Westport, Elizabethtown, and Newcomb, the largest bodies being in the last named. Small masses have been discovered and opened in an unimportant way in Crown Point, North Hudson, and Wilmington. These townships are well distributed over the county, which itself is a a large one, containing about 2,500 square miles. The reason that the titaniferous ores are limited to Essex County, so far as they have yet been identified, is that it contains the greater part of the gabbroic rocks, but it would not be surprising if in the outlying exposures in Franklin County additional occurrences of the ore should be met.

GEOLOGICAL FORMATIONS ASSOCIATED WITH THE TITANIFEROUS ORES.

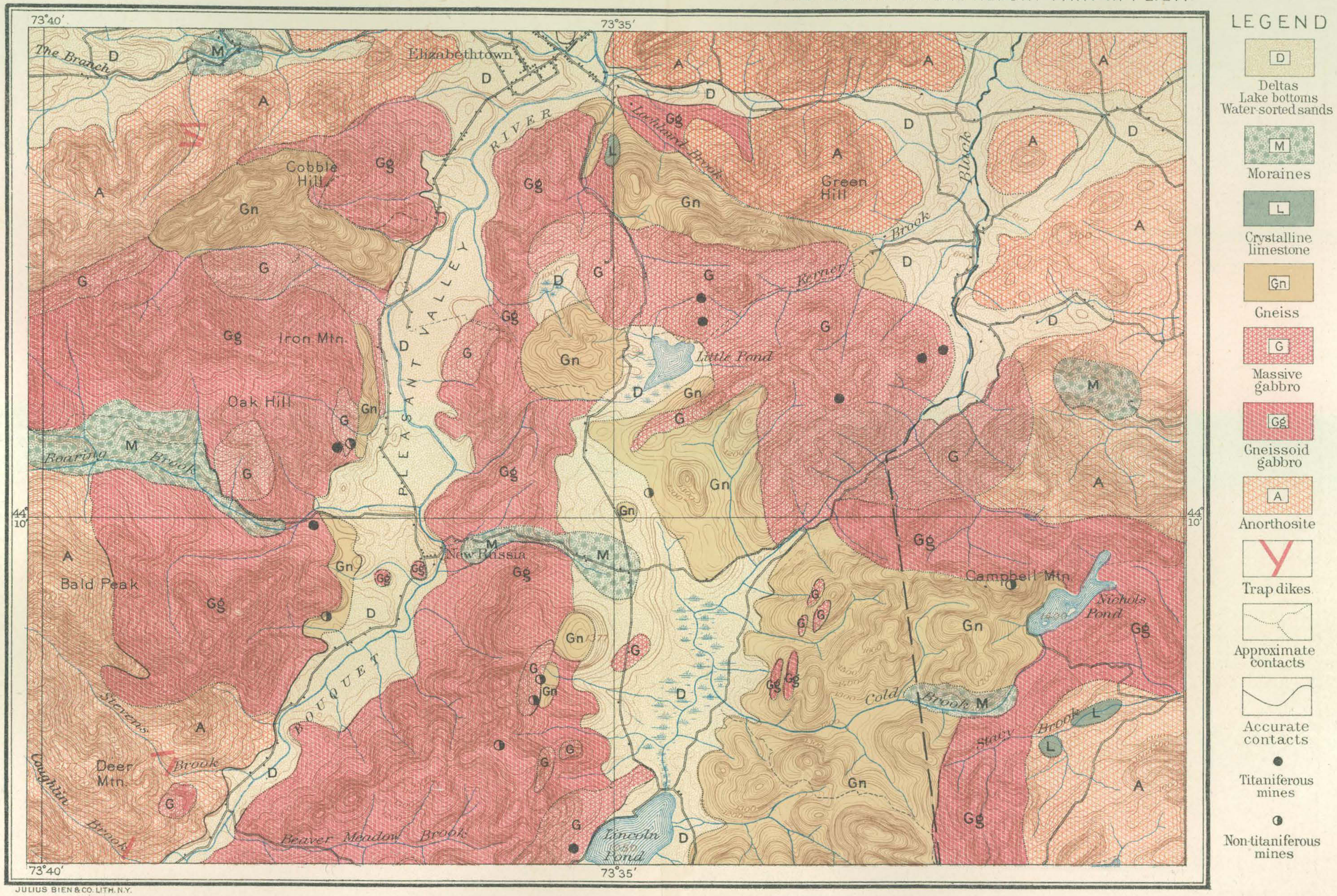
The titaniferous ores of the Adirondacks are associated in all cases with rocks of the gabbro family and with two well-marked varieties belonging to it. The two are contrasted in appearance and are easily recognized. The largest ore bodies are contained in rocks that are chiefly labradorite, in the coarsely crystalline granitoid aggregates that have been called anorthosite by the Canadian geologists, within whose territories they are abundant. A little augite or hypersthene is always present in a very subordinate capacity, and rims of garnets are common around the bisilicates. The ores in anorthosites are limited to Newcomb, Wilmington, and North Hudson townships, and lie among the highest peaks of the mountains. In their geological associations and general character they are practically like the huge masses of ore that occur along the lower St. Lawrence in Quebec and near Ekersund in southwestern Norway.

The smaller ore bodies, although still of very considerable size, are found in a dark basic gabbro or norite, in which the ferromagnesian silicates preponderate over the feldspar. Labradorite is the feldspar and green augite the chief bisilicate. Hypersthene is sometimes abundant and olivine is frequently present. Small garnets in granular rims about the bisilicates are quite invariably present, and shreds of biotite are by no means uncommon. Brown hornblende is an important constituent in and near the ore, and is also common throughout the mass of the rock. Small, irregular anhedra of titaniferous magnetite are always disseminated in the gabbro, and apatite is, of course, not lacking. In texture the rock approximates the diabasic granular type, because of the marked tendency of the feldspar to form lath-shaped individuals.

The anorthosite is illustrated by photomicrographs in Pl. LXII, *A* and *B*. The slide was prepared from the wall rock of an important ore body near Lake Sandford, Newcomb Township. The metamorphosed gabbro is shown in Pl. LVIII, *A*, and Pl. LX, *B*. The latter figure was prepared from a slide of the wall rock of an abandoned mine near Lincoln Pond, Elizabethtown, the former from the wall rock of the Split Rock mine, Westport.

The ores in the gabbro are contrasted in physical appearance with those in the anorthosite. The former are closely crystalline and dark gray, with a dense, compact aspect, like a finely crystalline igneous rock. The titaniferous magnetite is in relatively small individuals and is mingled with ferromagnesian silicates. The ore from the anorthosites is coarsely crystalline, like ordinary magnetites. It sometimes has a bluish shade, which is regarded by many as characteristic. It lacks the abundant ferromagnesian silicates, and contains large feldspars instead. The greater coarseness of crystallization is in great part due to the larger masses in which it occurs. The contrasts in the grain of the ores, however, are fully reproduced in the textures of the wall rocks, and the ores vary with the varying conditions under which each has crystallized.

The anorthosites and gabbros belong to a great series of intrusives which have come up through older gneisses and crystalline limestones. Considered in their entirety, the intrusives embrace other varieties of gabbroic rocks than the two just cited, varieties that lie between them as extremes, but as the intermediate types are not immediately concerned with the ores, they are not described in further detail. The intrusives correspond to the Norian of the Upper Laurentian of the Canadian geologists, and the gneisses and crystalline limestones are the representatives of the Canadian Grenville series. In the nomenclature adopted by the United States Geological Survey, both the older rocks and the intrusives must be included in the Algonkian on account of the presence of the limestones. After the intrusion of the gabbros



GEOLOGICAL MAP OF PORTION OF ELIZABETHTOWN AND WESTPORT, NEW YORK

BY J. F. KEMP

1898

Scale

1 0 1 2 3 Miles

Contour interval 20 feet

and anorthosites the Adirondack region was subjected to great dynamic metamorphism, so that the massive rocks were crushed and often drawn out into gneisses, and so involved with the older formations as to greatly obscure the stratigraphical relations. It is rather rare to find one of the Norian massive rocks that does not display some evidence of this metamorphism, but in a few cases limited areas of the dark gabbros have escaped it to a greater or less degree, and in the western part of Essex County the anorthosites are not greatly affected.

No Paleozoic sedimentary rocks occur near the ores, but it may be interesting to add that the Potsdam sandstone is the oldest of the Cambrian strata in the region, and that it is followed by the Calciferous, Chazy, Trenton, and Utica, after which no later sediments were formed until the Glacial period. There are two series of trap dikes, one pre-Potsdam but later than the general metamorphism, another post-Utica. They, however, have no connection with the ores under discussion. There are many nontitaniferous magnetites in situations not far, at times, from the titaniferous, but they are either on the contacts of the gabbro with more acidic gneisses or entirely in the latter.

The map shown in Pl. LVI illustrates the geology of a part of Elizabethtown, and contains within its area a number of the ore bodies which occur in the gabbro. The contacts of the several formations are approximate, as one can seldom locate them in the thickly wooded and drift-covered hills.

A relief map, based on the Port Henry and Elizabethtown sheets, has been prepared and is reproduced in Pl. LVII so as to show the topographical character of the country. The shores of Lake Champlain are the lowest portion of Essex County, the lake itself being about 100 feet above tide. The surface rises as one leaves the lake, until within a few miles even the valleys are 1,000 feet above it. The valleys and the intervening mountain ranges trend, as a rule, northeast and southwest. The summit of Giant Mountain, one of the higher peaks, just appears on the western edge of the map, but the highest peaks lie still farther west, around Mount Marcy. The location of some of the titaniferous ores is shown by the crossed hammers. In most cases they outcrop on the sides of the hills, but in one instance—Tunnel Mountain—the ore is exactly on the summit of a notable elevation.

DETAILS OF THE ORE BODIES.

SPLIT ROCK MINE, WESTPORT.

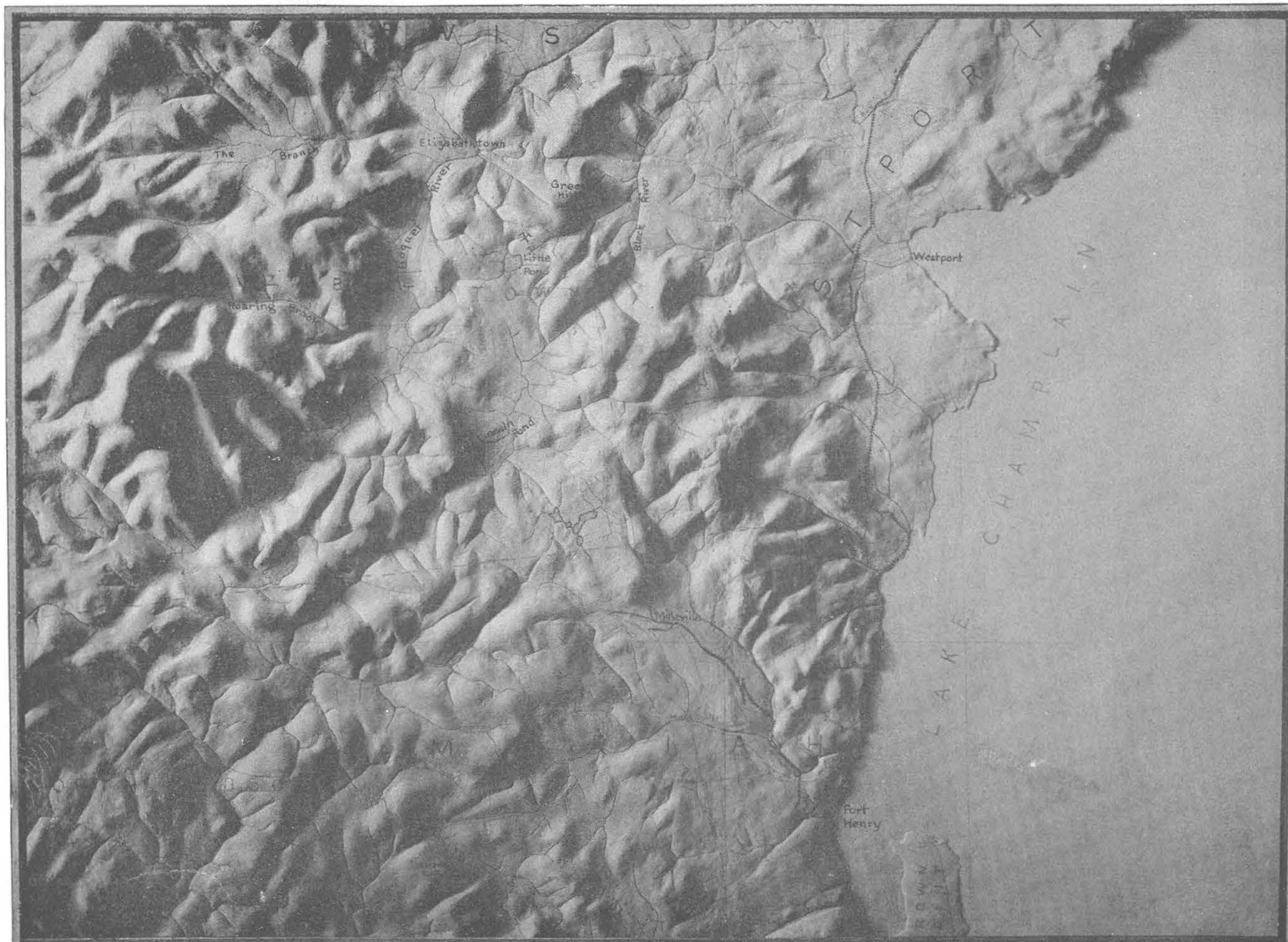
By referring to the relief map (Pl. LVII), the reader will note that the shores of Lake Champlain just north of Westport are formed by a series of hills or low mountains, called the Split Rock Range. The range is an outlier from the main body of the Adirondacks, and juts into the lake en echelon, as do a number of others. It is steep or precipitous toward the water, but slopes away more gradually on the northwest. The range consists chiefly of anorthosite, with which some basic gabbros and, at the northern extremity, outside of the region mapped, gneisses and crystalline limestone are involved. In a precipitous hillside, fronting the lake and about a mile south from the northern limits of the region, the Split Rock mine was opened many years ago, and a concentrating mill was built in the endeavor to utilize the ore.

The wall rock is a dark-green or black gabbro, forming a great intrusion whose limits are not known. It certainly extends a considerable distance each way from the ore. The ore outcrops at a point about 100 feet vertically above the lake. It is ten feet or more across, is flattened, and strikes into the hill N. 70–80° E. and dips 50° S. An open cut has been excavated 30 to 40 feet deep and 25 feet high. The cut is located in the face of a bare rocky cliff, so that the exposures of ore and wall rock are good, and the old dump which streams down to the lake, furnishes excellent and fresh samples of both.

At a distance from the ore the gabbro is a dark-green, faintly laminated rock, which is illustrated by Pl. LVIII, *A*.[1] It is a gabbro, with accessory hypersthene, and has been somewhat squeezed, so that secondary garnets have been developed in quantity. The minerals present are augite, hypersthene, brown hornblende, garnet, original plagioclase charged with pyroxenic dust (and possibly spinels), secondary plagioclase in clear rims around the last named, and magnetite. The chemical composition, from an analysis by W. F. Hillebrand, is given below, together with the analyses of the ore. The titanic acid is not especially high, considering the general composition of the rock; and this fact, combined with the low percentage of ferric iron, indicates that titaniferous magnetite is not particularly abundant in the rock itself. About three-quarters of the iron present must be in the bisilicates. The traces of vanadic oxide are interesting when considered in connection with the composition of the ore, as given later. The phosphoric acid is five times as rich in the rock as in the ore, indicating in this case a considerable elimination of the apatite molecule from the portion of the magma that yielded the ore—a process that did not always take place, as will be seen by comparing this analysis with the one of the Lincoln Pond ore. Sulphur, on the other hand, is low in the rock, but richer in the ore.

As one passes across the exposure the transition from wall rock to ore takes place gradually, but in a short space. Within a few inches the magnetite increases greatly in amount, until the mass is apparently almost a pure aggregate of this mineral. Close observation with a lens, however, and, still better, thin sections under the microscope, show

[1] The pink core is hypersthene; the pink granules are garnet; the green mineral is augite; the brown, hornblende; the black, magnetite; and the clear or dotted portion is feldspar.



RELIEF MAP OF THE ELIZABETHTOWN QUADRANGLE AND OF THE NEW YORK PORTION OF THE PORT HENRY QUADRANGLE.

that very considerable amounts of the ferromagnesian silicates are still present, although largely altered to serpentine, and the low percentages of iron corroborate the observation.[1] Along the contacts of ore and wall rock—if, indeed, contacts may be said to exist in this case—there is no evidence of disturbance or of the formation of the ore after the consolidation of the rock or of its inclusion as a foreign body. Everything stamps them both as constituting one integral rock mass.

The ore itself contains one curious and remarkable accessory substance. In veinlets through it and in crusts coating the bounding surfaces of cracks a very peculiar green isotropic material has been met, which is presumably a basic igneous glass allied to the sordawalite of Finland. It is a fine, clear green in thin section, perfectly isotropic, but near its contact with the ore it contains plagioclase crystals that afford cross sections like those of the famous rhomben-porphyries of Norway. The accompanying cut (Pl. LVIII, *B*) illustrates them. The feldspars are no longer fresh, but are in large part altered to calcite. Around each is an ingrowing fringe of green acicular crystals of chlorite that have apparently penetrated the feldspar, being developed by solutions from the outer glass. Throughout the glass are little blebs of magnetite, and on its surfaces small, well-developed octahedra are perched. The glass has a specific gravity of 2.822.

The relations of the glass to the ore are such that the glass can not well be regarded as a separate and later intrusion, unless it is credited with the power to thoroughly penetrate the mass through minute cracks and along fissures in a most extraordinary manner. Its crusts are never more than a quarter of an inch (5 to 7 mm.) thick, and dikelets have been observed much less. And yet the presence of glass in the midst of a purely plutonic rock is a most anomalous phenomenon, and unless it has been formed by some pneumatolytic process in the closing stages of the consolidation of the magma the writer is at a loss to account for it.

The same glass has been noted in the ores near Little Pond.

In the following analyses Nos. 600 and 601 are by W. F. Hillebrand. The unnumbered one is by George W. Maynard.[2]

[1] Microscopical study of thin sections is often serviceable in connection with crystalline magnetites and may reveal a surprising amount of hornblende or pyroxene in an ore that to the eye looks quite rich. A number of cases have already come under the writer's observation which were submitted by mining engineers. M. E. Wadsworth records a similar experience with the Cumberland, Rhode Island, ore: Bull. Mus. Comp. Zool., Harvard Coll., Vol. VII, 1881, p. 183.

[2] Jour. Brit. Iron and Steel Inst., Vol. I, 1874.

Analyses of wall rock and ore from the Split Rock mine, Westport.

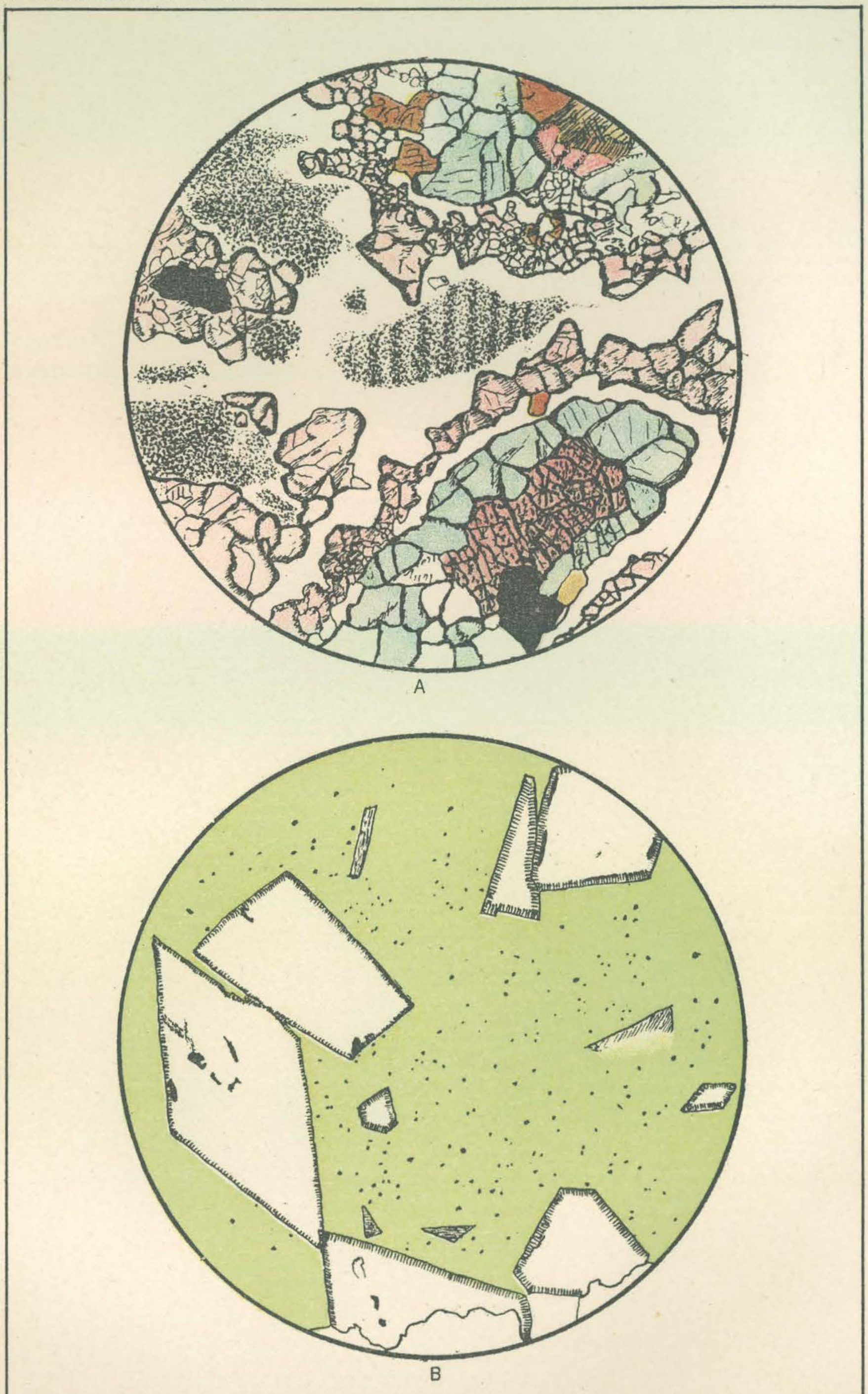
	601. Wall rock.	600. Ore.	Ore.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	47.88	17.90	16.46
TiO_2	1.20	15.66	14.70
Cr_2O_3	Trace?	0.51	....
Al_2O_3	18.90	10.23	0.34
Fe_2O_3	1.39	15.85	38.43
FeO	10.45	27.94	23.40
$NiO.CoO$	0.02	Not det.	Not det.
MnO	0.16	Little.	0.23
CaO	8.36	2.86	3.54
SrO	Trace.	....	....
BaO	Trace.	....	....
MgO	7.10	6.04	2.13
K_2O	0.81	Not det.	....
Na_2O	2.75	Not det.	....
Li_2O	Faint tr.	....	....
$H_2O-110°$	0.18	1.33	....
$H_2O+110°$	0.43		
P_2O_5	0.20	0.04	....
V_2O_5	Trace.	0.55	....
CO_2	0.12	0.10	....
S	0.07	0.14	....
	100.02	99.15	....
Fe	....	32.82	32.59
Sp. gr	3.090	4.138	....

SMALL PROSPECT HOLES IN WESTPORT.

Some small openings on lean ore have been made along the northwest side of the Split Rock Range near the Essex town line. The wall rock is a hornblendic gneiss, but as no analyses have been made of the ores to demonstrate whether they are titaniferous or not, further mention of them is not made.

A little south of west from the village of Westport, 2 miles distant, an isolated but unnamed hill rises to an elevation of about 1,200 feet above sea level. It is formed by an intrusion of gabbro, which is at times quite strongly gneissoid. Just below its western summit several pits were opened years ago which revealed two masses of ore.[1] In the one there are 4 to 6 feet of comparatively rich magnetite, which passes

[1] The two are briefly referred to as the Ledge Hill mines a paper by the writer, The geology of Moriah and Westport townships: Bull. New York State Museum, Vol. III, p. 350. The lot is No. 163 of the Iron Ore Tract.



JULIUS BIEN & CO. LITH. N.Y.

A. GRANULATED GABBRO, FORMING WALL ROCK AND SPLIT ROCK MINE.
B. GLASS, FROM ORE AT SPLIT ROCK.

on each side into wall rock that is little else than hornblende and garnet. The strike is east of north and the dip is steep to the west. A short distance west another cut about 6 feet wide has opened up a body of lean ore in gabbro. No analyses of these ores have been made, but they are titaniferous beyond doubt.

MINES AT TUNNEL MOUNTAIN, ELIZABETHTOWN.

The Black River heads in Lincoln Pond, in the southern-central part of the region shown on the map, Pl. LVI, and then flows east of north, passing through a wild and narrow pass, in which was located many years ago the old forge and little village of Kingdom. At the point where the river begins to form the boundary between Elizabethtown and Westport, it rounds the foot of an eminence on the northwest which is called Tunnel Mountain, from an adit that was run many years ago near the summit. It was intended that the adit should tap a large body of ore which outcrops higher up.

At the foot of Tunnel Mountain, where the two black circles are placed, two small pits have been opened, which are of geological significance, although they could never have been of much practical importance. They are situated on land belonging to John Tryan. The first pit is about 15 feet square by 10 feet deep, in lean ore, which exhibits but slight distinction from the wall rock, so gradual is the transition. It displays, however, much biotite, and in this respect resembles the Brazilian occurrences described by Derby.[1] In thin section titaniferous magnetite, olivine, brown hornblende, deep-brown biotite, garnet, and considerable clear, unclouded plagioclase were observed. The biotite is closely involved with the particles of ore. Forty feet north of the pit a ledge of quartzose gneiss was found, which had manifestly passed through severe dynamic metamorphism. In thin section it exhibited finely microperthitic feldspar, with no trace of twinning, and lenses of quartz as much as 20 mm. long by 8 mm. thick. Some dark silicates appeared in the hand specimen, but in the slide the only colored mineral is garnet. The quartz has a blunt, rounded end, a sharp demarcation from the feldspar, and strongly suggests a squeezed pebble. At all events, the rock is radically different from the ore or basic rock exposed in the pit, and one is forced to conclude that the latter is in a gabbro dike and not far from its contact with the country rock. Other outcrops in the forest unfortunately are lacking.

The dark basic rock of the pit, which has been called ore by courtesy, represents one of the first stages in the notable enrichment of a gabbro with magnetite, and one of the first steps in the process which may in extreme development produce a body notably rich in iron.

[1] O. A. Derby, Am. Jour. Sci., 3d ser., Vol. XLI, April, 1891, p. 311.

A partial analysis by W. F. Hillebrand gave the following results:

Partial analysis of dark basic rock from a pit at the foot of Tunnel Mountain.

	Per cent.
FeO	21.34
Fe_2O_3	11.52
TiO_2	10.55
Cr_2O_3	0.25
V_2O_5	0.34
P_2O_5	0.46
S	0.10
Total Fe	24.65

The specific gravity as determined by the writer at 20° C. was 3.199—a value in the upper limits of the normal basic igneous rocks, but notably higher than the normal gabbro.

Two hundred yards northwest of the last pit is another, 15 feet by 30 feet and about 10 feet deep. The walls are gneissoid gabbro beyond question, and the ore is of the type usually occurring in the gabbros. No analyses have been made, but its specific gravity is 3.964, which indicates much more iron than the amount contained in the last sample.

At the extreme summit of the mountain another mass of ore outcrops that is larger and richer than those of the pits at the foot. An open cut has been excavated about 40 feet long, 10 feet wide, and apparently 40 or 50 feet deep. It is now filled with water, but the dump is very large. The cut runs north and south and is parallel with the vertical foliation of the walls. Lean ore and norite extend 10 or 15 yards to the west, across the strike, and gradually pass into the usual massive rock. Some 200 feet vertically below the summit and south of it, in the side of one of the characteristic cross gulches of the mountains, an adit has been run with the intention of striking the ore in depth. It must be at least 100 or 150 feet long and has supplied a large quantity of fresh country rock, besides giving a name to the mountain. When examined in thin section the rock is found to be a true gneissoid norite, hypersthene being the most prominent bisilicate present. It is thus analogous to the basic rocks of Norway that contain titaniferous magnetite. Green augite, brown hornblende, plagioclase, and garnet are the other components. Thin sections of the ore reveal, in addition to the magnetite, brown hornblende, serpentinized olivine, garnet, and colorless transparent labradorite. Its mineralogy is illustrated by Pl. LIX, *A*.

A

B

JULIUS BIEN & CO. LITH. N.Y.

A. RICH ORE FROM TUNNEL MOUNTAIN MINE.
B. LEAN ORE FROM LITTLE POND MINES.

An analysis of the ore by W. F. Hillebrand gave the following results:

Analysis of Tunnel Hill ore (specimen 400).

	Per cent.
TiO_2	16.45
FeO	28.82
Fe_2O_3	20.35
SiO_2	13.35
Al_2O_3	8.75
Cr_2O_3	0.55
CaO	2.15
MgO	6.63
V_2O_5	0.61
P_2O_5	0.02
S	0.09
H_2O	1.68
CO_2	0.17
C	Trace.
Cl	A little.
Total	99.62
Fe	35.99

The ore is of low grade for an iron ore, and is rather high in titanium. The chromic and vanadic oxides are of special interest. The high alumina and magnesia make one suspect spinel, but none was identified in the thin section.

The geological relations of this ore body, except in so far as hypersthene is abundant in the wall rock, are precisely like those at the Split Rock mine. The ore passes gradually, although less abruptly, into the barren walls and with them forms a geological unit.

MINES NEAR LITTLE POND, ELIZABETHTOWN.

By referring to Pl. LVI it will be seen that at a point in the Black River Valley about 2 miles north of Tunnel Mountain a trail that is the survivor of an old and now abandoned highway runs westward along Kerner Brook through the mountains and passes a small lake called Little Pond. A short distance north and northeast of Little Pond two openings have been made upon bodies of titaniferous ore of considerable size. A great area of dark, basic gabbro is present in these hills and the openings have been excavated upon masses of ore that occur in it. The north pit is 20 feet by 20 feet and 15 feet deep. The south pit, 200 to 300 yards southeast, is run in a hillside and is 30 feet by 30 feet and 25 feet high at the working face. The ore contains the same green glass that was met at the Split Rock mine. Great expectations were raised by these ore bodies when first discovered; thus

W. C. Watson states in his survey of Essex County[1] that the ore forms an entire hill and is inexhaustible in amount.

The wall rock of the pits is the usual green gabbro of this region, but it has not been microscopically examined. The ore, however, from the south pit has been selected as a typical illustration of the lean varieties. Although in the hand specimen it looks black, massive, and fairly rich, under the microscope it is seen to be one-half silicates (see Pl. LIX, *B*).[2] Brown hornblende and olivine are the most abundant accessories, garnet is frequent, and shreds of plagioclase are present in smaller amount.

The following partial analyses, by W. F. Hillebrand, indicate the composition of the ore from each pit.

Analyses of the Little Pond ores.

	North pit, No. 389.	South pit, No. 392.
	Per cent.	*Per cent.*
TiO_2	18.82	13.07
FeO	29.78	28.35
Fe_2O_3	26.30	11.16
Cr_2O_3	0.75	0.37
V_2O_5	0.62	0.50
P_2O_5	Trace.	0.32
S	0.06	0.10
Total	76.33	53.87
Total Fe	41.57	29.868
Sp. gr (determined by J. F. Kemp)	4.410	3.833

No. 389 shows some increase in iron over those previously cited, but it is noticeable that the titanium advances with the iron. Phosphorus and sulphur are both low in 389, but the phosphorus of 392 is high.

In their relations to the wall rock these ore bodies are exactly like the others previously described.

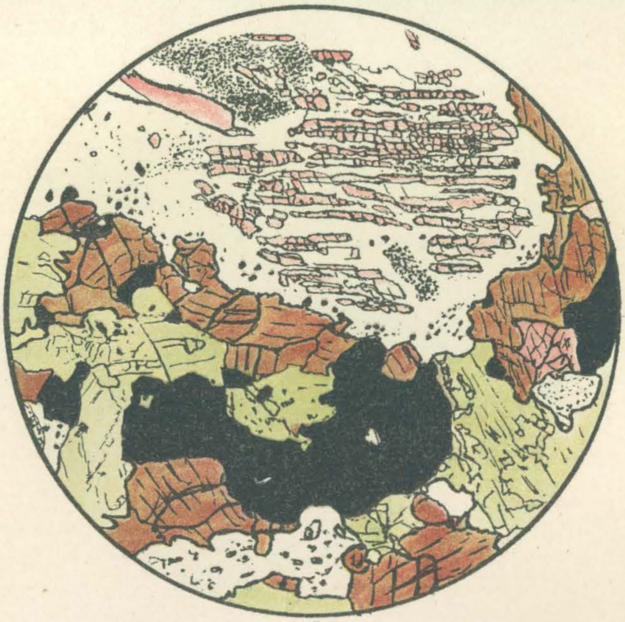
MINE NEAR LINCOLN POND, ELIZABETHTOWN.

A quarter of a mile northwest of Lincoln Pond, in a steep cliff of gabbro, an open cut has been run in on a mass of ore. The opening is known as the Kent mine, and it is the most extensive of all the openings upon the titaniferous ores in the township. It is 15 feet wide and 75 to 100 feet long. At the far end a shaft has been sunk to a depth not now visible, as it is full of water. The wall rock at this opening is less crushed and metamorphosed than is usually the case. It varies from a true norite to a gabbro with accessory hypersthene. Green augite,

[1] A general view and an agricultural survey of the county of Essex: Trans. New York State Agricultural Soc., Vol. XII, 1852, p. 649.

[2] In this section (Pl. LIX, B) the green mineral is augite; the brown, hornblende; the pink, garnet; the white, feldspar.

A.



B.

JULIUS BIEN & CO. LITH. N.Y.

A. THE UNMETAMORPHOSED NORITE, FORMING WALL ROCK AT LINCOLN POND.
B. CABBRO, SOMEWHAT METAMORPHOSED FROM SAME LOCALITY.

hypersthene, brown hornblende, plagioclase, and magnetite are the chief minerals present, while microperthitic untwinned feldspar is less common. Garnet varies from absence to richness. The garnet assumes at times the peculiar finger-like development in the plagioclase that is illustrated in Pl. LX, *B*. The pink mineral is garnet. Pl. LX, *A*, is drawn from a slide of unmetamorphosed wall rock. The green mineral is augite; the brown, hornblende; the pink, hypersthene; the white, feldspar.

The wall rock and ore afforded the following analyses, the former by George Steiger and the latter by W. F. Hillebrand.

Analyses of wall rock and ore from the mine near Lincoln Pond.

	Wall rock No. 160.	Ore No. 160a.
	Per cent.	*Per cent.*
SiO_2	44.77	11.73
TiO_2	5.26	12.31
Al_2O_3	12.46	6.46
Fe_2O_3	4.63	30.68
FeO	12.99	27.92
NiO, CoO	Trace.	Not det.
MnO	0.17	Not det.
CaO	10.20	3.95
BaO	Trace.	....
MgO	5.34	3.35
K_2O	0.95	0.26
Na_2O	2.47	0.50
H_2O —100°	0.12	} 0.64
H_2O +100°	0.48	
P_2O_5	0.28	0.82
V_2O_5	Not det.	0.04
CO_2	0.37	0.32
S	0.26	0.04
C	....	0.05
Cl	....	0.12
F	....	Trace.
Total	100.75	99.19
Fe	....	44.19
Sp. gr (determined by J. F. Kemp)	3.090	4.138

The gabbro or norite is a decidedly basic variety, and is unusually high in titanic acid. When the analyses are compared it appears at once that in the ore the Fe_2O_3 has relatively increased much more than has the FeO. The TiO_2 has also increased, while all the other oxides except P_2O_5, have decreased. The last named is remarkably high for a titaniferous ore, and the rather abundant apatite in the thin sections of the ore corroborates the analyses. The ore is richer in iron than any other sample taken from the pits in gabbro. The remarkable presence of carbon has been discussed on a previous page.

The ore passes into the wall rock within a few inches by an otherwise gradual transition, and the relations of both are not different from those of the ones previously described.

SMALL PITS IN THE WESTERN PART OF ELIZABETHTOWN.

In the foothills of the range whose culminating peak is Giant, and just west of the Boquet River, there is a belt of gneiss which is essentially composed of quartz and microperthite. On the western edge of the gneiss, and near its contact with a huge intrusion of massive and gneissoid gabbro that overlies it, a series of small ore bodies has been opened up. None of these appeared certainly titaniferous, and therefore none have been analyzed. They are shown on Pl. LVI, marked with the signs for nontitaniferous ores. The Pitkin bed lies south of Roaring Brook, near the highway. The Ross is north of the brook, and also near the highway. The Castoline pit, one of the oldest openings in the entire region, as it was discovered about the year 1800, is situated on the south bank of Roaring Brook, and has wall rock that is practically an amphibolite. It is marked by the titaniferous ore sign.

On Oak Hill, directly back of the Ross pit and above it, is an opening whose immediate wall rock is gabbro. An analysis of the ore by W. F. Hillebrand gave the following results:

Analysis of ore from the Oak Hill pit (specimen No. 363).

	Per cent.
TiO_2	5.21
FeO	22.81
Fe_2O_3	30.34
SiO_2	21.42
Al_2O_3	7.03
Cr_2O_3	None.
CaO	3.59
MgO	6.92
K_2O	0.41
Na_2O	0.53
H_2O	0.95
P_2O_5	0.14
S	0.04
Cl	0.42
CO_2	Trace.
C	Trace.
Mn	Trace.
Total	99.81
Fe	38.978

This ore is lower in TiO_2 than any other discussed in this paper. Its most interesting feature is the relatively high percentage of chlorine as compared with the phosphoric acid. Hillebrand's suggestion of the presence of scapolite, in order to account for this, has been previously noted. The deposit is a small one, and does not differ geologically from the larger ones.

ADDITIONAL OCCURRENCES OF TITANIFEROUS ORES IN GABBRO.

Several prospects have been opened in localities more or less remote from those just described. In sinking through the heavy cap of gabbro north of the Cook shaft, near Mineville, Messrs. Witherbee, Sherman & Co., while searching for the extension of the Cook shaft bed, penetrated a mass of titaniferous ore, of which no complete analysis is available. Mr. F. S. Witherbee informs the writer that it ran about 20 per cent TiO_2. It was called the Humbug vein.

It seems probable that the Crag Harbor vein, mentioned by E. Emmons,[1] is titaniferous. It occurs just north of Port Henry, where there is a huge mass of gabbro, and its recorded behavior in the early forges strongly suggests titanium. North of Hammondville, on the slopes of Moose Mountain, the Crown Point Iron Company opened, some years ago, two small pits in gabbro. The writer has visited the pits, and at the time learned from the company that the ore was very low in phosphorus and sulphur. The titanium prevented its use in the Crown Point furnaces.

Beyond question, there are other ore bodies in the innumerable areas of gabbro throughout the mountains, but except the Cheney bed, near Lake Sandford, and the exposures on Calamity Brook, which are subsequently mentioned along with the ores of this locality occurring in anorthosite, none additional have yet been discovered and opened.

TITANIFEROUS ORES NEAR LAKE SANDFORD, IN NEWCOMB TOWNSHIP.

While the iron-mining enterprises were slowly developing in the Champlain Valley, over sixty years ago, reports reached civilization that enormous exposures of magnetite existed at the headwaters of the Hudson, then far in the wilderness. An expedition was organized in 1835 and another in 1836,[2] and both penetrated to Lake Sandford

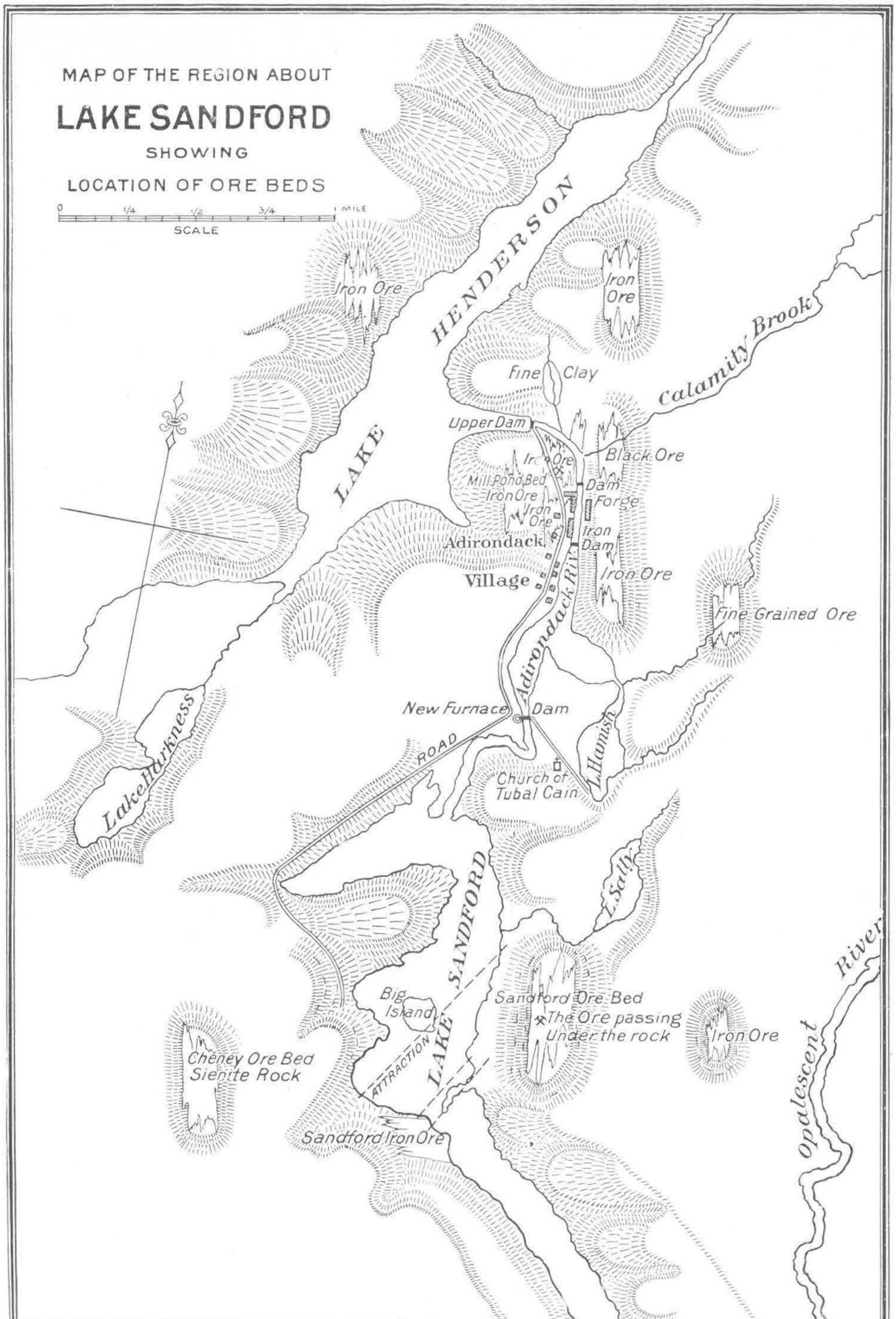
[1] Report on the Second District, New York State Survey, 1842, p. 236.

[2] W. C. Redfield, Some account of two visits to the mountains in Essex County, New York, in the years 1836 and 1837, with a sketch of the northern sources of the Hudson: Am. Jour. Sci., Vol. XXXIII, 1838, p. 301. The later developments are described by E. Emmons, Fourth Ann. Rept. on the Geology of the Second District of New York, Albany, 1840. This paper was reprinted for the promotion of the enterprise in New York in 1840, with the addition of a good township map of Essex County. The map shows a line of proposed railway from Lake Sandford to Clear Lake, where it was to intersect the highway to Port Henry. A hachured topographical map of the region around Lake Sandford gives the location of the ores. A copy of the pamphlet is in the library of Columbia

with the purpose of exploring for the ore bodies. They led to the inauguration of an enterprise in 1840, which remained in operation for nearly twenty years. Prof. Ebenezer Emmons became deeply impressed with the magnitude of the ores and gave them special attention in his Report on the Second District for the Natural History Survey of New York. He evidently regarded them as among the greatest of New York's mineral resources. In some respects Professor Emmons's opportunities for observation were better than those presented to-day, because prospecting trenches had been opened for him across the largest mass of ore. These have become filled up in the lapse of time, but his record of them is circumstantial and still serviceable. In the meantime, magnetic surveys have amplified the amount of ore, even as Professor Emmons knew it, and there is no doubt that it exists in vast quantity. Many analyses are also available to-day that throw light on its composition, and exact petrographical methods have increased our knowledge of the country rocks. It is, however, unfortunate that the locality lies just outside of the area that has been thus far mapped by the Survey, and recourse must still be had to the maps of earlier days. One of these, issued in the decade of the fifties, has been employed for Pl. LXI.

So far as known, all the important ore bodies lie within the drainage basin of the upper Hudson and at short distances from the stream itself or from the lakes in which it takes its immediate rise. Excluding some small outlying ponds, these are Lakes Henderson, Harkness, and Sandford, the last named being much the largest. The country rock throughout the valley is a typical and quite pure variety of anorthosite, except at the Cheney pit, where it is gabbro. The anorthosite contains labradorite in preponderating amount, and to the unassisted eye little else appears in the specimens. The labradorite is in large crystals, at times even several inches in length, and is commonly of a light-blue color, although brown varieties and others almost black are not lacking. The texture of the rock is coarsely granitoid. The component crystals have suffered but slightly from the crushing and mashing that is so widespread farther east. When studied with the microscope the anorthosite reveals occasional green augites, and much more rarely hypersthene, despite the fact that the latter impressed Professor Emmons so strongly that he frequently called the rock itself "hypersthene," probably because of the pegmatitic developments of this mineral which are sometimes met. Magnetite is not lacking as a component mineral, but it is far less prominent and frequent than in

University. Professor Emmons also published a rewritten account with a new map in his Final Report on the Second District, p. 244, Albany, 1842. Later historical details will be found in Winslow C. Watson's A general view and an agricultural survey of the County of Essex: Trans. New York State Agric. Soc., Vol. XII, 1852, pp. 649-898; and in the same author's History of Essex County, Albany, 1869. The early metallurgical experience has been described by A. J. Rossi, Titaniferous ores in the blast furnace: Trans. Am. Inst. Min. Eng., Vol. XXI, 1893, p. 832. The presence of titanium was not known to the early promoters, but it certainly had been recognized before 1852, as Watson speaks of it in that year.


MAP OF THE REGION ABOUT
LAKE SANDFORD
SHOWING
LOCATION OF ORE BEDS
0 1/4 1/2 3/4 1 MILE
SCALE
LAKE HENDERSON
Iron Ore
Iron Ore
Fine Clay
Calamity Brook
Upper Dam
Black Ore
Mill Pond Bed Iron Ore
Iron Ore
Dam
Forge
Iron Dam
Adirondack
Village
Iron Ore
Adirondack Riv.
Fine Grained Ore
New Furnace
Dam
ROAD
L. Harnish
Church of Tubal Cain
Lake Harkness
L. Sally
LAKE SANDFORD
Big Island
Sandford Ore Bed
The Ore passing Under the rock
Iron Ore
ATTRACTION
Cheney Ore Bed Sienite Rock
Sandford Iron Ore
Opalescent River

the basic gabbros. As no special analyses of anorthosites have been made for this paper, one by Prof. Albert R. Leeds[1] of a sample from the summit of Mount Marcy may be cited in illustration.

Analysis of anorthosite from Mount Marcy

	Per cent.
SiO_2	54.47
Al_2O_3	26.45
Fe_2O_3	1.30
FeO	0.67
CaO	10.80
MgO	0.69
Na_2O	4.37
K_2O	0.92
Loss	0.53
Sp. gr	2.72

It is evident from the analysis that labradorite must preponderate in the rock.

At the smaller ore bodies, which are the ones best exposed, the transition from wall rock to ore takes place quite abruptly and without marked development of ferromagnesian silicates, but Professor Emmons's records of the trenches across the large masses show that very considerable amounts of pyroxene and hornblende are associated with them. The ores impress the observer as being rock masses composed largely of a single ferruginous mineral, just as the anorthosites are rocks composed chiefly of a single feldspathic mineral. In the one the iron oxide has crystallized by itself, and in the other the silica, alumina, and soda have by themselves produced labradorite, while intermediate ferrous silicates have in large part, although not entirely, failed to form, probably from lack of magnesia. Labradorite crystals are frequently found included in the ore, but never in actual contact with it. They are separated from it by an intermediate zone, about 5 to 8 mm. wide, of ferromagnesian silicates. The zone is illustrated by Pl. LXIII, *A*, and is more fully described in connection with the Sandford bed.

The rock inclosing the Cheney ore was called "sienite" by Professor Emmons, who recognized that it differed from the normal labradorite rock. It is a gabbro, dynamically metamorphosed to a gneiss, and varies in no notable respect from those described from Elizabethtown and Westport. The composition of the Cheney ore presents some contrasts with that of the other ores near Lake Sandford.

The accompanying map, Pl. LXI, illustrates the distribution of the

[1] Notes on the lithology of the Adirondacks: Thirtieth Ann. Rept. New York State Mus. Nat. Hist., 1876; reprint, p. 14. Chemical News, March, 1877.

ore bodies. Just below the outlet of Lake Henderson, where the river bends to the south, is the so-called "Millpond" pit, which, together with loose surface bowlders, furnished the greater part of the ore smelted in the old furnace. An excavation 12 to 40 feet wide by about 100 feet long, with its depth concealed by water, now remains. The wall rock is dark-bluish anorthosite, thin sections of which, from a point very near the ore, are figured in Pl. LXII, *A* and *B*. The ore strikes nearly north and south and the dip is 75° E. Another pit, 10 feet wide by 18 feet long, has been opened on the hill to the southeast.

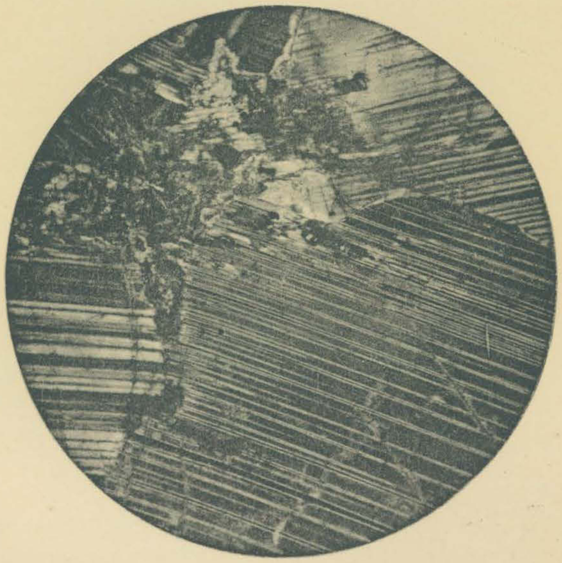
About 60 paces above the junction of Calamity Brook and the so-called Adirondack River fine-grained black ore appears in the bed of the brook and extends without a break for 200 paces or more up the brook. In the hand specimen it appears to be an exceedingly ferriferous gabbro, and it contains inclusions of anorthosite, through which run little dikes of pyroxene, garnet, and ore that end in streaks of pyrites. The inclusions of anorthosite are believed to be masses of the country rock which were torn off during the intrusion of the ore or ore-bearing gabbro and about and through which fumarolic action developed the little dikes and streaks of pyrites. The large dike itself contains considerable pyrites. Near the west contact there is a crushed or brecciated zone that shows some secondary vein products, but except for this the dike is firm and massive. About 300 yards from the junction the anorthosite again appears and extends for a quarter of a mile, at which point it is cut by a dike of ore 50 feet across, containing inclusions of anorthosite. Float ore was found upstream, as far as a dam for driving logs, but no more was observed in place.

Thin sections of these dikes of ore reveal rather coarsely crystalline aggregates of ilmenite or titaniferous magnetite, beautifully pleochroic hypersthene, green augite, and a little rich brown biotite. Regarded as ores, they vary in richness, being sometimes nearly pure magnetite (or ilmenite) and again more than half silicates. The relative amounts of each can be seen only in thin section, as all varieties look black and rich to the eye. They were called "black ore" by Emmons.

These same ores appear again to the south, and the pit called the "fine-grained ore," on Plate LXI, is of the same character, except that the thin sections show considerable plagioclase with reaction rims, and also some spinel. They may be prolonged in the "Sandford ore bed," 2 miles south, but they differ from the ore exposed now on the mountain east of Lake Sandford, in that the latter is much more coarsely crystalline.

The location of the "Iron Dam" is shown on the map. It is a mixed aggregate of ore and rock that is 10 to 15 feet in width and that strikes northeast. The ore forms an integral part of the rock mass and acts like a riffle in the stream. In the rear of the present club-house another small body of ore is exposed that appears to strike westerly into the hillside.

A



B

A. PHOTO-MICROGRAPH IN WHITE LIGHT OF ANORTHOSITE AT LAKE SANFORD

B. THE SAME WITH CROSSED NICOLS

The largest and most important of the ore bodies is the Sandford. It is situated on the west side of the lake of the same name, in or near the foot of the ridge that forms the divide between the lake and the valley of the Opalescent River. At the time of the writer's visit the ore was exposed in an open cut about three-quarters of a mile from the lake shore and about 300 feet above it. A working face 30 feet long and 10 or 15 feet high had been blasted into the hillside and had revealed no wall rock. The ore is pure titaniferous magnetite, except for included crystals of dark-green plagioclase that occasionally occur in it, like huge phenocrysts in a groundmass. Each is surrounded by a reaction rim, which prevents the actual contact of ore and feldspar. Microscopical study of thin sections reveals the phenomena which are illustrated by Pl. LXIII, *A*. The feldspar owes its green color to innumerable inclusions of very minute size, which appear to be pyroxene and spinel. A short distance from its borders the feldspar is rendered opaque by them, even in thin sections. Toward the border they diminish, and some larger ones can be identified as green spinel. The feldspar becomes water-clear, and besides the spinels contains a few flakes of reddish-brown biotite. Next follows a zone of brown hornblende of almost the same shade as the biotite, except for its pleochroism. In the midst of the hornblende is green serpentinous material, which has doubtless been derived from olivine. Next to the zone of ferromagnesian silicates comes the magnetite.

Feldspathic inclusions of this character are widely distributed through the ore, and are largely responsible for the rather striking percentages of alumina indicated by the analyses. The inclusions do not show good crystal boundaries, but often are beautifully twinned according to the Carlsbad law. The feldspars are regarded by the writer as representing portions of the anorthosite magma which have become involved in the iron ore. Their relations to the ore indicate that they are of earlier formation than its constituent anhedra, and the reaction rims are most probably the result of corrosive or resorptive action at a high temperature. The feldspars are therefore abnormal in their period of crystallization, and are earlier than those of the wall rock.

No other actual outcrops of this bed were seen, but float pieces of ore were abundant. Professor Emmons's four sections throw much light upon its width and character. His trenches were dug, as nearly as one can infer from the description, between the cut described above and the lake, and a little to the north. The length of the most southerly trench (No. III) is not accurately given, as he merely states that it was shorter than No. I. Six pits were sunk, all showing clean ore except one, which had hypersthene mingled with ore. By hypersthene may be understood some pyroxenic mineral. No wall rock was revealed. The next section to the north (No. II) was located 210 feet distant and was 610 feet long. Except in the first four pits, in which some decomposed feldspar and hypersthene were noted with the ore, excavation revealed clean exposures and seems not to have found the wall rock. The next section (No. I) was 268 feet north of the last and was the most detailed of all. Twenty-five pits were dug, covering 564 feet. Twelve of the pits revealed pure ore; ten had more or less feldspar, and sometimes black mica, hornblende, and garnet mingled with it; one is described as exposing lean ore, and two rock. From the sixteenth to the twenty-fourth pit 207 feet of pure ore are recorded. Still farther north, and 231 feet away, nine pits were dug, covering an unrecorded distance. Rock was met at each end; ore appeared in four pits; rock and ore in one; hypersthene and ore in one, and no record was made of one.[1] An examination of these sections makes it evident that the ore forms a great north-south band, with the minerals of the country rock at times forming streaks in it and occasionally being richly intermingled with it. Professor Emmons concluded that it dipped eastward at an angle of 75° and passed under the anorthosite. To the west the limits are not sharply defined, owing to the cover of glacial drift and sand, but recent magnetic surveys made by Messrs. Scranton and Sebenius indicate three lines of strong attraction that cross the lake as shown on the map, Pl. LXI, and that connect with known outcrops on the west shore.

The geological relations and associated rocks are practically the same as those recorded for the huge masses of titaniferous ores in Canada and Norway.[2] Anorthosites are the wall rocks in each case, and the geologists who have studied the ores have usually regarded them as integral, although abnormal, portions of an igneous rock mass, which have been produced during its crystallization and consolidation. J. H. L. Vogt, however, has interpreted one or two of these near Ekersund, Norway, as intruded dikes. The latter view applies to the exposures on Calamity Brook, but the coarsely crystalline ores in the

[1] These sections will be found in full detail in Emmons's Report on the Second District, New York Natural History Survey, p. 249.

[2] The general geology and petrography of the rocks containing the Canadian ores are best set forth by F. D. Adams, Ueber das Norian oder Ober-Laurentian von Canada: Neues Jahrbuch, Beilage Band VIII, pp. 419-499, Pl. XIX. An English translation by N. J. Giroux, with a map, appears in the Canadian Record of Science, 1894, pp. 169-198; 1895, January No., pp. 1-28; July No., pp. 1-28. The paper makes but passing mention of the ores. More attention is paid to them in a paper by F. D. Adams, On the igneous origin of certain ores, read before the General Mining Association of the Province of Quebec, Montreal, January 12, 1894. Earlier papers describe the phenomena, but do not discuss the method of formation.

E. J. Chapman, On some iron ores of central Ontario: Trans. Royal Soc. Canada, 1885, p. 9. The wall rock is not described.

E. J. Chapman, On some deposits of titaniferous iron ore in the counties of Haliburton and Hastings, Ontario. Idem., 1884, p. 159.

R. W. Ells, Report on the mineral resources of the Province of Quebec: Geol. Surv. Canada, 1888-89, p. 14K.

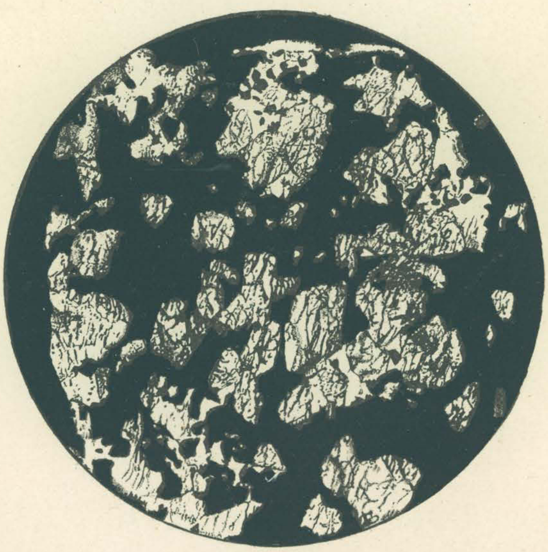
B. J. Harrington, On the iron ores of Canada: Idem., 1873-74, p. 227.

T. S Hunt, Idem., 1847, p. 59; 1867, p. 212.

Journal of the British Iron and Steel Institute, 1871, Vol. II, p. 130.

The most complete discussion of the Norwegian ores will be found in the following: C. F. Kolderup, Die Labrador-felsen des westlichen Norwegens: Bergens Museums Aarbog, 1846, pp. 1-222. References to earlier papers by Vogt, Dahll, Kjerulf, Reusch, Rosenbusch, and Thomassen are made in it.

A



B

JULIUS BIEN & CO. LITH. N.Y.

A. REACTION VEINS BETWEEN INCLUDED PLAGIOCLASE AND ORE. SANFORD PIT.
B. PHOTO-MICROGRAPH OF TITANIFEROUS ORE FROM MAYHEN LAKE, MINN.

anorthosites seem to be basin segregations from the general magma that yielded the country rock.

The Cheney pit is situated about 1 mile west of Lake Sandford. The pit is 35 feet wide, 15 feet high at the breast, and 20 to 30 feet deep. The wall rock is a gabbro gneiss, as already stated, and the ore contains more sulphur and phosphorus than do the others in the anorthosites. It emits a sulphurous odor when broken with the hammer. In thin section it is seen to be lean. Apatite is abundant, and brown hornblende, red-brown biotite, chloritized augite, and some plagioclase make up a large part of the aggregate.

A number of small masses of ore, in addition to those specially mentioned above, have been discovered, but they are not well exposed, and they add no new or significant facts to those already recorded. One just northeast of Lake Henderson is located on the map. Another projects slightly above the ground on the road to the "Lower Works" (Tahawus post-office), and some lines of attraction were found by Messrs. Scranton and Sebenius in a number of places around the Lower Works. The Lower Works are about 10 miles south of the "Upper Works," and are beyond the limits of the map. By the "Upper Works" is meant the furnace and houses shown on Pl. LXI.

The following analyses, which have been chiefly obtained from Mr. Auguste J. Rossi, illustrate the composition of the ores from the several pits. They have been in part published by Mr. Rossi,[1] and are also cited in a report by the writer on the geology of Newcomb Township, which has been made to Prof. James Hall.[2]

Analyses of ores from pits near Lake Sandford.

	Millpond pit.					Cheney pit.	
	1	2	3	4	5	6	7
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	10.73	13.38	19.74	20.24	20.49	8.25	15.77
Fe_3O_4	87.20	82.37	73.62	....	....	86.53	55.64
SiO_2	1.09	3.67	1.53	....	0.91	....	9.79
Al_2O_3	0.44	1.50	3.50	....	....	....	7.12
Mn_3O_4	0.13	....	....	....	....	....	....
CaO	Trace.	Little.	Little.	....	....	....	8.89
MgO	Trace.	0.50	1.60	....	....	....	3.00
P	None.	0.017	0.037	....	....	0.39	....
S	None.	0.068	0.08	....	....	0.74	1.00
Fe	63.45	59.56	53.62	55.62	54.80	62.15	40.33

[1] Titaniferous ores in the blast furnace: Trans. Am. Inst. Min. Eng., Vol. XXI, 1893, p. 832. The smelting of titaniferous ores: Iron Age, February 6 and 20, 1896.
[2] Fifteenth Annual Report New York State Geologist, 1898, p. 604.

Analyses of ores from pits near Lake Sandford—Continued.

	Sandford ore.						
	8	9	10	11	12	13	14
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	10.91	20.03	19.52	18.70	14.52	4.00	47.50
Fe_3O_4	87.60	70.73	70.80	71.03	....	....	....
SiO_2	0.87	2.46	1.39	1.34	1.39	....	....
Al_2O_3	0.53	3.50	4.00	....	5.81	....	....
P	....	....	0.022	....	....	....	....
S	....	....	0.028	....	....	....	....
Fe	62.65	51.22	51.30	51.44	56.60	62.66	36.86

The analyses were made by the following chemists: Nos. 1 and 8, Habershaw; Nos. 2, 3, 4, 7, and 11, Rossi; Nos. 5 and 10, Ledoux; No. 6, Wilbur; No. 9, Ricketts and Banks; No. 12, Miss White; Nos. 13 and 14, C. F. Chandler. No. 13 is of magnetic concentrates, No. 14 of tailings. In this case it would appear that magnetic concentration had effected a partial elimination of the titanium.

The analyses show that the ores are moderately rich in titanium, 20 per cent being the maximum. The Cheney ore excepted, they are in other respects extremely pure, and despite the percentages of TiO_2, the values in iron hold up very well. Sulphur and phosphorus are low. The Cheney ore resembles the ores in gabbro earlier described. No. 7 is of poor ore, No. 6 of rich. The ores deserve further investigation for V_2O_5, Cr_2O_3, NiO, and CoO. Mr. Rossi has observed traces of V_2O_5.

ORES ELSEWHERE IN ANORTHOSITE IN THE ADIRONDACKS.

A mass of ore has been observed by the writer's assistant, Charles Fulton, high up on the west side of Mount McComb, and from it loose pieces have streamed off down the mountain. It is of considerable, though not great, size, so far as the outcrop admits of estimate, and is inclosed in anorthosite. A small prospect has been dug about 2 miles southwest of Wilmington, and on one of the foothills of Mount Whiteface, but the dump shows the ore to have been very lean. The wall rock is anorthosite. A third mass is reported in the valley of Johns Brook, near the now abandoned trail from Keene Valley up Mount Marcy. A little brook near by has been named Iron Mine Brook. No observations have been made on it.

TITANIFEROUS IRON SANDS.

Titaniferous iron sands occur not infrequently along the shores of Lake Champlain, in streaks up to several inches thick, in the midst of other sands. They have fragments of pyroxene, hornblende, and especially of garnet, mingled with them, but are of no practical importance.

METHOD OF ORIGIN OF THE TITANIFEROUS MAGNETITES IN THE ADIRONDACKS.

In the preceding pages the point of view has been consistently maintained that the ore bodies are integral portions of the igneous rocks in which they occur, and are merely local enrichments of the mass with unusual amounts of one of its normal constituent minerals. This has not been done with the purpose of advocating one conception of the relations of ore and wall rock to the exclusion of others, but because the observed phenomena admit of no other reasonable interpretation. There is no evidence of the replacement of preexisting material by an entering foreign substance, nor of faults and vein formation, nor of crushed zones different from the neighboring walls; nor are the ores at the contacts of intrusions with country rock. On the contrary, the masses of ore, of irregular shape, are far within the intrusions, and especially in the gabbros they vary from rich titaniferous iron oxide, through leaner and leaner examples, until normal gabbro is reached. No minerals or elements occur in notable amounts in the ores which are not characteristic components of the wall rock. The difference between ore and rock is one of degree and not of kind. At Calamity Brook the ore itself forms a series of dikes in country rock of a different kind.

When the analysis of the process of formation is pushed still further, and when a sound chemical or physical explanation is sought for the local segregation of certain fractional parts of a great igneous magma, it must be confessed that hypotheses enter to a large degree. It may be remarked that while this problem is allied to those others which deal with the possible derivation of successive flows of different igneous rocks from a supposed parent magma, yet it is not of the same order of magnitude. The question, for example, as to whether the gabbros, anorthosites, trap dikes, and other igneous types in the Adirondacks are derived from a single original reservoir by a successive splitting of its magma, or from several separate sources, is a larger one, and in many respects a more hypothetical one, than that of the formation of limited masses of ore in a single intrusion. For the starting point of the discussion we may therefore assume distinct gabbro magmas and anorthosite magmas. The latter differ from the former in being higher in silica, alumina, and soda, and lower in magnesia and iron. The lime is practically the same in both. The gabbro has a slightly higher specific gravity than the anorthosite.

The group of the "ore-minerals" in an igneous rock is generally recognized to be the first to crystallize in the process of consolidation. The magnetite is of much higher specific gravity than the magma itself.

If the period of formation of the magnetite were sufficiently prolonged, and if its crystals were sufficiently large to overcome the surface tension with the liquid, it would settle in quantity to the bottom or lower portions of the magma, and would enrich those portions with iron oxide. The ferromagnesian silicates, which, while of less specific gravity than magnetite, are still of greater density than the magma, might be expected to accompany it in greater or less degree.[1] It is not entirely necessary for the magnetite to have crystallized in order to make possible a concentration by the settling out of heavy parts, because heavy liquids, if sufficiently immiscible, will do the same. Copper matte, for example, settles quite completely from the viscous mixture of matte and slag in the fore-hearth of a furnace, even when it constitutes only 5 or 6 per cent of the mixture. Circulations in the magma and convection currents would interfere with the complete development of the process, but if it were even partially carried out, so as to lead to the local concentration of iron oxide, the masses of the latter, when once established, might assume almost any position in the intrusion on its eruption and consolidation.

The idea that the early crystallizations, whose specific gravity exceeds that of the general magma, would sink and concentrate is an old one, and it has been employed by many observers to explain variations in the texture and mineralogy of igneous rocks. It has already been directly applied by Vogt to the titaniferous ores of Norway.[2] In the estimation of the writer it is the most reasonable of all the hypotheses advanced and it has the greatest claims to confidence.

The magnetic properties of the iron ores have also been suggested by Vogt and other observers as possible causes of segregation and as a source of attractions that might lead to their local accumulation. We

[1] Since these lines were written Lord Kelvin's important paper on the age of the earth has appeared (Philosophical Magazine, January, 1899, Abstract in the American Journal of Science, February, 1899, p. 160), and in it the basaltic rocks are explained as having originated during the early stages of the globe by this same process of the settling of minerals of high specific gravity in a fluid magma.

[2] J. H. L. Vogt, Dannelse af jernmalmforekomster, Kristiania, 1892. Résumé in German, p. 145. Professor Vogt believes in the efficacy of Soret's principle as a cause of the variability of magmas. This is, in brief, that in a complex solution whose different parts possess different temperatures the least soluble components tend to concentrate in the cooler portions. In the case of fused magmas the least soluble components are those that tend to crystallize first, i. e., the ores; while the cooler portions are near the contacts. Assuming, therefore, a reservoir of fused rock, Vogt conceives that from the upper part the basic minerals would concentrate toward the upper cooling surface, in accordance with Soret's principle; in the central part they would be held stationary by the conflicting operation of Soret's principle, leading them to rise, and their high specific gravities, leading them to sink; while in the lower part their great specific gravities would lead them to sink. As a second and totally different cause of segregation, Vogt suggests the magnetic properties of the iron oxides and the iron-bearing silicates. The latter cause is discussed in the text above.

G. F. Becker has thrown great doubt on the efficacy of so weak a cause as Soret's principle to produce differentiation, especially in such viscous material as fused rock, and the objection is a very serious one. The increase of basicity toward the contacts of intrusions is explained by him as due to convection currents which tend to coat the contacts with the early crystallizations, but inasmuch as the magnetites here under discussion are not at the contacts, the views have no immediate bearing on the present case. Cf. G. F. Becker, Some queries in rock differentiation: Am. Jour. Sci., January, 1897, p. 26. Note on computing diffusion: Idem, April, 1897, p. 280. Fractional crystallization of rocks: Idem, October, 1897, p. 257.

can not, in the present condition of our knowledge, be positive as to the effects of earth currents upon the metallic portions of fused magmas; but it can easily be shown that at a comparatively low temperature magnetite loses its magnetism and is inert. The experiment can be performed over a Bunsen burner; and it seems, therefore, improbable that magnetic attractions among the ore particles themselves are efficient causes of segregation at the high temperatures of fusion.

The ores on Calamity Brook are separate intrusions in the form of dikes, and are merely igneous rocks forming geological units of an exceptionally basic character. In considering the phenomena of separate intrusions, it is to be appreciated that TiO_2 plays in them much the same role as SiO_2, just as it does in slags, and its presence, to the same degree, removes the ores from the category of pure bases.

BRIEF REVIEW OF TITANIFEROUS ORES ELSEWHERE IN THE UNITED STATES AND ABROAD.

Titaniferous magnetite is richly disseminated in a knob of peridotite at Iron Hill, Cumberland, Rhode Island,[1] but the ore is too low grade to be utilized. Its commonest associated mineral is serpentine, which has been derived from olivine and pyroxene. Some plagioclase has also been noted. The ore is a close parallel with that at Taberg, Sweden.

Titaniferous ores have long been known in the crystalline rocks of New Jersey. They are especially developed in the Musconetcong belt from Schooleys Mountain westward to and across the Pennsylvania line. The exact character of the wall rock is not yet recorded, but it is probably squeezed gabbro. The percentages of TiO_2 are moderate.[2]

An extensive series of titaniferous ores is found in several belts in North Carolina. They occur in strongly metamorphosed rocks, which are as yet only recorded as hornblende-gneiss or schist.[3] Prof. H. D. Campbell informs the writer that masses of titaniferous ore occur in the Blue Ridge east of Lexington, Virginia.

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[1] M. E. Wadsworth, A microscopical study of the iron ore or peridotite of Iron-mine Hill, Cumberland, Rhode Island: Bull. Mus. Comp. Zool. Harvard Coll., Vol. VII, 1881, p. 183. Dr. Wadsworth quotes a report of the Rhode Island Society for the Encouragement of Domestic Industry, made in 1869. Additional notes will be found in his Lithological Studies and in the Bulletin of the American Iron and Steel Association for November 20, 1889. C. T. Jackson, Geological Survey of Rhode Island, 1840, p. 53. A. L. Holley, Notes on iron ore and anthracite coal of Rhode Island and Massachusetts: Trans. Am. Inst. Min. Eng., Vol. VI, 1877, p. 224. N. S. Shaler, Geology of the road building stones of Massachusetts, with some considerations of similar materials from other parts of the United States: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, p. 321. N. S. Shaler, Conditions of erosion beneath deep glaciers, based upon a study of the bowlder train from Iron Hill, Cumberland, Rhode Island: Bull. Mus. Comp. Zool. Harvard Coll., Vol. XVI, p. 185. Bailey Willis, Tenth Census, Vol. XV, analyses on p. 567.

[2] Local details and analyses will be found in the following Annual Reports of the New Jersey Geological Survey: 1873, pp. 53, 55; 1875, p. 35; 1876, p. 54; 1877, p. 49; 1878, pp. 99, 100; 1879, pp. 62, 67, 76; 1880, p. 125. R. W. Raymond, Trans. Am. Inst. Min. Eng., Vol. XXI, 1892, p. 275. B. F. Fackenthal, idem, Vol. XXI, 1892, p. 279. Isidor Walz, Am. Chemist, June, 1876, p. 453.

[3] North Carolina Geol. Survey, Vol. II, 1893, p. 181. J. P. Lesley, Notes on the titaniferous iron-ore belt near Greensboro, North Carolina; Am. Philos. Soc., Vol. XII, 1871, p. 139. H. B. C. Nitze, Bulletin 1, North Carolina Geol. Survey. Many notes and analyses are contained in this paper. Bailey Willis, On the Dannemora mine: Tenth Census, Vol. XV, p. 310.

The vast areas of gabbro in Minnesota north of Lake Superior have a number of masses of ore[1] that have attracted some attention, and one series near Mayhew or Iron Lake—along the national boundary not far from the larger Gunflint Lake—has been called the Mayhew Range. The masses reach 50 to 75 feet in thickness. Additional ores are known just north of Grand Marais, and within the city limits of Duluth. The igneous character of the ores has long been recognized, and they are collectively spoken of in the Minnesota reports as the "Gabbro-titanic group." The writer has had the opportunity of examining slides of rock and ore from Mayhew Lake through the kindness of Dr. U. S. Grant. Aside from some minor mineralogical variations, they are close parallels with the Adirondack gabbro ores. A photomicrograph of one of them is shown on Pl. LXIII, *B*. The transparent mineral is augite.

The existence of great deposits of iron ore in Wyoming was noted as early as 1849 by Lieut. Howard Stansbury. Their titaniferous character was recognized about twenty years later. Arnold Hague has described the ore as forming huge dikes in granite, with offsetting branches into the wall rock. Gabbro was also noted by Mr. Hague, protruding through the granitoid rocks. The gabbro is described by Zirkel as especially rich in labradorite. Diallage is also present. The writer has received from Prof. W. A. Knight, of Laramie, samples of this rock, which are described by him as forming the walls of titaniferous magnetite masses. They are a typical olivine-gabbro. Other samples are anorthosite, practically identical with those of the Adirondacks and Canada. It would appear that there is an eruptive center of gabbroic rocks, with a huge offsetting dike, that is nearly pure titaniferous magnetite.[2]

Titaniferous ores are known in three places in Colorado. One is the so-called Iron Mountain, in Fremont County,[3] which is situated about 50 miles west of Pueblo, in the Wet Mountain Valley, on a tributary of Grape Creek. The wall rock has been called "gray granite" by Putnam, as a field name; but a specimen of a granitoid rock, labeled Grape Creek, in the collections of the geological department of Columbia University along with the Grape Creek titaniferous ores, is a most excellent olivine-gabbro. Another mass of titaniferous ore occurs in Boulder County at Caribou Hill, in the northwestern corner of the county.[4] No determinations of the wall rock have been made. The third locality is in the Cebolla district, Gunnison County. The amount

[1] W. S. Bayley, Peripheral phases of the great gabbro mass of northeastern Minnesota; Jour. Geol., Vol. I, p. 818. Other papers on the gabbros are in the same volume, and one additional in Vol. III, p. 1. C. R. Van Hise, Bull. Geol. Soc. America, Vol. VII, 1895, p. 488. N. H. Winchell, Tenth Ann. Rept. Minnesota Geol. Survey, 1882, p. 85. N. H. and H. V. Winchell, Bulletin VI, Minnesota Geol. Survey, p. 136.

[2] Arnold Hague, U. S. Geol. Explor. Fortieth Par., Vol. II, 1877, p. 12. F. V. Hayden, U. S. Geol. and Geog. Surv. Terr., 1870, p. 14. Howard Stansbury, Exploration and Survey of the Valley of the Great Salt Lake, 1852, p. 266. F. Zirkel, U. S. Geol. Expl. Fortieth Par., Vol. VI, p. 107.

[3] F. M. Endlich, U. S. Geol. and Geog. Surv. Terr., 1873, p. 333. B. T. Putnam, Tenth Census, Vol. XV, p. 472.

[4] Regis Chauvenet, Notes on iron prospects in northern Colorado: Biennial Report of the Colorado State School of Mines, 1886, p. 16. B. T. Putnam, Tenth Census, Vol. XV, p. 476.

of ore is large, but no determinations of the wall rock have been made.[1]

Huge masses of titaniferous magnetite occur in the Norian areas of Quebec and Ontario, Canada. On the Saguenay River, near Lake St. John, they constitute considerable hills and are comparable with those near Lake Sandford, New York. Other masses are known at St. Hypolite and St. Julienne, north of Montreal; at Bay St. Paul, on the St. Lawrence, 54 miles below Quebec; on the Rapid River, near its place of discharge into the Bay of the Seven Islands, St. Lawrence River; in the townships of Brome and Sutton, just north of Vermont, and in the counties of Victoria, Halburton, Peterboro, and Hastings, in eastern Ontario. The ores in the Norian rocks are in anorthosites, but the wall rocks have not been determined in the last two general localities. The literature will be found cited on p. 414.

The researches of O. A. Derby in Saõ Paulo, Brazil, have brought to light titaniferous ores, which occur with a complex series of eruptives, but which are regarded as the basic extreme of nepheline-bearing rocks. The varieties rich in ore are called jacupirangite, and are summarized as follows:

> The rocks included under this title are allied to the nepheline-bearing series, and present the various types of pure magnetite, magnetite with accessory pyroxene, pyroxene with accessory magnetite, and pyroxene and nepheline, with biotite and olivine as accessory, or (in the case of the former, at least) essential elements. All these types are most intimately associated as parts of the same mass, and the gradual passage from one to the other has been most satisfactorily proven. The most constant and characteristic element is a violet titaniferous pyroxene.[2]

The titaniferous ores of Norway are most widely known of all, because they have been most largely utilized. In their geological relations they present the closest parallelism with those of the Adirondacks and Canada. The chief localities are Ekersund (or Egersund) and Soggendal, in the southwestern portion of the Scandinavian peninsula. Just as in the Adirondacks, there are ores in anorthosite and ores in norite. The former are lenticular or elongated in outline and more or less mixed with bisilicates, but they shade out into true labradorite rocks or anorthosites. The general geological relations of those in the norites are the same. They grade into the country rock and are regarded as ultrabasic segregations from an igneous magma. Some ore bodies near Ekersund are interpreted by J. H. L. Vogt as intruded dikes, comparable with the occurrences on Calamity Brook, Lake Sandford, and at Iron Mountain, Wyoming. According to Vogt, smaller masses of ore occur at Langven and Gomoen, in the Krageroe Fiord, in olivine-hyperite, a diabasic gabbro. David Forbes has given a few details of

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[1] Regis Chauvenet, Iron resources of Gunnison County: Ann. Rept. Colorado State School of Mines, 1887, p. 18. Iron resources of Colorado: Trans. Am. Inst. Min. Eng., Vol. XVIII, p. 272.

[2] O. A. Derby, Magnetite ore districts of Jacupiranga and Ipanema, Saõ Paulo, Brazil: Am. Jour. Sci., April, 1891, p. 311. Conversations with Dr. Derby before the issue of this paper first stimulated the writer's interest in titaniferous ores.

lenticular ore bodies in metamorphic schists on some small, rocky islands called Dybsunds Holmene, in the Krageroe Fiord. Additional ones occur in true gabbro at Skonevig, in the Matre and Akre fiords.[1]

The principal Swedish locality is Taberg, where the ore is a peridotite, richly impregnated with titaniferous magnetite. It forms a hill of considerable extent, but the ore is lean. Similar but smaller occurrences are known at Langhult, Ransberg, and Iglama. At Ulfo ores are found in olivine-diabose, and at Alno in association with nepheline-syenite. The aggregate of ilmenite and spinel at Routivare has been described on page 389.[2]

Titaniferous ores have also been reported from Finland, but the writer has been unable to find descriptions of them. The iron-bearing sands of New Zealand contain 8 per cent of TiO_2.[3]

[1] Tellef Dahll, Om de geologiske undersögelser i Kristiansands stift: Förhandl. videnskabs. Natfm. i Stockholm, 1863. David Forbes, On the composition and metallurgy of some Norwegian titaniferous ores: Chemical News, December 11, 1868, p. 275. S. Forbes, Jour. British Iron and Steel Inst., 1874, p. 131. Th. Kjerulf, Om ganggjennemskjäringer ved Ekersund: Nyt Magazin for Natv., Vol. XXVII, 1883. C. F. Kolderup, Die Labradorfelsen des westlichen Norwegens: Bergens Museums Aarbog for 1896, especially p. 159. H. H. Reusch, A visit to the titaniferous iron mines at Soggendal, Norway: Geol. Fören. i Stockholm Förhandl., 1877, p. 197. Neues Jahrbuch, 1878. H. Rosenbusch, Die Gesteine von Ekersund: Nyt Magazin for Natv., Vol. XXVII, 1883. T. Ch. Thomassen, Geologiske undersögelser paa Folgefondens halvö: Idem, Vol. XXIV, p. 287. J. H. L. Vogt, Norske ertsforekomster, No. V: Archiv für Mathem. og Naturvidenskab., Kristiania, Vols. X and XII, 1887. Om dannelsen af de vigtigste i Norge og Sverige representerede Grupper af jernmalmförekomster: Geol. Fören. Stockholm, Förhandl., Vol. XIII, p. 476, 683, Vol. XIV, p. 211; Geol. Mag., Vol. IX, p. 82; Neues Jahrbuch, 1893, Vol. II, p. 69. See also Zeitschr. für prakt. Geologie, January, 1893, p. 6, October, 1894, p. 384. The papers of Vogt and Kolderup are of chief value for reference.

[2] R. Ackerman, Iron manufacture in Sweden at the present time: Iron, new series, Vol. VII, 1876, p. 514. A. G. Hogbom, Ueber das Nephelin-Syenite Gebiet auf der Insel Alnö: Geol. Fören. i Stockholm Förhandl., Vol. XVII, 1895, pp. 100, 214. W. Petterson, Om Routivara jernmalmsfält i Norrbottenslän: Idem, Vol. XV, 1893, p. 45: Neues Jahrbuch, 1894, Vol. I, p. 88. Hj. Sjögren, En ny jernmalmstypa representerad af Routivara malmberg: Idem, Vol. XV, 1893, pp. 55, 140: Neues Jahrbuch, 1894, Vol. I, p. 88. A. Sjögren, On the Taberg Iron-ore Deposit: Idem, Vol. III, 1876, p. 42: Neues Jahrbuch, 1876, p. 434. A. E. Törnebohm, Om Taberg i Småland, och ett par dermed analoga jernmalmförekomster: Idem, Vol. V, p. 610; Neues Jahrbuch, 1882, Vol. II, p. 66. J. H. L. Vogt, On Taberg: Zeitschr. für prakt. Geologie, January, 1893, p. 8.

[3] E. M. Smith, On the treatment of New Zealand magnetic iron sands: Proc. Iron and Steel Inst., May, 1896. Engineering and Mining Journal, June 13, 1896, p. 566.

GEOLOGY OF THE McALESTER-LEHIGH COAL FIELD INDIAN TERRITORY

BY JOSEPH A. TAFF

ACCOMPANIED BY

A REPORT ON THE FOSSIL PLANTS

BY DAVID WHITE

AND

A REPORT ON THE PALEOZOIC INVERTEBRATE FOSSILS

BY GEORGE H. GIRTY

CONTENTS.

GEOLOGY OF THE M'ALESTER-LEHIGH COAL FIELD, INDIAN TERRITORY, BY JOSEPH A. TAFF.

FOSSIL PLANTS FROM THE M'ALESTER COAL FIELD, BY DAVID WHITE.

PALEOZOIC INVERTEBRATE FOSSILS FROM THE REGION OF THE M'ALESTER COAL FIELD, BY GEORGE H. GIRTY.

ILLUSTRATIONS.

GEOLOGY OF THE McALESTER-LEHIGH COAL FIELD, INDIAN TERRITORY.

By JOSEPH A. TAFF.

INTRODUCTION.

The McAlester-Lehigh coal field lies wholly within the Choctaw Nation, and is, therefore, part of the Productive Coal Measures of the Indian Territory. The Indian Territory coal field connects the Arkansas coal regions lying along the Arkansas River Valley with the coal measures of Kansas, Missouri, and Iowa. The Indian Territory coal field forms a rudely triangular area which extends up the Arkansas-Canadian River Valley across the Choctaw Nation into northeastern Chickasaw Nation and thence, in general, bears a little east of north across the Creek and Cherokee nations into Kansas.

The area of the coal measures, from the lowest productive coal to the top of the series in the Indian Territory, is nearly 20,000 square miles.

In 1890 Dr. H. M. Chance examined a part of the coal measures of the Choctaw Nation between McAlester and Cavanal along the line of the Choctaw, Oklahoma and Gulf Railway and published a report in the proceedings of the American Institute of Mining Engineers for 1890, under the title of Geology of the Choctaw Coal Field. This work is the first detailed account of the coal-bearing rocks of the Indian Territory, and has been of great service to the coal operators as well as to the geologists who have subsequently entered the field.

Prof. J. J. Stevenson made a reconnaissance of the coal-bearing rocks of the Choctaw Nation in 1895, and correlated[1] the rock section made by Dr. Chance with an unpublished section of the coal-bearing rocks of western Arkansas by Mr. Arthur Winslow.

Dr. N. F. Drake made a reconnaissance[2] of the coal measures of the Indian Territory north of the latitude of Hartshorne in 1896. In this survey Dr. Drake traced the coal-bearing rocks from Kansas across the Cherokee, Creek, and Choctaw nations to the Arkansas coal field.

[1] Notes on the Geology of Indian Territory, J. J. Stevenson: Trans. N. Y. Acad. Sci., Vol. XV, pp. 50-61.

[2] A geological reconnoissance of the coal fields of the Indian Territory, by Noah Fields Drake: Proc. Am. Phil. Soc., Vol. XXXVI, pp. 326-429. Also Leland Stanford, jr., University Publications, Contributions to Biology from the Hopkins Seaside Laboratory, Vol. XIV., 1898.

Parts of the field were studied in much detail and in his publication there is given a broader view of the geology of the Indian Territory coal field than has heretofore been presented.

The United States Geological Survey has been engaged since 1895 in sectionizing and making a topographical map of the Indian Territory and has now almost completed the field work. For the benefit chiefly of those who possess the land the whole country has been divided into square blocks which contain 36 square miles or sections and are called townships. At each corner of a township an iron post, surmounted by a brass cap, is set into the ground. At the corner of each square mile or section of the township a stone or post is also set up, and where trees are present one in each of the four sections adjoining is marked, showing the number of such section. Midway between each section corner stones or posts are also erected on the line and one tree in each section adjoining is marked. A plat of a township is shown in fig. 77.

Then, for convenience, the country is divided into larger rectangular blocks, each containing about 950 square miles and bounded by certain longitude and latitude lines. Each block thus divided is called a quadrangle, and for each a separate map is drawn. The boundaries of these quadrangles are not marked upon the ground, and their positions can be determined only by reference to the map.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIG. 77.—Plat of township.

The field work upon which this paper is based was begun by the writer and Mr. George B. Richardson in July, 1897, and carried on over the McAlester and parts of the Atoka and Coalgate quadrangles, with a view to publication in folios of the Geological Atlas of the United States. A great thickness of strata, composed of sandstones and shales, in the southern half of the McAlester quadrangle yielded no evidence of age. This fact, with the existence of very excessive faulting and folding which affect the strata, precludes the publication of a report upon them before work in the adjoining districts has been done. The Lehigh coal district is a part of the Atoka and Coalgate quadrangles, and its geology, with that of the coal district of the McAlester quadrangle, forms the subject of this paper.

Fossil plants were collected from the roof shales of the principal coal beds, and from other rocks where such plants could be found, ranging through nearly 3,500 feet of strata from the lowest coal upward. Mr. David White's study of these fossils and his resulting correlations have proved of great scientific value, and have served as a check upon the stratigraphic work in determining the position and identity of workable coal beds. Mr. White's study of these plants also determines that the age of the Hartshorne or Grady coal is that of the Lower Coal Measures, and probably the lower part, as the section of these rocks is known in Pennsylvania, Missouri, and Kansas; and that the McAlester coal belongs to the Upper Coal Measures, and most likely near the base. The value of fossil plants as an aid in correlating workable coal beds can not be too highly appreciated, especially where the rocks have been greatly folded, and where the surface has been worn down and the hardest rocks concealed, as in parts of this region.

The fossil shells were identified by Dr. George H. Girty, whose report upon them is published in an accompanying paper.

Acknowledgments.—The results which are presented in this report are in a large measure due to the services of Mr. George B. Richardson, who assisted me in the field and in the office. I wish to express my appreciation of his energy and accuracy in work. Dr. Geo. I. Adams assisted in the survey of the northern part of the Lehigh district, and the value of his services is highly commended. The Geological Survey is indebted, for numerous courtesies, to many whose names can not be mentioned. Especial thanks, however, are due to Mr. Luke W. Bryan, mine inspector for the Indian Territory; Mr. Edwin Ludlow, Mr. William Cameron, and others operating coal in the McAlester-Lehigh coal field, for information furnished and services rendered.

TOPOGRAPHY.

GENERAL RELATIONS.

The McAlester-Lehigh coal field forms part of two of the three geographic subdivisions coming within the bounds of the Choctaw Nation. A brief account of the three geographic provinces will be given, so that a better understanding may be had of the local geographical relations of the coal field. These three geographic subdivisions are (1) the Ouachita Mountain range, the central province, which bears westward from the vicinity of Little Rock, in Arkansas, to the Missouri, Kansas and Texas Railway, between Limestone Gap and Atoka, in the Choctaw Nation; (2) the Red River plains, which extend from the southern base of the Ouachita Mountains southward into Texas; and (3) the Arkansas-Canadian River basin, which is a southeastward extension of the prairie plains of Kansas, Oklahoma, and northern Indian Territory.

THE OUACHITA MOUNTAIN RANGE.

The Ouachita Mountain range[1] is a system of parallel and low mountains which rise, in general, to higher elevations as they succeed each other from the sides toward the center. From the eastern end, near Little Rock, the crests of these ridges rise gradually from nearly 500

[1] Name applied by Dr. John C. Branner to the range of mountains which extends from the vicinity of Hot Springs, Arkansas, across the State into Indian Territory. Ann. Rept. Arkansas Geol. Survey, 1888, Vol. I, p. 59.

feet to nearly 3,000 feet at the eastern border of the Indian Territory. Continuing westward from the Indian Territory line, they descend to about 1,000 feet in elevation at the west end of the range near Atoka. The ridges and mountains of this range are due to the excessive and sharp folding and faulting of the thousands of feet of shales and sandstones as the range was uplifted, and to the erosion of the streams, which have eaten down slowly in the hard sandstones and comparatively rapidly in the soft shales. Where there is a narrow exposure of shale a restricted valley is found, and where there is a wide surface of shale, between thick masses of sandstone, an almost equally wide and generally level valley occupies it, while the sandstones stand high above the valleys as prominent ridges or mountains.

THE RED RIVER PLAIN.

The Red River plain is a broad expanse of country, generally smooth, which slopes gradually away southward from the base of the Ouachita Mountains and laps around their western end. The Red River plain is underlain by friable sandstone, soft clays, and limestone of Cretaceous age, or by the Cretaceous base level, a nearly smooth plain upon Paleozoic rocks from which the Cretaceous sediments have lately been removed. The southern part of the McAlester-Lehigh coal field is characteristic of the Cretaceous base level and is transition ground between the Red River plain and the Arkansas-Canadian River basin.

THE ARKANSAS-CANADIAN RIVER BASIN.

The Arkansas-Canadian River basin, being a part of the prairie plains in Indian Territory, is neither smooth nor deeply dissected. The rivers in this region have worn down their channels nearly to a level, and by meandering from side to side have produced generally wide flood plains. All the larger tributary streams to these rivers in the Choctaw Nation have kept almost equal pace with them in their downward as well as lateral cutting until they, too, meander in wide level basins. Two hundred to 300 feet above these river basins and between their tributary streams the general plain of the country may be seen in the level-crested ridges and flat-topped hills.

TOPOGRAPHY OF THE M'ALESTER-LEHIGH DISTRICT.

The McAlester district belongs to the Canadian River basin, while the Lehigh is in the Red River drainage. North of Kiowa the waters gather in Peaceable, Brushy, Coal, and Gaines creeks. The general direction of drainage is northeast into Gaines Creek and then northward beyond the limits of the field into the Canadian River. South and west of Kiowa the streams flow south and southeast, and all belong to North Boggy, Middle Boggy, and South or Clear Boggy drainage. The Boggy creeks join their waters southeast of this field and flow into

Red River. The watershed or divide between the drainage systems of the Canadian and Red rivers in this field is entirely worn down, so that it can not be perceived except by careful inspection. It is an almost level plain northwest and southeast of Kiowa. The discussion of this plain is given below under the head of "Post-Cretaceous denudation."

THE CRETACEOUS BASE LEVEL.

As one travels across the McAlester-Lehigh coal field from north to south the landscape is seen to vary but little until the vicinity of Atoka is approached. The generally level plain land is interspersed with low, level-crested ridges and more elevated flat-topped wooded hills. Near Atoka the ridges and hills become lower and finally their crests sink to a level with the prairie valleys. As the ridges and valleys blend, the timber which covers the surface of the stony ridges and hills grows thin and finally disappears Thus there is a scope of gently rolling prairie land which extends from the vicinity of Atoka westward across the south end of the coal field. The higher points in this stretch of land form a Cretaceous base-level, a once level plain, over which the Cretaceous sea transgressed as it rose over the country, and on which the Cretaceous rocks were deposited. Into this plain, near what is now the Cretaceous border, the streams have just begun their downward cutting into the coal-bearing rocks since the Cretaceous sands have been removed. Immediately south of this recently uncovered plain the sands which formed the beach and near-shore deposits of the Cretaceous sea are in place. For several miles north into the coal field in the region of Lehigh the crests of the ridges grow gradually higher in elevation and the valleys deeper. The crests of these ridges lie almost within the original Cretaceous base-level. Farther northward still across the McAlester quadrangle the crests of the highest ridges and hills mark an almost level plain at an elevation of nearly 900 feet above sea level. How far the crests of these ridges and hills are removed from the original base-level here can not now be determined on account of the limited area studied. Beds of conglomerate composed of coarse quartz pebbles, silicified wood, and sand lie upon the chert ridge at the eastern border of the coal field east of Atoka from the Cretaceous area northward for several miles. Continuing farther northward beyond Stringtown, 10 miles from the main Cretaceous land, bowlders of this conglomerate still remain upon the slopes and at the base of the ridges, although they have been removed from the crests. Coarse quartz and quartzite pebbles resembling in character those of the Cretaceous occur thinly scattered in the more elevated valleys almost throughout the McAlester coal field. Pebbles of the same character were noted upon the crests of the flat-topped ridges in the northern part of the McAlester quadrangle at elevations of 750 to 800 feet above sea and about 150 feet above their more general occurrence in the valleys. There are no means known, at present, by which to determine whether these pebbles descended from the old level once occupied by Cretaceous rocks or whether they have been transported from other higher elevations and deposited since Cretaceous time. The fact remains, however, that the crests of the higher ridges over this entire coal field north of the clearly defined Cretaceous base-level are at the same general altitude—nearly 900 feet above sea. The tops of these hills and ridges of the highest level are generally flat and are capped by nearly horizontal rocks. The crests of the ridges at lower elevations are sharp, but are generally level.

POST-CRETACEOUS DENUDATION.

As the Cretaceous sediments were removed from the surface of this coal field, or as the land was uplifted from its base-leveled condition after Cretaceous time, the streams began to cut down into coal-bearing rocks. The uplift was of broad extent, since the crests of the ridges lie in a nearly level plain, and since the Cretaceous rocks at the southern border of the field are tilted probably but little more than when they were deposited in the sea. Though elevated, as the land is now, and as it probably has been for a long period of time, its nearly level condition has prevented the streams from eroding their channels rapidly. As a result of these conditions of uplift and erosion, all but the hard rocks have been worn down to the same general level. Thus a peneplain occurs throughout the McAlester-Lehigh coal field at an elevation of about 700 feet above the sea. Everywhere within this field the shale surfaces have been reduced to this lower level, and where the rocks have been folded so that they dip at high angles sandstones and shales have been reduced equally by erosion. Typical examples of this planing down of hard and soft rocks alike may be seen in the region of Kiowa, between Kiowa and Savanna, and between Kiowa and Hartshorne. In this region the small streams meander in scarcely perceptible basins in the peneplain. At the time of the maturity of this peneplain the surface was most likely at a lower elevation than at the present time. Indications of this may be seen in the more or less marked terraces which separate the local flood plains of the larger streams from the peneplain.

SAND PLAINS.

At a time when the surface of the country had been reduced nearly to its present state a deposit of gravel, sand, and silt was formed across the northern part of this coal field. This sand lies in a nearly level plain at an elevation of 700 to 750 feet above sea level and occupies a position below the level of the hills and ridges across which it passes and but little above the valleys of the larger streams. In many respects this sand plain resembles a deserted river channel, but it takes its course through a part of the district independent of the present drainage basins of the region. At the west side of the McAlester quadrangle the sand plain occurs at the south side of Coal Creek valley, above which it is elevated about 50 feet. The sand plain is nearly level and grades almost imperceptibly into the low hills to the south. From Coal Creek Valley the plain extends almost east to the valley of Perryville Creek, and thence down the north side of Perryville and Peaceable creeks. From south of Alderson it bears northeast to the elevated valley between Brushy Creek and a branch of Gaines Creek east of Alderson. From this vicinity it continues northeastward through the gap of the sandstone ridge now occupied by Brushy Creek west of Gowen. In the valley of Brushy Creek, as in the valley of Coal Creek, the sand plain is elevated nearly 50 feet above its flood plain. Subsequent erosion has removed the greater part of this sand plain, so that its original limits can not everywhere be made out. Where it approaches or crosses an elevated ridge there is indication of a channel previously cut in which the gravel and sand were deposited. Elsewhere later erosion has gone so far that the nature of the subtopography of the sand plain can not be clearly interpreted.

FLOOD PLAINS.

Although elevated nearly 600 feet above sea the streams, as before stated, have generally very little fall. The principal creeks, Brushy, Peaceable, Coal, Gaines, and Boggy, have basins little deeper than the smaller streams but are relatively very wide. Through these flood basins, which are in many places more than a mile in width and are almost perfectly level, the channel of the stream meanders back and forth in a very crooked course. The basins are flooded at high water and are silted with a fine mud. At low water the flow is almost imperceptible, and in many places the channels are strewn with the trunks of fallen trees. In the time of long drought the streams, with the exception of Clear Boggy, usually do not flow, and the water stands in pools.

GEOLOGY.

GEOLOGY OF THE McALESTER DISTRICT.

The map of the McAlester district (Pl. LXIV) shows all the rocks of the McAlester quadrangle above the base of the known Productive Coal Measures. The southern boundary line of these Coal Measures would be upon the base of the Hartshorne coal, but the Hartshorne sandstone, which lies next below, is included for the convenience of the location of the coal. The northern, eastern, and western limits of the area mapped are arbitrarily drawn.

The rocks are sandstones, shales, and coal. They occur in beds or strata one above another in definite order. When formed in water near the shore, as was the case with the purer and coarser sandstones, or in the sea farther from the shore and in wide, shallow basins, as with the shales or shaly sandstones, or in swamps along low shores, as was most probably the case with the coal, all the beds were nearly horizontal and consisted of incoherent sand, soft mud, and probably boggy or peaty beds, respectively. As the land sank down and other beds were deposited over these, the sand, mud, and carbonaceous beds became compact, and after long periods formed hard rock. When the highest beds which now occur in this coal field were laid down, there was a depth of rock above the Hartshorne coal of nearly 6,300 feet. Since that time they have been folded up and down, as horizontal leaves might be, and then worn down so that all their edges appear at the surface, running in various directions across the field, and dipping at various angles from the surface.

The outcropping edges of the various associated beds of sandstone, shale, and coal are outlined on the map, and their positions beneath the surface are indicated in the structure sections.

There are rocks estimated to be nearly 18,000 feet in thickness which occur below the productive coal beds and to the south of them, but they do not contain coal of importance so far as known. The uppermost bed of this great series, the Hartshorne sandstone, lies almost immediately below the Hartshorne coal, and because of its value in locating the coal it is considered in this discussion.

It has not been possible to separate, with precision, the rocks of this coal field into divisions of the Coal Measures. The age of fossil plants from the roof shales of the Hartshorne coal, as determined by Mr. David White, places these in the Lower Coal Measures. Fossil plants from the roof shales of the McAlester coal are shown to belong in the Upper Coal Measures. A discussion of the comparative age of these beds is clearly set forth in Mr. White's paper in this report. There are nearly 2,000 feet of strata, principally shale, between these two coal beds, which have not produced sufficient fossil evidence to indicate, even approximately, the division line to be drawn between the Upper and Lower Coal Measures.

The Hartshorne sandstone.—This is a brown to light gray sand rock which has an extreme thickness of about 200 feet. Near the top the beds are very thick and some are massive. Upon the surface they occur as roughly rounded masses and thick ledges. Below, and especially in the lower part, many of the beds are thin and slabby and are associated with sandy shales. South of Hartshorne and between Gowen and Cherryvale this sandstone has its widest expanse where it has lowest dip and produces a considerable ridge. Traced southwest from Hartshorne its dips become steeper and it is generally worn down, or the thicker beds crop out only as narrow ridges. In the region east and south of Kiowa, and in the Savanna arch southwest of Savanna, it is worn down level with the plain until only occasionally a ledge of sandstone may be seen above the surface. One mile south of Savanna it occurs in a high hill and narrow sharp ridge along the south side of Chun Creek. From Cherryvale east to the limits of the McAlester quadrangle the sandstone is on edge or dips steeply toward the north and forms a prominent sharp ridge, except where worn away by Gaines Creek. The Hartshorne coal lies above this sandstone and is separated from it by a thin but variable bed of shale. The indicative value of this sandstone should be appreciated by the coal prospector, since wherever the sandstone can be traced coal may be expected to occur.

The McAlester shale.—This formation, for convenience of discussion, may be divided into a series of three parts. The lowest one is composed almost entirely of shale, with thin sandstone and coal, in all 800 feet thick. Locally sandstone occurs with thin coal beds near the center of this shale. The Hartshorne or Grady coal occurs at the base of this shale. The middle division of the McAlester shale is composed of three to four beds of sandstone separated by shale 100 feet to 200 feet thick. Together these beds of sandstone and shale are about 500 feet thick. The lowest of these sandstone beds caps the mesa of Belle Starr Mountain and the ridge northwest of Hartshorne. Here it is nearly 200 feet thick. Over most of its surface area, however, the sandstone is not well exposed. The upper division is almost entirely of shale nearly 700 feet thick and the McAlester coal is about 50 feet above its base. Several thin seams of coal occur in this shale also, but none have been found thick enough to be workable. The shale is blue, gray, or black, with the gray color predominating.

A thin band of buff fossil iron ore occurs near, below the McAlester coal. This iron ore, which may not be widespread in its occurrence, associated with the thin bedded sandstone nearly 50 feet thick, may prove a valuable aid to the prospector in locating the McAlester coal. A striking characteristic of the McAlester shale is its surface feature. Being almost throughout a soft shale it is worn down nearly to a level plain. In the region of McAlester, Krebs, and Alderson the smooth plain is upon the upper division of this shale. The basin plain north of Hartshorne, called by Dr. Chance the Grady Basin, is upon the lower division of this shale. It would be desirable, were it possible, to map the middle division of the McAlester shale as an aid to the prospector in locating the McAlester coal. Where the dips are as steep as they are over a large part of the occurrence of the rock at the surface, the sandstones are worn down to a level with the plain and are concealed.

The Savanna sandstone.—Next above the McAlester shale there is a series of sandstones and shales about 1,150 feet thick. The shaly beds combined are probably thicker than the sandstones, but since the sandstones are better exposed and their presence is so strongly impressed upon the observer in the prominent ridges which they make, sandstone seems the more appropriate term. There are five principal sandstone beds, which have different thicknesses, from nearly 50 feet to 200 feet, the one at the top and the one at the base being generally thicker than the intermediate ones. These sandstones may be distinguished only by their position in the section or their thickness of bedding. They are brown or grayish-brown, fine grained, and compact. Except in the uppermost beds, upon which the town of South McAlester is built, the beds are generaly thin and in part shaly. The uppermost sandstone occurs in two members, 75 to 100 feet thick, separated by variable blue clay shales. The uppermost beds of this sandstone are found in many places to be massive, and those in contact with the shale are often beautifully ripple marked. No coal of any value has been found associated with these beds of sandstone in the McAlester district, though a thin bed has been reported to occur in the upper part of the series. Where the rocks dip at low angles they make ridges. The ridges are prominent features of the landscape in the vicinity of South McAlester, south of Krebs and of Alderson and north of Gaines Creek Valley, near the eastern border of the quadrangle. Southwest of Kiowa and upon the east side of the Lehigh coal field these sandstones are prominent ridge makers. It is true that they are tilted at very high angles on the east side of the Lehigh district, but the drainage of North Boggy Creek is generally parallel with the trend of the ridges, besides which the soft shales are easily eroded. Both east and west of McAlester, between Hartshorne and Kiowa, and in the district southwest of Savanna, these beds dip at angles varying from 40° to 90°. In these localities the sandstones and shales have been nearly equally worn down almost to a level plain. Near stream channels, however, where recent erosion has removed adjacent soft rocks, low ridges occur upon the crops of the sandstones. Elsewhere sandstone ledges are elevated but little, if any, above the generally smooth prairie.

The Boggy shale.—There is a mass of shale and sandstone above the Savanna sandstone nearly 3,000 feet thick. Throughout a part of this field it is possible, and would be desirable, to separate these beds and map them as two or more series of beds from both stratigraphical and structural points of view. In other parts of the field, however, it is not possible to trace or map beds of sandstone or shale in separate collections of strata, since they are concealed by superficial deposits or are worn down to a smooth surface so that all rocks alike are concealed beneath the soil. No coal of workable extent or other beds of economic importance have been found in these rocks to warrant greater effort in detailed mapping. In the Boggy shale there are probably not less than sixteen beds of sandstone ranging in thickness from 20 to 150 feet, separated by shale from 100 feet to 600 feet thick. One coal bed, about 2 feet 6 inches thick, has been located and worked to a small extent, though now abandoned. This coal bed is about 400 feet above the base of the Boggy shale and has been prospected and worked, to a small extent, on the Missouri, Kansas and Texas Railway, at points 1 and 3 miles south of South McAlester. In other parts of the field, upon further investigation, it may prove to be workable.

The shales of this series are exposed to a very slight extent. In the few hill slopes and stream cuttings where observed the shales are bluish fissile clay containing ironstone concretions, thin wavy sandstone plates, and shaly sandstone strata. The sandstones fall in one general class and vary but little in minor detail of texture. They are generally brownish or gray and some beds are quite ferruginous. In some of these the iron ore cuts the face of the ledge or particular bed into a network of angular blocks as if filling a plexus of mud cracks. All the sandstones are fine grained and were without doubt deposited under very similar conditions. These beds being high in the series of this coal field, occupy the central portions of the synclinal basins and the regions of least disturbance in the northeast and northwest parts of the McAlester quadrangle. Under these conditions they lie in many places in nearly horizontal positions. By erosion the soft clays are removed from above and they come to cap elevated flat hills and mesas and form terrace-like benches around their slopes. Through parts of the field, then, these beds are well exposed for inspection. The hills in view from South McAlester, 1½ miles southwest, are capped by heavy sandstone beds in the lower part of the Boggy shale. Likewise the mesa-like hills 3 miles south of Savanna, and Kiowa hills, a long flat mesa southwest of Kiowa, are formed of sandstone near the middle of the Boggy shale. Sandstone beds in nearly the same position cap the level-crested hills in the northeast corner of the McAlester quadrangle.

The Thurman[1] *sandstone.*—This rock overlies the Boggy shale and has an exposure of about 200 feet within the McAlester quadrangle. The lower part, constituting 50 feet or more of strata, is a conglomerate composed of angular or little rounded chert fragments in a brown sandstone matrix. Brown sandstone and shaly beds occur above the conglomerate as far as exposed within the McAlester quadrangle. These beds occur in the flat-topped hills north of Coal Creek and in the tableland in the northwest corner of the McAlester quadrangle. They lie in a nearly horizontal position, and the conglomerate and sandstone form cliffs and steep slopes where they crop on the brinks of the hills.

The Guertie[2] *sand.*—At a period which appears to be recent in geological time an extensive deposit of gravel, sand, and silt was spread over a part of the McAlester coal field. The recent age of this deposit is inferred from the fact that the surface of the land has been changed but little since the time the gravel and sand were laid down. These gravels and sands are not cemented into hard rocks; instead, they are

[1] Shawnee on map (Pl. LXIV). Since the map was printed it has been found that the name "Shawnee" has already been used for another formation.

[2] Peaceable on map (Pl. LXIV). Since this text was written surveys have been carried further west, showing large areas of this sand around the town of Guertie, the name of which has been adopted for the formation.

incoherent deposits, and resemble recent river or lake sand plains. When the coarse gravel and sand are at the surface they are forest covered, but when they are silted over there is usually a prairie which blends imperceptibly with the general peneplain of the higher valleys. There are indications from its condition that the surface upon which the gravel and sand were deposited was a deserted river channel. The gravel, sand, and silt are spread out in a long and somewhat sinuous band 30 miles long and from 1 to 4 miles wide. Upon the north side especially this sand plain abuts against high lands. Beginning upon the west side of the McAlester quadrangle, these sand and gravel deposits are confined to the basin of Coal Creek. They extend to the high hills on the north and grade into the level plain which gradually rises on the south. From Coal Creek basin the sand plain bears eastward to the valley of Perryville Creek, along which it extends to Peaceable Creek valley east of the Missouri, Kansas and Texas Railway. The south side of this deposit coincides with Peaceable Creek valley, while the north side extends almost to the divide between Peaceable and Gaines creeks. From Peaceable Creek valley south of Alderson the sands bear northeast to the valley of Gaines Creek near the mouth of Brushy Creek, beyond which it has not been traced. One mile south of the mouth of Brushy Creek the borders of the elevated channel which contains the gravel may be seen where it crosses a high ridge. Brushy Creek has chosen this gap and now flows through its center.

The material of the gravel is all foreign to this region. It is composed of brown quartzitic sand, conglomerate, and various shades of red, white, and black quartz, jasper, and chert. The gravel occurs at the base of the deposit, but is not everywhere present there. It is generally most abundant near the center of the area that contains it. Near the border of the basin, and in many places above the coarser sand, a fine yellow sand or silt occurs, and this is found in wells to be stratified with layers of red and yellow clays. A well 30 feet deep, nearly 3 miles southeast of Barnet, exposed a thick deposit of yellow or bluish silt underlain by several feet of clean quicksand which was followed below by quartz gravel and sand.

This sand is a source of good water, but it conceals the outcrop of workable coal, especially between Alderson and Brushy Creek, where the deposit of sand and silt attains considerable thickness.

GEOLOGY OF THE LEHIGH DISTRICT.

The map of the Lehigh district (Pl. LXV) was drawn from township plats before the office drafts of the Atoka and Coalgate quadrangles, of which it is part, were made. This being the case much of the desired detail of culture was omitted.

The geology of the Lehigh district is directly connected with that of the McAlester district through the range of hills that extend from the southeast corner of the latter district along the northeast side of the former. The formations and beds of rock as they occur in the Lehigh district differ in lithologic character and thickness from the same rocks in the McAlester district to such a degree that they are discussed separately. The coal also is of different character and, so far as known, is not the same as that occurring in the McAlester area.

The Hartshorne sandstone.—This sandstone is in the valley of North Boggy Creek and is not exposed at the border of the McAlester and Lehigh districts. The outcrop of the sandstone forms a ridge which extends nearly southwest along the western border of North Boggy Creek valley and to the valley of Muddy Boggy Creek. Throughout this course the rocks dip very steeply toward the northwest. From Muddy Boggy Creek valley southwest and around the south side of the Lehigh Basin the dips gradually change from 80° to as low as 5°. For 6 miles southwestward from the east side of the Lehigh district, across T. 1 N., R. 12 E., the rock is a brownish fine sandstone. From T. 1 N., R. 12 E., southwestward the sandstone changes to a breccia of chert fragments in brown sandstone matrix and continues so to the south side of the Lehigh Basin, where the breccia is gradually changed to a fine brown sandstone.

The McAlester shale.—Toward the southeast this shale appears to decrease in thickness and at the same time to become more sandy. In the McAlester district the sandstone beds in this shale are variable in thickness and for the most part shaly. As the outcrop of these beds is traced southward to the east side of the Lehigh Basin the sandstones become more prominent in exposure and at the same time cherty to the extent of becoming chert breccia or conglomerate. As was the case with the Hartshorne sandstone, the element of chert in these sandstones decreases toward the south side of the Lehigh Basin and finally disappears. There are four, and in some places probably more, cherty sandstone beds in this shale in the east side of the Lehigh Basin. There are but two sandstone beds of importance in the McAlester shale on the west side of the basin, and they occur in the lower half of the formation.

There are two workable coal beds in the McAlester shale in this district, one near the base and one in the upper part; but there are no means yet ascertained to determine whether or not they are the same as the Hartshorne and McAlester coals, respectively.

The Savanna sandstone.—The lithologic variation of the Savanna sandstone through the Lehigh district is similar to that of the sandstones which have been described. These sandstones become chert breccias throughout the east side of the Lehigh Basin. Toward the southeast side of this basin the amount of chert grows less, and disappears before the west side of the basin is reached.

The Boggy shale.—A circular area in the central part of the Lehigh Basin, a small area on the northeast side, and a larger one on the northwest side of the district contain the Boggy shale. Except in the

Lehigh Basin the rocks of this series are practically the same in character as in the McAlester district. They are shales and sandy shales with numerous thin sandstones of practically the same quality, texture, and color. No coal of any importance has been found in these rocks in the Lehigh district. In the Lehigh Basin the sandstones which occur in the shale appear to be more numerous and thicker than elsewhere in the district. They are composed in large measure of angular chert fragments of small size cemented together in a sand of reddish-brown ferruginous quartz.

The chert material entering into the breccias and sandstones through the section of several thousand feet in the Lehigh Basin is of the same character. It is angular white chert, the fragments of which vary in size from minute particles to pebbles an inch in diameter. All of such material is angular or very slightly rounded.

It may be noted that the chert breccias and cherty sandstones in the Lehigh Basin do not extend over a distance north and south of more than 12 miles and east and west of more than 6 miles, while the vertical range is through a section of nearly 3,000 feet of strata. An interesting feature in connection with the occurrence and the origin of this chert material is the location of a ridge of chert exposing strata 800 feet thick, whose beds dip at angles of 60° to 80° toward the east, situated 3 miles east of the Lehigh Basin. The north end of the outcrop of the chert in this ridge is opposite the north limit of the chert which occurs in the Coal Measures in the Lehigh Basin. The south end of the chert ridge passes under Cretaceous strata opposite the south end of the Lehigh Basin. The degraded chert in the chert ridge can not easily be distinguished from the weathered chert in the sandstone of the Coal Measures.

STRUCTURE.

General relations.—At the eastern border of the McAlester quadrangle the general strike of the rocks is east and west. This structure continues eastward to the Arkansas line, as shown by Dr. Chance, who examined these rocks and reported upon them in 1890. In Arkansas the same general strike of the rocks prevails from the Arkansas line down the Arkansas River Valley to the Tertiary overlap of the Mississippi embayment, both in the Upper and Lower Coal Measures, as shown by the work of the Arkansas Geological Survey. From the eastern border of the McAlester quadrangle westward the strike of the rocks, as shown in Pl. LXVI, changes from west to southwest and then south to the Cretaceous border near Atoka, Indian Territory.

From the Chickasaw Nation eastward these rocks have the same general structure, which is that of wide canoe-shaped synclines lapping upon narrow, compressed, and often slightly overturned anticlines. This is also the typical structural character of the Northern Appalachian region. Like the structure in the Appalachian region, again, the folding here becomes less intense toward the north and west, nearer the interior of the coal field. The belt of folded coal-bearing strata varies from 10 to 15 miles in width. North and west of this folded belt the rocks are somewhat crumpled, but maintain a slight downward grade toward the north and west. The structure sections and accompanying map (Pl. LXIV) will illustrate the essential features of the rocks of this coal field.

The Kiowa syncline.—The Hartshorne sandstone is at the base of the Productive Coal Measures of this coal field. South of Hartshorne this sandstone is a ridge maker and is usually exposed at its crop, where it dips to the north at about 30°. The dip decreases northward, and is horizontal at the center of the basin, 3 miles distant, where the sandstone lies not more than 600 feet beneath the surface. At Gowen, 3 miles still farther north, it comes up on the north side of the basin, forming a prominent ridge. From Hartshorne it strikes westward and then southwestward to the limits of the quadrangle, with dips varying from 40° to 80° toward the north and northwest. From Gowen, on the north limb of the syncline, the rocks bear a little north of west to the vicinity of Alderson, where they turn toward the north and pass across the axis of the McAlester anticline. The axis of this syncline, as in a typical canoe basin, pitches abruptly westward at the east end, northeast of Hartshorne, for a short space, and then becomes nearly horizontal north of Hartshorne. Sandstones which cap the flat-topped mesa of Belle Starr Mountain appear at the same elevation in the ridge northwest of Hartshorne, pitching 6° toward the west. From the vicinity of Hartshorne southwest this syncline becomes rapidly broader and deeper for 6 to 8 miles, and then grows narrower, with a gradually rising axis to the vicinity of Kiowa. Opposite Kiowa this synclinal basin is about 4 miles wide. From Kiowa toward the southwest the basin grows gradually broader to the limit of the McAlester quadrangle, where it divides into two synclines separated by a peculiar anticline; one of these extends nearly due south, ending in the Lehigh Basin, while the other bears southwestward into the southern part of the Coalgate quadrangle, where it becomes broad and flat.

The contraction of the Kiowa syncline near Kiowa appears to be due to a northwestward movement of the strata from the south side of the basin. The northwestward overthrust of the older rocks southeast of Kiowa corresponds in strike and movement with those of the coal-bearing beds on the south side of Kiowa basin.

The McAlester anticline.—The axis of the McAlester anticline enters the quadrangle upon the east side, in the valley of Gaines Creek, and bears very nearly west for 10 miles, where, at a point between Alderson and Cherryvale, it divides into two folds. One of these divisions of the fold bears southwest by way of Savanna to and beyond the border of the quadrangle. This south division of the anticline is called the Savanna anticline. The other, a more direct continuation of the main fold, bears northwest from Cherryvale for nearly 3 miles and then west to McAlester, where it curves southwest and passes the limits of the quadrangle parallel with the Savanna anticline.

The strata involved in the McAlester anticline from the eastern border of the quadrangle to Cherryvale have been thrust over toward the north, so that the beds upon the north side are on edge in places. At other places, especially south of Cherryvale, the Hartshorne sandstone has been overturned and, it is believed, faulted.

Through its course from Cherryvale eastward the axis of the anticline is almost horizontal. From Cherryvale westward it pitches downward rather abruptly at from 16° to 20°. The Krebs syncline crosses the McAlester arch east of Krebs and depresses it as well as deflects it northward. North of Krebs, however, the McAlester arch regains its normal condition as an unsymmetrical fold, and continues westward, with nearly horizontal axis, to a point about 6 miles southwest of McAlester, where it pitches rapidly for a short space, then becomes a low, wide symmetrical arch, and as such continues to the western limit of the McAlester quadrangle. Upon the south limb of the McAlester anticline, near the axis, the rocks dip usually from 10° to 25°, while upon the north limb, except where the arch is low, and near the western border of the quadrangle, they dip from about 30° to 90°, and in a few places, as noted, are overturned and faulted, dipping southward nearly 90°.

The Savanna anticline.—This fold joins the McAlester anticline about 2 miles east of Krebs, and thence bears almost due southwest to the western border of the quadrangle. In the northeastern part of its course it is not a well-defined fold. It is little more than a southwestward pitching swell upon the southern limb of the McAlester anticline. South of Krebs the ill-defined axis of this fold pitches southwest probably 10°, and south of McAlester it begins to rise. South of Savanna this axis rises rather abruptly at an angle of nearly 20°. From Savanna it continues southwestward almost level to a point northwest of Kiowa, where it begins to pitch downward, and so continues beyond the limit of the McAlester quadrangle.

Northeast from Savanna the rocks dip gradually away toward the northwest and southeast from the axis of the fold. South and southwest of Savanna the fold near the axis becomes sharply contracted and elevated, so that the rocks dip northwest 40° to 60° and southeast 55° to 90°. This fold between Savanna and Kiowa may be compared to an inverted and narrowly contracted canoe. The south side of this inverted canoe is so crushed near the northeast end that the rocks are vertical, while at the end near by the dip will not exceed 20°. The same is true near the southeast end, northwest of Kiowa, except that there has been greater compression upon the northwest side of the fold.

The Krebs syncline.—Southwestward from the vicinity of South McAlester, for a distance of nearly 10 miles, the Krebs syncline is a normal canoe basin. Upon the sides and end of the canoe the rocks dip nearly equally—about 15°. Upon the southern side of the syncline farther southwest, opposite Savanna, the dips increase to 45°, and from Savanna to the western border of the quadrangle this dip is generally maintained, though it is in places greater. From the southeast side of this basin the dip decreases rapidly toward the northwest from 45° to 10° within the space of a mile. For a wide space the rocks in the central part of this basin are nearly horizontal, and upon the north side of the basin, near the west side of the quadrangle, the beds rise gradually upon the low arch of the McAlester anticline.

The syncline from Krebs eastward across the McAlester anticline can not be easily defined. It is shallow and rises with a gradual upward incline to the axis of the McAlester anticline. From the same point on the McAlester anticline this syncline pitches at a low angle downward toward the east. Northeast of Cherryvale the axis bears northeastward and then east, crossing the side of the quadrangle about 2 miles south of the northeast corner. As is the case in the vicinity of Savanna, the rocks here in the south side of the basin dip steeply toward the north over about 1 mile, and then for a wide space the rocks are nearly horizontal. From the center of the basin northeast of Cherryvale the rocks rise at a low angle to the limit of the quadrangle.

Minor folding north of the McAlester anticline.—Nearly due north of Krebs a narrow and short anticlinal fold extends eastward from the McAlester anticline. Upon the north side the rocks are steeply upturned, while upon the south side the dips are very low. This local anticline is a well-defined structural feature for more than 3 miles from the McAlester anticline. The rocks upon the north side dip at continually lower angles as they are followed eastward. Upon the south side they become horizontal near the axis for 3 or 4 miles, where the anticline becomes simply a swell upon the northern limb of the Krebs syncline and is lost as a structural feature.

An ill-defined shallow basin occurs north of the McAlester anticline west and northwest of McAlester. The axis of this basin lies 2½ to 3 miles north of the McAlester anticlinal axis and is nearly parallel with it. North of the town of McAlester this basin takes a more northerly turn and passes beyond the limits of the quadrangle. Within 6 miles of the western border of the quadrangle the northern limb of this syncline is nearly horizontal, and further west the fold loses character as a structural feature, becoming simply a wide and very shallow depression upon the northern limb of the McAlester anticline.

Local folding near Hartshorne.—From Hartshorne southwestward for nearly 6 miles the Hartshorne sandstone, with shale, minor sandstone beds, and coal overlying it, is crumpled in an unusual manner. This structure is upon the southern limb of the Kiowa syncline. South and west of Hartshorne the Hartshorne sandstone dips north at 15° to 25°.

One-half mile southwest of Hartshorne this sandstone strikes almost due north for nearly 1 mile with dips toward the east, then west for nearly a mile with dips toward the north, and then south nearly a mile with dips toward the west, where it takes a southwest bearing with steep dip toward the northwest. Thus a short and almost square anticlinal fold is indicated with axial trend almost perpendicular to the general structure of the Kiowa syncline. Six miles southwest of Hartshorne the same sandstone turns in strike from southwest to almost directly northwest, and continues for half a mile with dips toward the northeast. At this point it turns in strike nearly 90° and bears again southwest. Rocks which lie 600 to 1,200 feet above the Hartshorne sandstone show in their outcrop a local syncline and anticline, one lying above the other upon the south limb of the Kiowa syncline, between the structures noted one-half mile and 6 miles, respectively, southwest of Hartshorne. The axes of these folds are parallel with the trend of the Kiowa syncline.

The cause of this buckling of the Hartshorne sandstone and associated rocks may be suggested by the location of the structures in the obtuse angle at the junction of the major east-west and northeast-southwest trends of folding in this district.

Faults and shear zones.—The faulting in this coal field is of minor importance and local extent. The sandstone beds, which are exposed in ridges, curve back and forth across the field, so that faults of much magnitude may be easily detected. A fault that may be called the Cherryvale fault occurs on the north limb of the McAlester anticline with strike parallel to the folding. Its location could not be determined with precision, but it occurs between the mines in Cherryvale and the crest of the ridge about one-fourth of a mile south of the town. The fault is an overthrust from the south. It is believed to extend not far from Cherryvale toward the east, and but a few miles toward the west.

Local faulting occurs in the sandstone ridge in the town of South McAlester, as may be seen in the railroad cut north of the station. It is of small extent and does not displace the sandstone which forms the ridge to more than barely appreciable extent.

In the vicinity of Kiowa, where the beds in the south side of the Kiowa basin have been deflected toward the northwest, the sandstone beds have been broken by cross faults or zones of shearing in a number of places. This structure is especially prominent in the limestone ridge, below the coal-bearing beds, immediately south of Kiowa, where it has been thrust strongly over toward the northwest. Near the south side of section 25, T. 3 N., R. 13 E., the Hartshorne sandstone is broken and displaced laterally 200 feet. The sandstone on the east side is thrust toward the north with respect to the sandstone on the west side. This sandstone is inclosed in several hundred feet of shale, so that it is not possible to trace the displacement farther than the limit of the sandstone. Near the middle of section 3 and the north side of section

10, T. 2 N., R. 13 E., other shear zones or cross faults occur in the Hartshorne sandstone. In the first instance the sandstone on the southwest side of the break is thrust northward and overturned, while that on the other side remains with normal northwest dip. In section 10 the displacement is in the opposite direction.

These features of structure are not of great importance of themselves, but a knowledge of their occurrence and character will be of much value to the prospector and miner who operate coal in their vicinity.

The Lehigh basin.—This basin is a southern prolongation, in part, of the Kiowa syncline. It is broad and deep in the central part, opposite Lehigh, and much contracted and elevated at the north end, where it joins the Kiowa syncline. The contraction at the north end is due to the eastward bearing and enlargement of the Coalgate anticline at its north end. The Lehigh basin in surface outline is elliptical. It is relatively deep and its axis lies near its eastern side. The Savanna sandstone series and other associated beds which outcrop on the east side of this basin are upturned until they are almost vertical. Along their outcrop they form a prominent ridge. As they extend around the south end of the basin, west of Atoka, these beds separate in outcrop as the dips become less, and the thick sandstone strata form low ridges which curve, one after the other, in gradually widening lines. From the vicinity of Lehigh on the west side for a distance of 6 miles inward toward the axis the beds dip about 4°. Beyond this the rocks increase in dip to nearly 10° toward the center of the basin. It will be seen by this description and by reference to the section and map that the Lehigh basin is structurally unsymmetrical. Extensive westward overthrusting and faulting of the beds lying beneath the coal-bearing strata, between Limestone Gap and Atoka, immediately east of the Lehigh basin, have pressed the coal-bearing rocks westward and upward, while the same beds on the west side of the basin have been but little disturbed. The basin is canoe-shaped, its axis rising at both the north and the south end.

The Coalgate anticline.—This anticline is a peculiar structural feature. From Coalgate southwestward this fold is broad and very obtuse. The strata below the Lehigh coal bear westward around the south end of the Lehigh basin and then northward toward Coalgate. Southwest of Coalgate these beds curve gradually westward and then southwestward into the swamps of Clear Boggy Creek. The Lehigh coal bed in its outcrop emphasizes the character of this anticlinal structure more strongly. From Lehigh the strike of the coal bears nearly due north, with low east dip to Coalgate, where it turns abruptly southwestward. One mile northeast of Coalgate this coal rises and is exposed for nearly 8 miles in an elongated dome bearing northeastward. The Lehigh coal and the sandstones and shales for several hundred feet above the coal dip 10° to 15° from the axis of this dome. From a point about 7 miles northeast of Coalgate the rocks upon the axis of the Coalgate anticline pitch rapidly northeastward. This pitch gradually grows less until the anticline is lost as a structural feature in the center of the Kiowa syncline near the west end of the Kiowa Hills, southwest of Kiowa.

Three to five miles northwest of the axis of the Coalgate anticline there is a parallel shallow syncline whose axis is nearly parallel to that of the Coalgate. The axis of this syncline rises toward the northeast and the syncline dies out or coalesces with the Kiowa syncline opposite the northeast end of the Coalgate anticline.

DISTRIBUTION OF COAL.

The separation of this coal field into two districts, viz, the McAlester and the Lehigh districts, is made for the following three reasons: (1) The two coal-mining districts are separately and independently developed; (2) it has not been possible to trace the beds of coal from one district to the other, on account of the excessive disturbance which the rocks have suffered, causing the beds to be thrown almost upon edge, and on account of the erosion which has worn these beds down and concealed them in much of the territory; (3) the McAlester district is confined to the McAlester quadrangle, which was mapped separately from that of the Lehigh district, which is in the Atoka and Coalgate quadrangles.

Fossil plants were collected from the shales associated with the coal beds in the McAlester district, but the shales of the Lehigh field failed to afford fossils sufficient to determine the relative age of the coals. Over a very large part of the McAlester-Lehigh coal field the workable beds of coal have not been prospected, nor have their thickness or quality been determined. Prospecting and developing coal belongs to the province of the prospector and miner; the geologist can do no more than locate the outcrop of the coal, indicate its position and extent beneath the surface, and test its quality.

COALS OF THE M'ALESTER DISTRICT.

Two productive coal beds have been found in the rocks of the McAlester district, separated by shale and sandstone 1,300 feet thick. The Hartshorne coal is at the base of the McAlester shale series, and the McAlester coal is 700 feet below the top. Since these coal beds have different areas in part, and occur under somewhat different conditions of structure, it is convenient to discuss them separately.

THE HARTSHORNE OR GRADY COAL.

The Hartshorne coal lies above the Hartshorne sandstone and is separated from it by a few feet of shale. The accompanying section, fig. 78, which is a part of the section obtained in drill hole No. 7, in the SE. $\frac{1}{4}$ of sec. 32, T. 5 N., R. 17 E., will show the details of coal and associated shale in the Hartshorne basin, where the coal has been thoroughly prospected by the drill and where it is now extensively mined.

In the Hartshorne or Grady basin.—The coal in this basin is situated most advantageously for mining. This basin is the depressed eastern end of the Kiowa syncline, and is comparatively wide and flat. The Hartshorne mine is situated upon the south side of the basin, and the mines east of Gowen are upon the north side. The east end of the basin brings the coal to the surface about 2 miles east of the McAlester quadrangle. In the center of the basin, north of Hartshorne, the coal is nearly 600 feet beneath the surface. The central part of the basin is quite flat, affording easy hauling of coal to the shafts of the mines. Fig. 79 illustrates a section across the Hartshorne basin.

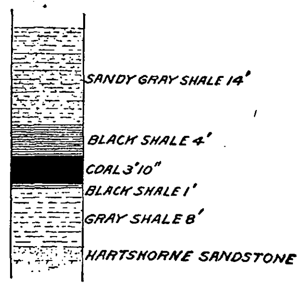

FIG. 78.—Section of coal and associated shale in the Hartshorne Basin.

The workable area of Hartshorne coal in this basin at a depth of less than 1,000 feet beneath the surface is nearly 15 square miles, or 9,600 acres. Immediately southeast of the Hartshorne basin this coal increases in dip from about 20° to nearly 90°, and for nearly 5 miles farther southwest the coal is almost on edge. The Hartshorne coal varies in thickness from a thin band to 8 feet. The average and usual thickness is about 4 feet.

In the Kiowa syncline.—In the Kiowa syncline or basin, of which the Hartshorne may be considered a part, the rocks extend from the Hartshorne basin southwestward to the Lehigh district. The Hartshorne coal in this basin is beyond the depth of present mining possibilities, except upon the south border near the outcrop. This coal from the vicinity of Hartshorne southwestward upon the south side of the

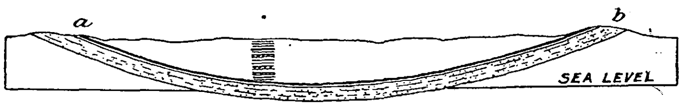

FIG. 79.—Section across the Hartshorne Basin. *a*, Hartshorne coal; *b*, Hartshorne sandstone.

basin has been prospected in but few places, and its thickness or quality has not been determined. The outcrop of the coal may be determined approximately by reference to the map. The coal, here as elsewhere, occurs above the Hartshorne sandstone and is separated from it by a short interval of shale. Along the outcrop the coal dips toward the northwest at angles varying from 40° to 90°. From Brushy Creek west through most of the distance the dip is but little more than 40°. Where the Hartshorne sandstone crops out the dip of the coal may be determined from that of the sandstone.

If the coal were followed downward from the surface toward the axis or center of the basin the dip would be found to decrease gradually. Along the center of the basin southwest of Peaceable Creek the Hartshorne coal is estimated to be nearly 3,500 feet beneath the surface.

The area of Hartshorne coal in the Kiowa basin is about 200 square miles. This can not be economically mined, however, except to a limited depth, and that by slope from the outcrop upon the bed of coal. The depth to which the coal may be mined will depend upon the amount of water in the mine, the structure of the coal, and other conditions that can not be determined at the outset in steep slopes. A fair estimate of the workable Hartshorne coal in the south side of the Kiowa basin is 15 square miles.

On the McAlester anticline.—Especially upon the south side of the McAlester arch, the Hartshorne coal is more advantageously situated for mining. As has been explained in the consideration of structure, this arch or anticlinal fold, from the eastern limit of the McAlester quadrangle to the vicinity of Krebs, is not symmetrical, but is overturned toward the north. Upon the south side of the arch the coal dips toward the south at about 20°, while on the north side the dips vary from 40° to 90°, and the beds are, in part, faulted.

Coal could be mined successfully between Gowen and mine No. 12, 2 miles east of Krebs. This coal is about 1,300 feet beneath the McAlester coal at Krebs, where the dips are slight and toward the west. It is at a depth of nearly 1,300 feet beneath the surface at Alderson and at mine No. 9 on Brushy Creek, near the south side of sec. 29, T. 5 N., R. 16 E. South of the outcrop of the coal from mine No. 12, near the center of sec. 12, T. 6 N., R. 15 E., 3 miles eastward, the rocks dip nearly 20°, until a depth of more than 3,000 feet is reached. Then the dips become lower as the axis of the Kiowa basin is approached. In the valley of Brushy Creek, however, from the outcrop west of Gowen the dip of the coal decreases and gradually changes from south to west, and beneath mine No. 9 it is nearly 6° west.

A superficial deposit of sand conceals the outcrop of the Hartshorne coal over a large part of its course between the vicinity of Alderson and Brushy Creek. The outcrop, however, lies at the south base of the sandstone ridge through its extent from Gowen nearly to mine No. 12. Upon the north side of this arch, from the vicinity of Cherryvale eastward to the border of the McAlester quadrangle, the coal will be mined under difficulties similar to those encountered on the south side of the Kiowa basin. The coal dips at a very steep angle and is probably faulted in the vicinity of Cherryvale. No attempt to prospect or exploit this coal east of Cherryvale is known. The area of Hartshorne coal that may be mined upon the McAlester arch is estimated at not less than 20 square miles.

On the Savanna anticline.—But little is known of the Hartshorne coal in this fold. The portion that would bring the Hartshorne coal to the surface extends from a point 1 mile south of Savanna to 2 miles northwest of Kiowa. The rocks of this arch are so closely compressed that the Hartshorne sandstone and coal, if it occurs, dips away from the axis at angles of 45° to 90°. If this coal has its usual thickness of nearly 4 feet it may be mined with the same success, doubtless, as the McAlester coal at the Fairview mine, on the Missouri, Kansas and Texas Railroad, 3 miles southwest of Savanna, where the same structural conditions exist.

Where the rocks pitch downward on the axis of the arch 1 mile south of Savanna the Hartshorne sandstone dips about 15° in the same direction. At this point and 2 miles northwest of Kiowa, where the fold pitches at about the same rate toward the southwest, mining operations may be successfully carried on if the coal is found to be valuable. If the coal occurs in workable thickness upon the Savanna arch, the area that may be mined economically will not exceed 6 square miles.

In conclusion, it appears that there are not more than 58 square miles of the Hartshorne coal in the McAlester district that may be worked by the most improved machinery and by methods best adapted to the conditions of mining in folded strata.

THE M'ALESTER COAL.

The McAlester coal is in the McAlester shale nearly 700 feet below its top. It is separated from a sandstone which is below by an interval of shaly beds estimated at about 50 feet thick. It is believed that this shaly interval varies in thickness and that the shale and coal are separated in places by only a few feet of fire clay and shaly sandstone. The accompanying section, fig. 80, will illustrate the position of the McAlester coal and the McAlester shale above it.

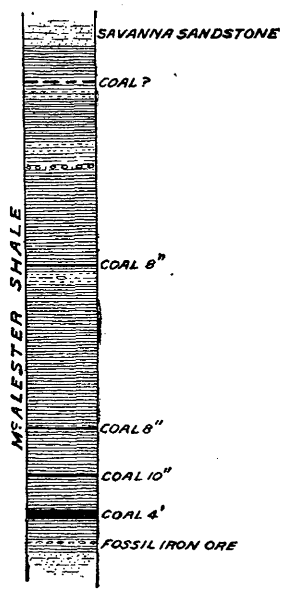

FIG. 80.—Section of McAlester coal and shale at mine No. 5 (Krebs).

This coal is 3 feet to 4 feet 1 inch thick. In so far as known, it generally grows thinner toward the east. At McAlester it is 4 feet; at Krebs mine No. 5 it is 4 feet 1 inch; in Cherryvale mines it is 3 feet 6 inches, and at mine No. 9 on Brushy Creek it is 3 feet thick, while at Fairview mine, near Savanna, it has a thickness of 3 feet 8 inches. The bed is solid coal except in rare instances, where a thin bony layer or pyrites concretions occur. Where the coal is thinner than 4 feet, in the mines so far developed, there is usually a bony coal at the top which, with the workable coal, makes approximately 4 feet.

The McAlester coal is highly bituminous, as is shown by the table of analyses. The slack coal from the Krebs and Alderson mines and others in the vicinity is coked near Krebs and at Alderson. This coal produces a lustrous and rather finely porous coke.

On the McAlester arch.—Coal is well situated for mining on the McAlester arch, especially on the south side. The anticlinal arch, by pitching westward, carries the coal beneath the surface a few miles west of McAlester. East from McAlester, by the rising of the arch and by the great amount of erosion which has worn the rocks down, the outcrop of the coal on the north side diverges from that on the south side. The outcrop on the south side bears southeastward through Krebs and Alderson to mine No. 9 on Brushy Creek, where it turns south and southwest upon the south side of the Kiowa basin. The crop of this coal upon the north side of the arch bears eastward from McAlester for 6 miles, where it turns toward the south and west and approaches within 2 miles of Krebs. From this point it curves south for a short space and then bears east to the border of the McAlester quadrangle by way of Cherryvale. Upon the south side of the arch in the vicinity of McAlester the coal dips south at 20° to 29°. Eastward the dips grow less until in the region of Krebs they are 6° to 10° toward the west and southwest. From Krebs to Alderson the dips are toward the southwest and south and increase to nearly 20°. Eastward from Alderson they grow less until at mine No. 9 the dip is west about 6°. Throughout this course the McAlester coal may be mined probably for a mile or more from the outcrop. These conditions are well understood, as the extensive mining operations at McAlester, Krebs, and Alderson will attest.

Upon the north side of the arch, from the vicinity of McAlester eastward 6 miles, the coal dips north from the surface 60° to 80°. This coal will not be worked profitably until the more advantageous ground upon the south side of the arch has been exhausted. North of Cherryvale, as the coal crop turns toward the south and southwest, the dips become low. At Cherryvale the dip is about 16° north, and eastward from Cherryvale the dip increases until it is about 25° at the eastern border of the McAlester quadrangle.

The shallow basin north from Cherryvale, which has an area of nearly 2 square miles, is the most valuable field of this extent upon the north side of the McAlester arch. The axis or trend of this small basin bears nearly east and west, and pitches at a low angle toward the east. North of Cherryvale the coal at the center of this basin is not more than a few hundred feet beneath the surface. Northward from the outcrop of the McAlester coal, east of Cherryvale, the dips grow rapidly less, until at a depth of about 700 feet they are not greater than 10°.

The area of this coal that may be mined from the crop to a depth of 1,000 feet, on the McAlester arch, is about 35 square miles.

In the Kiowa syncline.—The conditions of structure under which the McAlester coal occurs are very nearly the same as those attending the appearance of the Hartshorne coal in this basin. The McAlester coal outcrops above and nearly parallel with that of the Hartshorne.

It dips toward the northwest at various angles, ranging from 40° to 60°, and generally above the average of these extremes. It is not known whether or not the coal is continuous through the southeast side of this basin. The high dip of the rocks and the generally obscure surface exposures have deterred the prospector and miner from making any serious attempt to develop the coal.

The area of the McAlester coal that may be worked under the most favorable conditions in the south side of this basin is nearly 15 square miles.

In the Krebs basin.—Except at the northeast end, bordering the McAlester arch, which has already been described, and on the sharp fold of the Savanna arch, which will be described below, the McAlester coal is so far beneath the surface in the Krebs basin that the question of its being mined in the near future need not be discussed. At South McAlester and along the Missouri, Kansas and Texas Railroad from this town nearly to Savanna the McAlester coal is at a depth of 1,500 to 1,800 feet. From South McAlester southwest along the axis or center of the basin the coal gradually grows deeper until the limits of this coal field are passed.

On the Savanna arch.—There is a small area of McAlester coal on the Savanna arch available for mining, and its favorable location along the Missouri, Kansas and Texas Railroad gives it additional importance. The coal occurs here as in the south side of the Kiowa basin, almost parallel with the Hartshorne coal and sandstone. It lies above the Hartshorne sandstone and is separated from it, as usual, by about 1,300 feet of shale and sandstone. In the mine near Savanna this coal dips northwest nearly 55°. In the mines at Johnstown and Fairview, 2 and 4 miles, respectively, southwest of Savanna, it dips 48°. East of Savanna the dips become lower as the outcrop passes across the arch, where it pitches toward the northeast. As the crop approaches the southeast side of the arch, southeast of Savanna, the rocks are broken and the dips become very steep, and from this locality southwest along the arch the coal continues dipping steeply toward the southeast. The area of coal now workable on the Savanna arch is about 10 square miles.

The total area of McAlester coal that may be worked in this district is about 60 square miles.

OTHER COALS OF THE M'ALESTER DISTRICT.

The other coals of the district have not been found to be economically workable. Not less than four thin coal seams occur in the lower division of the McAlester shale, which is exposed in the Hartshorne basin, but they are either too thin to be worked or contain thin shales interstratified with the coal. Similar thin coal beds occur in the upper part of the McAlester shale, but none have been found of workable thickness. Another coal bed, 2 feet 6 inches thick, was reported by Dr. H. M. Chance to occur about 2,000 feet above the McAlester coal in the Boggy shale. It crops in the valley about 1 mile south of South McAlester, west of the Missouri, Kansas and Texas Railroad, where it was mined from slopes, but was not found profitable, and the mines were abandoned.

COALS OF THE LEHIGH DISTRICT.

Two beds of coal occur in the Lehigh district which are known to be of workable value, but only one of these, the Lehigh coal, is exploited on a commercial scale. The other coal bed, which is below the Lehigh coal, has been prospected, but has not been mined, although its reported thickness and quality indicate a valuable deposit.

THE LEHIGH COAL.

The Lehigh coal is the highest known bed of coal in the Lehigh district. It occurs in the section here near the position occupied by the McAlester coal in the same series of the McAlester district, yet it has not been possible to determine whether or not the coals are the same. The roof of the McAlester coal is a dark blue shale with an abundant fossil flora. The shale above the Lehigh coal is of similar physical character, but contains a numerous fossil fauna, composed principally of fresh or brackish water shells. Fossil plants could not be found in sufficient numbers to compare the Lehigh coal, stratigraphically, with any other known horizon. The difficulty in tracing individual beds of rock from one district to the other has been pointed out in the discussion of structure and stratigraphy. In the vicinities of Lehigh and Coalgate the crop of the Lehigh coal bed has been located by the prospector and the coal has been stripped from its surface exposure over much of its course. From Lehigh the crop of the coal bears south and then east around the south end of the Lehigh basin. As it approaches Boggy Creek, bearing northeast from the south end of the basin, the dip increases from 10° to nearly 60°. Along the east side of the basin the rocks at the horizon of this coal dip at 60° to 65°. From Coalgate the outcrop of the coal bears southwest by "Dead Horse" mine to the swamp of Clear Boggy Creek. From mine No. 5, 1 mile northeast of Coalgate, the crop of the Lehigh coal continues northeast over a distance of 7 miles, surrounding a long-oval dome in the Coalgate anticline. At the center of this dome, in the valley of Coal Creek, T. 3 N., R. 11 E., the outcrop of the coal on each side of the dome is separated about 2 miles. The coal dips away from this dome 10° to 25°. The thickness of the Lehigh coal is about 4 feet.

The area of this coal that may be mined in this district to a depth of 1,000 feet vertically beneath the surface is approximately 35 square miles.

OTHER COALS OF THE LEHIGH DISTRICT.

A coal bed of workable thickness occurs nearly 1,200 feet beneath the Lehigh coal. It is separated from a thick sandstone bed below by a thin shale interval, as is the case with the Hartshorne coal in the McAlester district. It is believed that this coal occupies a position in the section in this district nearly related to that of the Hartshorne coal in the McAlester district, but it can not be traced satisfactorily from one district to the other. It has been prospected at a number of points from 1 mile west of Atoka to the west side of the Lehigh basin, 4 miles southwest of Lehigh, and it has been mined at a number of places by stripping at the outcrop. The full thickness of this coal was not exposed, but is reported by reputable operators to be of workable thickness and fair quality. From the south end of the Lehigh basin the crop of this coal bed bears northwest to the axis of the Coalgate anticline, a structure which is merely suggested by a wide curve produced by the outcrop of the coal and associated beds as they turn westward toward Clear Boggy Creek west of Coalgate. At the south end of the Lehigh basin, near the Coalgate branch of the Missouri, Kansas and Texas Railroad, the coal dips northwest about 30°. As the crop of the coal passes westward the dip changes rapidly to 10° and then to near 5°, which is maintained along the west side of the basin.

The area of this coal which may be worked to a depth of 1,000 feet in the Lehigh district is approximately 25 square miles.

COMPOSITION OF COALS.

The best means of determining the value of coal for practical purposes, beyond the tests given by its physical properties, is by proximate chemical analysis. It must be borne in mind, however, that such a chemical analysis is an insufficient basis for a complete estimate of the value of coal. A proximate analysis will determine its grade in the anthracite or bituminous series of coals and will establish its fuel ratio, but it will not determine whether it will produce a merchantable coke, or the class of domestic or steaming uses to which it is best adapted. These latter adaptabilities will require to be ascertained by practical tests.

The coals of the McAlester-Lehigh field are all highly bituminous, as may be seen by a comparison of their percentages of volatile combustible matter and fixed carbon. The volatile matter in no instance is less than 37 per cent, and the fixed carbon will average about 52 per cent. The amount of moisture is remarkably low, averaging about 2 per cent. Except in the case of the Lehigh coal, the amounts of sulphur and ash are not excessive.

The Hartshorne coal is relatively hard for highly bituminous coal. When properly mined it breaks into cubical blocks of considerable size and is successfully shipped. The amount of slack or waste coal is small. It is a desirable steaming and domestic coal and produces a finely porous commercial coke of good grade.

The McAlester coal, as shown by the analysis, is higher in grade than the Hartshorne coal, containing less sulphur and a little less ash, although the Hartshorne coal is preferred for steaming purposes. In physical properties there is but little difference in these coals. The McAlester coal is probably a little softer, producing more slack in mining, although it is shipped with ease. It produces an excellent coke.

The slack and, it may be, the run-of-mine from the mines in the Krebs region are coked on an extensive scale for commercial purposes both at Krebs and at Alderson. The McAlester coal, which is mined at Savanna and Fairview, appears to be the same in physical character and in quality as that mined at McAlester, Krebs, Alderson, and Cherryvale in the northern part of the field.

The Lehigh coal, which is mined at Lehigh and Coalgate, differs in composition and in quality both from the Hartshorne and the McAlester coals. It is lower in specific gravity and is more fissile and friable. Chemically it is high in sulphur and ash and contains more water than the other two coals. In spite of its lower grade, however, it is mined commercially in the Lehigh-Coalgate region on an extensive scale.

The analyses of coals in the following table were made by Dr. W. F. Hillebrand, of the United States Geological Survey, from collections made by the writer. All of the samples were taken from the commercial product at the mine ready for shipment. Many specimens were collected from loaded cars or from the tipple. These were then broken and mixed and a parcel was taken for analysis:

Table of proximate chemical analyses of coals.

Name of coal bed.	Location of mine.	Moisture in vacuo over H_2SO_4, 20 to 24 hours.	Volatile combustible matter, less moisture in vacuo.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Character of coke.	Color of ash.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
Hartshorne	Shaft No. 1, Hartshorne.	1.68	41.00	51.91	5.41	2.72	0.012	Lustrous, with dull-black patches; not swollen.	Reddish brown.
Do.....	Hughes's mine, 2 miles east of Krebs.	1.04	37.96	55.84	5.16	2.00	0.012	Dull; slightly swollen.	Do.
McAlester.	Shaft No. 10, Krebs.	1.74	37.00	56.86	4.40	0.65	0.014	Lustrous, with black patches; moderately swollen.	Light brown.
Do.....	Sample's Slope, 1 mile west of McAlester.	2.08	37.52	56.02	4.38	0.80	0.016	Lustrous; not strongly coherent.	Do.
Lehigh	Shaft No. 5, Lehigh.	3.56	41.61	41.12	13.71	4.56	0.024	Coherent; lustrous.	Dark reddish brown.

REMARKS BY CHEMIST.—The volatile matter was determined by exposing for seven minutes 1 gram of coal, in a platinum crucible, to the heat of a Bunsen burner, when the flame was about 2 cm. high, the bottom of the crucible being at a distance of 8 cm. from the top of the burner. It is to be borne in mind that a portion of the sulphur (presumably over half) appears in the tabulation as volatile combustible matter.—W. F. HILLEBRAND, chemist; F. W. CLARK, chief chemist.

REPORT ON FOSSIL PLANTS FROM THE McALESTER COAL FIELD, INDIAN TERRITORY, COLLECTED BY MESSRS. TAFF AND RICHARDSON IN 1897.

By David White.

DISTRIBUTION AND CORRELATIONS.

LOCALITIES.

The material forming the subject of this report furnishes essentially the first paleobotanical data concerning the Carboniferous which have been brought to light from the regions southwest of Kansas and Arkansas. It gives therefore the first evidence relating to the vertical range and geographical distribution of the northern Coal Measures plant types in the southwestern portion of the Western interior basin. The careful observation of this distribution furnishes at once, in proportion to the completeness of the collections, a more or less adequate basis for the correlation of the plant-bearing series in the Indian Territory with the Coal Measures sections in other portions of the United States.

Thirteen localities are represented in the assemblage of specimens, although more than one-half of the local collections are so small and incomplete as to possess no intrinsic or precise correlative value, the only fossil from one of the localities being *Stigmaria.*

On the basis of the stratigraphical studies made in the field by Messrs. Taff and Richardson these localities may be arranged in three groups.

A. The first group to be considered, since it is represented by the larger and more important part of the material, includes the plant beds in the horizon of the McAlester coal. The specimens from this stage were collected at the localities indicated below, viz:

(1) One-half mile west of McAlester. This is the largest and most significant collection made. The matrix is a very light bluish-gray, fine argillaceous shale, in which the vegetable tissue is finely preserved as a carbonaceous film. As at other localities in this horizon, the material is quite friable, and is consequently badly broken.

(2) Krebs mine No. 11.

(3) Cherryvale, westernmost mine.

(4) Savanna. The number of fragments from this point is small, although the plant vestiges are so distinct as to reveal eleven species.

(5) Alderson, west mine. Only a few small fragments were collected, among which, as at the above-named localities, the robust type of *Alethopteris serlii* is the predominant species.

B. The localities constituting the second group are distant from each other, approximately, 100 feet stratigraphically, and not much farther geographically, at a stage about 2,000 feet above the McAlester coal, in a cut on the Missouri, Kansas & Texas Railway, one-half mile south of South McAlester. From the upper of the two beds we have a very small collection of fossils, well preserved in soft bluish clay shale, which is very friable, and weathers a pale yellowish green. The flora, comprising fifteen species, is the highest collected. The collection from the horizon 100 feet lower consists of very small fragments in chips of ferruginous sandstone. These are unfortunately quite insufficient to enable identification, although representing an interesting stage, from which it is hoped additional material may in future be gathered.

C. The third group of localities, which furnishes, by reason of the limited number of specimens collected, a rather meager flora, is reported by Mr. Taff as belonging to the horizon of a coal about 1,500 feet below the McAlester coal. The points at which material was gathered are:

(1) NW. ¼ sec. 12, T. 5 N., R. 15 E., 2 miles east of Krebs. In this, by far the largest collection from this stage, fragments of nineteen species of plants are found. The matrix is a very dark, somewhat fissile, thin-bedded shale.

(2) Mine No. 12, SW. ¼ sec. 12, T. 5 N., R. 15 E., 2 miles southeast of Krebs. This lot consists of a few weathered ferruginous crusts, on which only three species are clearly identifiable.

To the same stage are supposed to belong two quite insufficient and insignificant lots from the roof of the Grady coal at Hartshorne and at mine No. 2 at Gowan.

There remain two other lots, which, on account either of the remoteness of the locality or of the dissimilarity of the flora, I have omitted from the three categories proposed above. The first of these is a rather small collection in ironstone nodules, from Johnsville, near Savanna, supposed, on the evidence of stratigraphy, to belong to the horizon of the McAlester coal. The other is a wholly insufficient collection embracing a few fragments of weathered shelly ironstone gathered at mine No. 6½, sec. 2, T. 1 S., R. 10 E., Atoka quadrangle. The ironstone fragments are left by the dissolution of the soft blue shales overlying the Lehigh coal, which is regarded as probably belonging to a stage higher than the Grady coal, and probably lower than the stage in the Missouri, Kansas and Texas Railway cut. It is to be regretted that ample material was not gathered for a satisfactory comparison and correlation on paleobotanical grounds.

The collected floras of the localities enumerated above are indicated in the accompanying table. For convenience of comparison the species from the three above-described groups or stages are summarized in the three colums at the right of the chart. The lists therein represent the floras, so far as yet known, of these somewhat widely distant zones in the McAlester coal field. It will be observed that but two plant forms appear to be common to all three stages. It is probable, however, that the collection of additional material will naturally increase the number of common species; but it is reasonably certain that the percentages will remain nearly the same and that some of the fragments which, owing to incompleteness or imperfection, are referred to the same species, thus causing the record of that species in more than one zone, may, when supplemented by better examples, prove to represent quite different forms. The small floras from Johnsville and from mine No. 6½, between Lehigh and Coalgate, in the Atoka quadrangle, are for the present omitted from consideration, and are therefore not included in this summary.

Table showing geographic distribution of fossil plants in the McAlester coal field, Indian Territory.

List of species.	Stage of McAlester coal.															
	½ mile west of McAlester.	Krebs, No. 11 mine.	Cherryvale.	Savanna.	Alderson, west mine.	½ mile south of South McAlester (upper bed).	½ mile south of South McAlester (lower bed).	Johnsville.	2 miles east of Krebs.	2 miles southeast of Krebs.	Hartshorne.	Gowan, No. 2 mine.	No. 6½ mine, sec. 2, T. 1 S., R. 10 E.	McAlester coal stage.	Grady-Hartshorne stage.	Missouri, Kansas and Texas Rwy. cut stage.
Mariopteris nervosa (Brongn.) Zeill									×						×	
Mariopteris cf. *sillimanni* (Brongn.)									×						×	
Mariopteris sp										×					×	
Mariopteris sphenopteroides (Lx.) Zeill	×								×						×	
Mariopteris occidentalis D. W	×		×											×		
Mariopteris occidentalis var. *villosa* D. W									×						×	
Mariopteris capitata D. W	×													×		
Pseudopecopteris macilenta (L. & H.) Lx	×													×		
Pseudopecopteris cf. *squamosa* (Lx.)						×			×						×	×
Sphenopteris lacoei D. W	×													×		
Sphenopteris taffii D. W	×			×										×		
Sphenopteris sp. indet	×													×		
Sphenopteris sp. indet						×										×
Aloiopteris winslovii D. W	×													×		
Aloiopteris sp			×											×		
Pecopteris dentata Brongn	×		×	×										×		
Pecopteris unita Brongn						(?)	×		×						×	×
Pecopteris elliptica F. & W						×								×		
Pecopteris richardsoni D. W	×		×											×		
Pecoptoris lesquereuxii D. W						×										×
Pecopteris squamosa Lx		×		×										×		
Pecopteris vestita Lx. var. *minor* D. W									×	×					×	
Pecopteris cf. *serpillifolia* Lx	×	×												×		
Pecopteris villosa Brongn.?	×													×		
Pecopteris (*Asterotheca*) sp	×													×		
Pecopteris candolliana Brongn				×										×		
Pecopteris oreopteridia (Schloth.) Brongn		×		×										×		
Pecopteris polymorpha Brongn							×									×
Alethopteris serlii (Brongn.) Goepp	×	×	×		×	×		×	×					×	×	×
Alethopteris serlii var. *missouriensis* D. W	×													×		
Callipteridium inæquale Lx.?	×	×												×		
Callipteridium mansfieldi Lx	×		×											×		
Callipteridium sullivantii (Lx.) Weiss			×											×		
Callipteridium sp													×			
Odontopteris wortheni Lx								×								
Neuropteris (*Cyclopteris*) sp								×		×					×	
Neuropteris cf. *fasciculata* Lx									×						×	

Table showing geographic distribution of fossil plants in the McAlester coal field, Indian Territory—Continued.

List of species.	Stage of McAlester coal.															
	⅓ mile west of McAlester.	Krebs, No. 11 mine.	Cherryvale.	Savanna.	Alderson, west mine.	⅓ mile south of South McAlester (upper bed).	⅓ mile south of South McAlester (lower bed).	Johnsville.	2 miles east of Krebs.	2 miles southeast of Krebs.	Hartshorne.	Gowan, No. 2 mine.	No. 6½ mine, sec. 2, T. 1 S., R. 10 E.	McAlester coal stage.	Grady-Hartshorne stage.	Missouri, Kansas and Texas Rwy. cut stage.
Neuropteris scheuchzeri Hoffm								×	×						×	
Neuropteris jenneyi D. W		×												×		
Neuropteris griffithii Lx. var. *occidentalis* D. W	×													×		
Neuropteris harrisi D. W									×						×	
Neuropteris rarinervis Bunby?						×										×
Neuropteris missouriensis Lx	×	×	×	×									(?)	×		
Neuropteris missouriensis var. *nervosa* D. W								×								
Neuropteris cf. *tenuifolia* (Schloth.) Stb											×				×	
Neuropteris caudata D. W						×										×
Dictyopteris cf. *rarrii* (Lx.)								×								
Dictyopteris gilkersonensis D. W	(?)			(?)				×	×					×	×	
Calamites sp. indet		×												×		
Calamites cf. *cannæformis* Schloth			×											×		
Calamodendron approximatum (Schloth.) Brongn												×			×	
Asterophyllites equisetiformis (Schloth.) Brongn		×					×							×		×
Annularia stellata (Schloth.) Wood	×					×								×		×
Annularia sphenophylloides (Zenk.) Gutb	×			×										×		
Annularia sphenophylloides var. *intermedia* Lx						×										×
Cyclocladia sp									×						×	
Macrostachya sp. indet										×					×	
Macrostachya communis Lx		×												×		
Sphenophyllum cuneifolium (Stb.) Zeill									×						×	
Sphenophyllum emarginatum Brongn	×	×		×		×			×					×	×	×
Sphenophyllum suspectum D. W	×			×										×		
Radicites cf. *capillaceus* (L. & H.) Pot	×		×											×		
Lepidodendron choctovense D. W						×										×
Lepidodendron sp											×				×	
Lepidophyllum brevifolium Lx	×	×												×		
Lepidophyllum lanceolatum L. & H	×	×		×		×	(?)							×		×
Lepidophyllum cf. *mansfieldi* Lx.?	×													×		
Lepidophyllum truncatum Lx									×						×	
Lepidocystis brevifolius (Lx.)	×		×											×		
Lepidocystis vescicularis Lx									×						×	
Lepidophloios sp													×			
Tæniophyllum sp.?		×														
Cordaites communis Lx		×	×			(?)								×		(?)
Cardiocarpon branneri Fairch. & D. W.?			×											×		
Rhabdocarpos multistriatus (Presl) Lx	×										×			×	×	

STATE OF KNOWLEDGE AS TO AMERICAN DISTRIBUTION.

A glance at the columns on the right shows that 69 forms or species of plants occur at one or more of the three zones represented in the collections. Twenty-four species are found in the roof of the Grady coal, 43 species in the stage of the McAlester coal, about 1,500 feet higher, and 15 species in the third plant-bearing stage, about 2,000 feet above that. From the relatively small percentages of species common to two stages it will at once be seen that there are marked differences between the floral characters of the three stages.

It would be most useful and advantageous if, taking each of these three floras as representative of its particular zone, we might trace the distribution of the species through the other coal fields of the United States, and thereby obtain data of the highest value and accuracy in correlating the McAlester zones with the principal divisions of the Coal Measures as established in Missouri, Illinois, or the Ohio-Pennsylvania fields. But, unfortunately, as I have elsewhere shown,[1] there are at hand almost no data of consequence relating to the floras of any but the Lower Productive Coal Measures in any of the areas named. In fact, in Pennsylvania, the type region of the bituminous series in the Appalachian province, our knowledge of the floras of the various stages between the Kittanning and the top of the Waynesburg coal ("Permian") is limited to a short list of species found below the Pittsburg coal near Wheeling, West Virginia. Otherwise the floras of the Upper Productive Coal Measures (Monongahela series), the Lower Barren Measures (Elk River series), and even the Freeport group in the upper part of the Lower Productive Coal Measures (Allegheny series), are still to be made known. It is evident that under these circumstances nothing can be gained by an attempt to trace at present the distribution of the species in any type section in the type region of the Appalachian bituminous fields, since no type paleobotanical section has yet been constructed. In Ohio, Indiana, Illinois, or Missouri the conditions are not greatly superior, so fragmentary, incomplete, and disconnected are the paleobotanical data relating to any other than the Lower Coal Measures. Until, however, a series of systematically constructed paleontological sections can be established for reference or comparison of the higher Carboniferous floras, we are left to depend largely on comparisons with the anthracite fields, and on analogies drawn from the biological evidence contained in the floras under consideration.

STAGE OF THE McALESTER COAL.

An inspection of the entire list of the plants so far collected from the McAlester coal field shows the genus Mariopteris, as construed by the

[1] Bull. U. S. Geol. Survey No. 98, 1893, pp. 118, 119.

writer, to be fairly well represented, while Pecopteris and Neuropteris are evidenced by a relatively large number of species. Lepidodendron is poorly represented, while no traces of Sigillaria are found in the collections. As is natural, Neuropteris is more frequent in the lower zone; Pecopteris in the higher zones.

Taking first into consideration the species from the horizon of the McAlester coal, we find Mariopteris represented by species of the *cordato-ovata* type, a group whose nearest related forms are present in coal G in the northern anthracite series, the higher Coal Measures of Kansas, and at Van Buren, Arkansas. *M. sphenopteroides* has not before been found above the middle Kittanning of the Lower Productive Coal Measures (Allegheny series) or the Lower coals (Des Moines series) of Henry County, Missouri. *Sphenopteris taffii* is also present at the Penitentiary mine at Lansing, Kansas, while *Aloiopteris winslowii* ranges from the Lower Coal Measures up into the higher measures at Garnett and Ottawa, Kansas.

Of the considerable number of species of Pecopteris over the McAlester coal a portion, including *P. richardsoni*, *P. lesquereuxii*, with simple nerves, and *P. candolliana*, are generally regarded as indicating Upper Coal Measures in all coal fields. *P. dentata* is represented by the later broadly dilated variety, while the plants known in this country as *P. oreopteridia* and *P. villosa* Brongn.? range from coal E of the anthracite or the Kittanning upward for some distance, probably at least into the Lower Barren (Elk River) Measures of the northern basins.

In the genus Neuropteris we have a variety extremely close to the type known only from coal E or F at Port Griffith, in the Northern Anthracite field, though it is nearly related to *N. clarksoni* from the G vein of the same field (extremely rarely found as low as the D vein) and the Kittanning of western Pennsylvania, or at Mazon Creek, Illinois. It occurs also at the Penitentiary mine in Kansas. *N. missouriensis* comes from the Des Moines series (Cherokee shales) of Henry County, Missouri. *Macrostachya communis* is described from the Kittanning (Allegheny series) of Pennsylvania. *Annularia sphenophylloides* will be noted as present. *Sphenophyllum suspectum* is nearly related to *S. lesquereuxii* from the Des Moines series of Missouri or to *S. oblongifolium* of the Stephanian series in Saxony.

Although *Lepidophyllum brevifolium* is recorded as confined to the lower coals only, the species from McAlester appears to agree very closely with specimens from the Upper Coal Measures of the Bristol coal field in England. *L. lanceolatum* appears to be not rare at the horizon of coals E or F in the anthracite series. *Cardiocarpon branneri* has been described in manuscript[1] from Van Buren, in the Upper Coal Measures of Arkansas. *Rhabdocarpos multistriatus*, found also at that place and in the higher coal series of Kansas, is reported as occurring

[1] In a report on the plants of the Coal Measures of Arkansas, by Prof. H. L. Fairchild and the writer.

also at the base of the Productive Coal Measures. It is probable that this species, which appears to need revision, has little stratigraphic value.

From the above review of the stratigraphic occurrence, so far as this is known, of the more restricted species, it appears quite certain that the horizon of the McAlester coal is younger than coals C or D in the Northern Anthracite field, the Kittanning coal of the Pennsylvania bituminous regions, and the lower coals in the Des Moines series of Henry County, Missouri.[1] Basing our conclusions as to the stage of this coal on the relations of the stages of the known floras nearest related, the deduction seems probable that the horizon of the coal at McAlester is nearer the stage of coals F or G in the Northern Anthracite field, and within the Upper Coal Measures, as that term is employed in Kansas and Arkansas.

A comparison of the McAlester flora with such collections from the higher Coal Measures series as I have been able to examine shows, as a matter of fact, the closest affinities of that flora with those represented in the Lacoe Collection, U. S. National Museum, from Ottawa, Lawrence, or Garnet, Kansas. I have no personal knowledge of the stratigraphy of the region or the position of these coals in the local subdivisions of the Upper Carboniferous in Kansas; but Dr. Charles R. Keyes, whose work in the Western Interior Basin is well known, informs me[2] that the Ottawa and Garnet plants probably come from an as yet unpublished subdivision of shales just beneath the Plattsburg limestone of Broadhead, while the Lawrence plants may have come from near the top of the Lawrence shale of Haworth. So long as little or nothing is known of the floras of each of the subdivisions of the higher measures in this region it would be manifestly unwise to definitely refer the McAlester coal to a stage near the Plattsburg limestone of Broadhead or the Lane shales of Haworth—i. e., 200 to 400 feet above the base of the Upper Coal Measures—since the fossils of some other as yet paleobotanically unknown subdivision of the series may show a flora identical with that in Indian Territory. Nevertheless it seems most probable from the affinities, as well as the identities of the floras, that the flora of the stage of the coal in question is in the same major division, the Upper Coal Measures (Missourian), of the Western Interior Basin, and it appears probable also that it represents a horizon in the lower part of the Missourian later than the Bethany limestone. From the little that is known of the floras between the Kittanning (Lower Productive Coal Measures), and the roof of the Waynesburg coal (Upper Barren Measures), in the Ohio-Pennsylvania region, it is very difficult to discern correlative evidence that seems to justify even a moderate degree of credulity. The writer is, however,

[1] The age of the lower coals of Henry County, Missouri: Bull. Geol. Soc. Am., Vol. VIII, 1897, pp. 287-304.

[2] Letter dated February 28, 1898.

disposed to regard the flora in hand as very probably older than that of the Pittsburg coal (the base of the Upper Productive Measures), while it is quite possible that it is not younger than the Freeport group, the upper portion of the Lower Productive Coal Measures. What portion of the Coal Measures of the trans-Mississippian series corresponds to the intervening Lower Barren Measures of the eastern region has not yet been ascertained.

As arguing against too high a reference of the flora under discussion may be cited, first, the presence therein of species presumably of ordinarily older range, such as *Mariopteris sphenopteroides*, *Pecopteris villosa?*, *P.* cf. *serpillifolia*, *Lepidophyllum brevifolium*, and other Lepidodendreæ; and, second, the absence of Permian forms or species.

STAGE OF THE MISSOURI, KANSAS AND TEXAS RAILWAY CUT.

Notwithstanding the meagerness of the material collected, the flora from the Missouri, Kansas and Texas Railway cut one-half mile south of South McAlester is interesting on account of its nature and important bearing on the subject of zone correlation, especially in view of the wide interval, about 2,000 feet, between it and the McAlester coal.

From this, the highest of the plant beds discovered by Messrs. Taff and Richardson, 15 species were collected, of which 6 are also present in the McAlester coal and 4 in the Grady coal, while 7 are not represented in the collections from the other stages. An examination of the small flora from this stage reveals the presence of such Coal Measures types as *Pseudopecopteris squamosa*, *Pecopteris unita*, *Alethopteris serlii*, and *Lepidophyllum lanceolatum*, while *Neuropteris rarinervis* is perhaps present. The form of the first-named species belongs to the dilated, sublobate *Ps. anceps* type, such as that found at Lansing, Kansas. *Pec. unita* is a small form approaching *P. elliptica* F. & W., which also seems to be present. The latter is perhaps the only species of the flora in hand that is in any sense characteristic of the so-called "Permian" or Upper Barren Measures of the Appalachian region. *Pecopteris polymorpha*, which seems to be present, is a high Coal Measures and anthracite form, characteristic of the Stephanian of the Old World. The intermediate variety of *Annularia sphenophylloides* is also indicative of a high stage, though our knowledge of the vertical distribution of the form is, as in so many other cases, painfully incomplete. The stage of the railway cut has clearly less in common with the Lower Coal Measures than has the McAlester coal. Considering, however, its typically Coal Measures aspect, the presence of the Lepidodendra, and the absence of any of the types characteristic of the Permian, the time of this stage seems to the writer to be much earlier than the Permian or Upper Barren Measures. In other words, notwithstanding the great stratigraphic interval between it and the McAlester coal it seems probable that a great thickness of beds may intervene between this stage and the base of the Permian.

The reference of the floras of the McAlester coal and the railway cut to the Upper Coal Measures (Missourian) has a very important bearing on the question of the zone of the floras described by the writer from the outlying Carboniferous basins of southwestern Missouri.[1] At the time of the publication of that report, the material for comparison being less than at present, it was thought that the stage of these local ponds occupying Paleozoic sinks in the Lower Carboniferous limestone might lie within the upper part of the Lower Productive Coal Measures. More recently, however, the study of the floras of the Kanawha series of West Virginia, and of the Lower Coal Measures of Missouri,[2] has led me to regard the former as younger—perhaps contemporaneous with some portion of the Lower Barren Measures. A number of the most interesting and peculiar of the species from those outliers had not been seen elsewhere. It is, therefore, important to note the occurrence of these species, *Mariopteris capitata*, *Neuropteris jenneyi*, *N. caudata*, and *Pecopteris lesquereuxii*, together with *Pseudopecopteris macilenta* and *Sphenopteris lacoei*, in the floras just discussed. The close relations of the floras leave little doubt that the outlier floras of the zinc region of Missouri belong to the same division of the Coal Measures as the plants above the McAlester coal, while it is suggested that they possibly represent a stage not very far from that of the plant beds in the railway cut.

STAGE OF THE GRADY COAL.

The flora of the Grady coal embraces 24 species, of which only 5 are also found in the McAlester flora and 4 in the railway cut, while 17 are not present in the collection from the higher zone. Over one-half of the forms are Neuropterids and Mariopterids, thus, in the absence of later types of Pecopteris, indicating for the coal a stage in the Lower Coal Measures.

An inspection of the list of species confirms this indication and goes so far as to preclude a correlation with the upper portion of the Lower Coal Measures. *Mariopteris sillimanni*, a derivation of the Pottsville *muricata* group, is found in the Kittanning at Cannelton, Pennsylvania. *M. sphenopteroides* ranges from near the base of the Lower Productive Coal Measures through coal D of the Illinois region, but has not, I believe, been found in any region at a higher stage until its discovery in the roof of the McAlester coal. *Pseudopecopteris squamosa* appears to be represented by the original *squamosa* type, which seems to be characteristic of the coals close above the "Buck Mountain" bed of the Southern Anthracite field, or coal C of the Northern Anthracite field. *Pecopteris vestita* is found in the lower coals of Henry County, Missouri, and its affinities and nearest relations are with forms confined to the basal portion of the Lower Productive Coal Measures. *Pecopteris unita*

[1] Bull. U. S. Geol. Survey No. 98, 1893.
[2] Age of the coals of Henry County, Missouri: Bull. Geol. Soc. Am., Vol. VIII, 1897, pp. 287–304.

is one of the species of wide range, but its large form appears to be more characteristic of the coals D to G of the Northern Anthracite field, perhaps ranging higher in the Southern Anthracite field, although it is common at Mazon Creek, in a horizon that may not be older than the Lower Kittanning. It may occur as low as the Clarion, the second coal of the Lower Productive Measures (Allegheny series), while the extent of its ascent from that stage is not known. This species has, therefore, little value except as proof that the Grady coal is post-Pottsville, a proof wholly unnecessary in the presence of so many other non-Pottsville species, or the great scarcity of Pottsville forms. *Alethopteris serlii* has a wide Coal Measures range, while to *Odontopteris wortheni* have been referred specimens in collections from near the base of the Coal Measures and from the Upper Barren Measures, or so-called Permian. This species represents, in the opinion of the writer, merely heterophylly in the *Neuropteris scheuchzeri* group. The fragment in hand belongs to a small form occasionally met in the lower coals of the Lower Productive Coal Measures, though it appears to range higher in the Nova Scotia series.

Of the species of Neuropteris, *N. fasciculata* appears to belong to the horizon of Mazon Creek, though it possibly ascends to the Freeport coal. *N. scheuchzeri* is represented by the small, narrow form which is in general more restricted to the basal portions of the Lower Productive Coal Measures. *N. missouriensis* has heretofore been known only in the lower coals of Henry County, Missouri, which are regarded by the writer as probably younger than the middle Kittanning coal of the Lower Productive Coal Measures. *N. tenuifolia* is too ill defined and misunderstood at present in our collections to warrant its use in correlation. The plant here described as *N. harrisi* has as yet been collected only in the region of Atkins or Russellville, Arkansas, in what appears to be mapped as the Lower Coal Measures of that State. *Dictyopteris carrii* is found at Mazon Creek, Illinois, and Kingston, Pennsylvania, but *D. gilkersonensis* has been known up to the present only in the Henry County, Missouri, coals.

Sphenophyllum emarginatum has a wide range, beginning at the base of the Lower Productive Coal Measures. *Lepidophyllum truncatum* and *L. vesicularis* are known best from Cannelton, Pennsylvania (Kittanning coal), though they doubtless range some distance both above and below. The latter species is with difficulty separable from *L. fraxiniformis*, identified by Professor Lesquereux in many specimens from Campbell's Ledge, near the top of the Pottsville series in Pennsylvania.

From the above incomplete review of the range of the more characteristic species, or species whose vertical range, so far as observed, appears to be not great, it would seem that the Grady coal may be near the horizon of Mazon Creek, Illinois, or Cannelton, Pennsylvania, in the Lower Productive Coal Measures (Allegheny series). As tending to indicate a stage not lower than the Kittanning group, several species may be cited that either are yet unknown below that group, or are in general presumably rather more characteristic of a higher stage. Such are the *Mariopteris sillimanni*, *Pecopteris squamosa*, *P. unita*, *Neuropteris missouriensis*, *Lepidophyllum truncatum*, and perhaps also the variety of *Mariopteris occidentalis*. Opposed to the weak influence of this minor evidence is the presence of a number of species whose forms are more or less specially characteristic of the lower coals of the Lower Productive Coal Measures. *Neuropteris harrisi*, *Calamodendron approximatum*, and *Sphenophyllum cuneifolium* belong to this category, to which the small narrow form of *Mariopteris nervosa* might be added. Stronger proof on the side of an earlier age for the coal is found in the absence from the collection of *Annularia stellata*, *A. sphenophylloides*, and many of the fern species common in the middle of the Allegheny series, especially the higher Sphenopterids, and the larger or diversified Pecopterids, the only representatives of the latter being such as might be found near the base of that series. It is, of course, possible that additional collections will reveal the presence of the Annulariæ, as well as additional ferns; yet the proportionate distribution of the flora will perhaps remain the same.

Taking into account, therefore, the more characteristic elements of the flora and their distribution, it appears that the Grady coal is referable to the Lower Productive Coal Measures (Allegheny series) of the northeastern bituminous fields, its stage being probably near the middle of that series, and presumably in the lower half. It must be remembered, however, that, while this opinion seems to have the support of the paleobotanical evidence at present in hand, the collection made by Messrs. Taff and Richardson from the Grady coal is small, and our knowledge of the plants of the Freeport coal group and Lower Barren Measures is unfortunately quite limited. It is possible, therefore, that future collection may radically affect this correlation, although I do not expect any serious modification thereof.

The collection of fossil plants from Johnsville is too scant and the species are too few to warrant an attempt at independent correlation. As before stated, it is regarded by the stratigraphers as coming from the roof of the same coal as that mined at McAlester. The fragments of ironstone are nearly covered with a rather large form of *Neuropteris scheuchzeri*. While the few species contained in the collection do not appear to constitute an association such as occurs in and appears to be characteristic of the collections from other points a few miles distant in the McAlester coal, and while its floral fragments are not such as would per se incline the paleontologist to refer it, in the absence of any other information, precisely to the same coal, there is nothing whatever present which can be construed as evidence of any importance tending to disprove its contemporaneity. As remarked above, the collection is, in fact, too insufficient to possess any real stratigraphical value.

From the Lehigh coal, mine No. 6½ in the Atoka quadrangle, the collection consists of only a few small fragments of ironstone containing apparently three species, none of which are definitely determined. The material seems to indicate a Coal Measures age for the coal.

COMPARISON OF THE FLORAS OF THE McALESTER DISTRICT WITH THOSE FROM THE COAL FIELD OF ARKANSAS.

It is to the highest degree desirable that the coal measures of the McAlester coal field be correlated as far as possible with the corresponding measures of that part of the same original basin now contained in Arkansas, both on account of the economic knowledge as to the identity or extent of coals and coal-bearing series and for the sake of ascertaining, by means of paleontological collections or detailed stratigraphy, the relations, equivalence, or stratigraphic characters of the several disconnected and fragmentary floras as yet brought to light in both regions.

At the present moment the only systematic publications dealing with the Paleozoic floras of Arkansas are the Botanical and Paleontological Report on the Geological State Survey of Arkansas (1860)[1] and the Coal Flora,[2] both by the distinguished early investigator and elaborator of the fossil floras of this country, Prof. Leo Lesquereux. Owing to the stratigraphical conclusions reached by him while in the field, all the fossil plants from the Arkansas Carboniferous were supposed to lie below the "Millstone grit" (Pottsville conglomerate), and we therefore find them recorded[3] as "Subconglomerate." The analysis of the distribution of all those species, the localities for which are given in these reports, shows,[4] however, that the plants from Jenny Lind Prairie and James Fork of the Poteau River are unmistakably from the true Coal Measures, while those from Males's (now Privett's) coal bank in Washington County belong to the Pottsville, or, as shown by the more recent study of the latter, to the Sewanee division (upper) of the Pottsville series.

No further official attempt was made to obtain data relating to the stratigraphical paleobotany of the Coal Measures of Arkansas until near the close of the late geological survey of that State, when Prof. H. L. Fairchild, at the instance of the State geologist, visited a number of the coal-mining centers of the State, and, after encountering various difficulties, brought back small collections of fossil plants from a half dozen localities. This material, with a collection from near Van Buren, Crawford County, Arkansas, was discussed in a short joint report to the State Survey by Professor Fairchild and myself. Reference has

[1] Geol. Surv. Ark., Vol. II, pp. 294-399. Pls. I-VI, pp. 308-317.

[2] Description of the Coal Flora of the Carboniferous Formation in Pennsylvania and throughout the United States, Second Geol. Survey Pa., Rept. Prog. P (3 vols. and atlas), 1879-1884.

[3] Op. cit., Vol. III, p. 854, 855.

[4] Bull. U. S. Geol. Survey No. 98, 1893, p. 109.

been made by Dr. J. P. Smith[1] to this report, which, owing to the cessation of geological publications by the State, has not yet been printed. In order to not forestall the paleontological contents of the latter, which are largely the result of painstaking and enthusiastic studies on the part of the senior author, reference will be made only to certain plant-bearing localities, with the assumption that the floras of these localities are in some degree representative of the respective subdivisions of the Arkansas Coal Measures in which they appear, on the evidence of the areal geologists, to lie.

The stratigraphical classification and nomenclature of the divisions of the Upper Carboniferous in Arkansas appear to be the subject of some lack of uniformity and consequent confusion on the part of the various geologists of the late State survey. Thus, Dr. Winslow,[2] in his report on the geology of the coal regions of Arkansas, divides and maps a portion of the coal regions of the State in three series, viz: (1) Upper or western coal-bearing division; (2) intermediate or barren division, and (3) lower or eastern coal-bearing division. All these divisions appear to be included by Dr. Branner[3] in his "Upper Coal Measures," the remainder of the "Coal Measures, or Pennsylvanian," being classed as "Lower Coal Measures" and Millstone grit. Dr. J. Perrin Smith, in his interesting memoir on "Marine Fossils from the Coal Measures of Arkansas,"[4] appears to differ by including the Pottsville conglomerate series (Millstone grit) in the Lower Coal Measures, a reference which, while it may not conflict with the evidence of fossil invertebrates, departs from the ordinary usage of geologists, while at the same time conflicting directly with the testimony of the fossil plants.

The material from the Arkansas Coal Measures is, unfortunately, far from sufficient to form a basis for correlation between other districts, yet the relations between several of the floras are such as to strongly suggest membership in the same division. Thus the flora of the Grady (Hartshorne) coal in the McAlester field has so much that is in common with or similar to that collected at Ouita, or perhaps Spadra or Coal Hill, that it seems highly probable that it belongs to the same division of the Coal Measures, i. e., the Lower or Eastern coal-bearing division, as described and mapped by Winslow, or near the base of the Upper Coal Measures of Branner and of Dr. J. P. Smith.[5]

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[1] Proc. Am. Phil. Soc., Vol. XXXV, No. 152, 1897, p. 17.

[2] A preliminary report upon a portion of the coal regions of Arkansas, Ann. Rept. Geol. Survey Ark., 1888, Vol. III., pp. 10, 11.

[3] Thickness of the Paleozoic sediments in Arkansas: Am. Jour. Sci., 4th ser., Vol. II, 1896, pp. 229-236, with map.

[4] Proc. Am. Phil. Soc., Vol. XXXV, No. 152, 1897, p. 16.

[5] There is ample basis for a strong suspicion that unless the conditions in the Arkansas-Indian Territory region are similar to those in the region of the Kanawha River in southern West Virginia, in which great expansion of the basal portion of the Allegheny series is found, the Grady coal in the one State and the Ouita coal in the other are not very far from the base of the Lower Productive Coal Measures as deposited in the northern and eastern bituminous fields, in which case the Lower Coal Measures of the Arkansas geologists may include little, if any, more than the Pottsville series (Millstone grit) of the Eastern regions. Paleontological evidence relating to this question is much to be desired.

It is possible too, although the more scanty material for comparison does not invest the suggestion with so much probability, that the flora of the McAlester coal belongs similarly to the series containing the Jenny Lind, Huntington, or Van Buren floras.

GENERAL CONSIDERATIONS.

An important phase of the study of the plants from the McAlester coal field is the light thrown thereby on the proportionate thickness of the divisions of the Coal Measures. If we assume that the evidence of the plants, though too scanty, perhaps, to justify complete confidence, is approximately correct in pointing toward a stage in the lower part of the Lower Productive Coal Measures (Allegheny series) of the northern and eastern fields for the Grady coal, and a place between the Kittanning group of that series and the Pittsburg coal (base of the Upper Productive Coal Measures), in the same regions for the McAlester coal, it is evident that, while the Lower Productive Coal Measures are probably greatly expanded in comparison to those of the Pennsylvania section, being comparable perhaps with the Kanawha series of West Virginia and eastern Kentucky, the greatest and most remarkable expansion of the Carboniferous series exists in the upper part of the Coal Measures. No evidence is, I believe, yet at hand to fix the limits of this astonishing dilation of the Upper Coal Measures (Stephanian), which has no parallel east of the Mississippi River, unless it be in the Joggins section of Nova Scotia.

The horizon in the Missouri, Kansas and Texas Railway cut, 2,000 feet above the McAlester coal, is fairly clearly some distance below the Permian, perhaps a long way, since it has Lepidodendra and no types characteristic of the Permian.

Compared with the major divisions of the Upper Carboniferous of the Old World, the flora of the Grady coal seems plainly Westphalian, its closer relations being with the floras of the Middle, or perhaps the Lower, Coal Measures of Great Britain, the Valenciennes series of the Franco-Belgian region, and the lower floras of the Schatzlar series of Bohemia. The McAlester flora, on the other hand, is clearly Stephanian, being comparable to the flora of the Upper Coal Measures of Great Britain, the Commentry flora in France, and of the Saarbrück series or Upper Coal Measures of Germany.

SYSTEMATIC ENUMERATION OF THE FOSSIL PLANTS, WITH NOTES, AND DESCRIPTIONS OF NEW SPECIES.[1]

PTERIDOPHYTA

FILICINEÆ.

TRIPHYLLOPTERIDEAE.

PSEUDOPECOPTERIS Lesquereux, 1880.

Coal Flora, 1, p. 189 (pars).

PSEUDOPECOPTERIS MACILENTA (L. & H.) LX.

Pl. LXVII, figs. 10, 11.

1835. *Sphenopteris macilenta* Lindley and Hutton, Fossil Flora, II, Pl. CLI.
1855. *Sphenopteris macilenta* L. and H., Geinitz, Verst. Steink. Sachsens, p. 14, Pl. XXIII, fig. 1.
1880. *Sphenopteris macilenta* L. and H., Fontaine and I. C. White, Permian Flora, p. 12.
1835. An *Sphenopteris lobata* Gutbier (non Morris), Abdrücke, p. 44, Pl. I, figs. 11-15, Pl. X, figs. 1-3?.
1836. *Aspidites macilentus* (L. & H.) Goeppert, Systema, p. 357.
1869. *Sphenopteris (Aneimioides) macilenta* L. & H., Schimper, Traité, I, p. 400.
1877. *Diplothmema macilentum* (L. & H.) Stur, Culm-Flora, II, p. 124 (230).
1885. *Diplothmema macilentum* (L. and H.) Stur, Carbon-Fl. Schatzlarer Sch., I, p. 375.
1877. An *Diplothmema lobatum* (Gutb.) Stur, Culm-Flora, II, p. 123 (229)?.
1880. *Pseudopecopteris macilenta* (L. & H.) Lesquereux, Coal Flora, III, p. 754, Pl. XCVIII, fig. 2.
1888. *Pseudopecopteris (Sphenopteris) macilenta* (L. & H.) Lesquereux, Proc. U. S. Nat. Mus., XI, p. 85(?).
1893. *Sphenopteris (Pseudopecopteris) macilenta* L. & H., D. White, Bull. U. S. Geol. Survey No. 98, p. 55, Pl. I, fig. 4, 4*a*.

Fronds tripinnate; rachis rather strong, slightly flexuous; primary pinnæ oblique, distant, oval-lanceolate, acute; secondary pinnæ alternate, distant, oblique or sometimes at right angles or even reflexed below, linear lanceolate, 2 to 8 centimeters or more in length, 1 to 3 centimeters in width; secondary rachis rather narrow, slightly depressed above, raised below, usually flexuous to correspond with the position of

[1] The short notes recorded under the various species on the following pages are only such as relate particularly to the specimens from the McAlester coal field. Full descriptions of a large number of the species and genera, accompanied by somewhat critical comparative observations, will be found in a monograph on the Flora of the Lower Coal Measures of Missouri, now in press (Mon. U. S. Geol. Survey, Vol. XXXVII).

each pinnule, naked in the lowest parts, bordered by a narrow decurrent margin of the pinnules above.

Pinnules large, thin, alternate, distant, oblique to the rachis, except those at the base of the pinnæ, more or less cuneate, usually irregularly trisublobate, the borders slightly arched; those in the middle portions of the pinnæ broad, rather ovate, cuneate below or rounded cuneate to the decurrent base, bordering the rachis with a narrow lamina; those above becoming more cuneiform below, less distinctly lobate, sometimes bilobate, or rounded and entire at the apex, with broader attachments, gradually becoming more and more united, the uppermost being narrow, cuneate, rounded, passing on to the connate, narrow, obtuse terminal pinnule; those in the lower portions of the pinnæ more distinct, less oblique to the rachis, more contracted below, appearing pedicellate, broader, sometimes rhomboidal, rather more indistinctly trilobate, the lobes decurrent and sometimes feebly irregularly lobed again, always rounded below, the basal pinnules less oblique, more deeply, and often palmately, lobate.

Principal nerves distinct below, very acutely decurrent, slender, arching outward, and forking two to four times as the pinnules broaden, becoming faint near the border; fructification unknown.

Although the specimens here included appear to be in complete agreement with the material described in detail[1] from the Carboniferous outliers in southwestern Missouri, it is still a matter of some doubt as to whether it is proper to continue its reference to the species described by Lindley and Hutton.[2] As will be seen from a comparison of Pl. LXVII, fig. 10, of this report, the larger pinnules are, in general rather broader; but the upper pinnules in particular are noticeable on account of their much more compact mode of arrangement and their oblong or but slightly cuneate form with broad rounded apices. It is possible that the nervation of the British type may resemble that of the American plant more closely than would be inferred from the figures. In the form of the upper pinnules it differs rather more strongly from the Old World plant than does the specimen figured by Lesquereux[3] from Cannelton, Pennsylvania, or other fragments from the higher anthracite series at Olyphant, Pennsylvania.

The reference to Gutbier's *Sphenopteris lobata*[4] given in my synonymy of *Pseudopecopteris macilenta*[5] should perhaps be stricken therefrom, although this species and the *Cyclopteris valida* of Dawson[6] constitute the nearest relatives of the type in hand.

The specimens from the anthracite and other Coal Measures series of

[1] Bull. U. S. Geol. Survey No. 98, 1893, p. 55, Pl. I, figs. 4, 4*a*.
[2] Fossil Fl. Great Britain, Vol. II, Pl. CLI.
[3] Coal Flora, Vol. III, 1884, p. 754, Pl. XCVIII, fig. 2.
[4] Abdrücke u. Verst., p. 44, Pl. V, figs. 11, 12, 14, 15; Pl. X, figs. 1-3.
[5] Op. cit., p. 55.
[6] Flora of the Devonian period in N. E. America: Quart. Jour. Geol. Soc: London, Vol. XVIII, 1862, p. 319, Pl. XVII, fig. 52.

the Northern States represent a species totally different from that labeled under this name in several collections from the "Subconglomerate series" (Pottsville) of the southern Appalachian region. The reference of the plant in question to the genus Pseudopecopteris, or possibly to Eremopteris, is indicated by the mode of development of the pinnules as well as by the nervation, but it is not yet certain to which of the two genera it more properly belongs.

Locality.—Roof of the McAlester coal, one-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6433, 6434.

PSEUDOPECOPTERIS SQUAMOSA Lx.

1854. *Sphenopteris squamosa* Lesquereux, Bost. Jour. Nat. Hist., VI, No. 4, p. 420.
1858. *Sphenopteris squamosa* Lesquereux, in Rogers, Geol. Pa., II, 2, p. 862, Pl. X, fig. 3.
1876. *Pecopteris neuropteroides* Boulay (non Kutorga), Terr. houill. nord. Fr., p. 32, Pl. II, figs 6, 6?
1879. *Pseudopecopteris anceps* Lesquereux, Coal Flora, Atlas, p. 7, Pl. XXXVIII, figs. 1-4; text, 1 (1880), p. 207 (cum syn.).
1889. *Pseudopecopteris anceps* Lx., Lesley, Dict. Foss. Pa., II, p. 796, text fig.
1883. *Sphenopteris nevropteroides* (Boul.) Zeiller, Ann. Sci. Nat., (6) Bot., XVI, p. 186.
1886. *Sphenopteris nevropteroides* (Boul.) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. II, figs. 1, 1*a*, 2, 2*a*; text (1888), p. 349.
1887. *Sphenopteris neuropteroides* (Boul.) Zeiller, Kidston, Foss. Fl. Radstock Ser., p. 349.
1897. *Pseudopecopteris squamosa* (Lx.) D. White, Bull. Geol. Soc. Am., VIII, p. 291.

The plants included, properly I believe, under this name show a slight modification in time which seems to a certain extent characteristic of different zones, and which, although clearly representing only early and late phases of the same species, might with good reason be varietally differentiated. The first and older type, found at the base of the supra-Pottsville series in the Southern Anthracite coal field and in the lowest coals of the Lower Productive Coal Measures, exhibits a strong tendency to the small, compact, rounded, imbricated pinnules exemplified in the type described as *Sphenopteris squamosa* Lx. In the higher beds of the series the plant is more robust, its pinnules larger, often more loose, with a more frequent tendency to become trilobate, a facies slightly indicated in the examples figured as *Pseudopecopteris anceps.*

A number of specimens in the collection are apparently specifically inseparable from examples obtained at the Penitentiary mine, near Leavenworth, Kansas, referred to this species, although the pinnules are rather more open and dilated than in the typical form from the anthracite series.

Localities.—Fragments apparently referable to the early form of this species were found 2 miles east of Krebs, Indian Territory, in roof of the Grady coal. U. S. Nat. Mus. Reg. 6717. Specimens, uncommonly dilated, probably representing the latest stage of the same fern, are present in the collection from the Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, horizon about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6654.

MARIOPTERIS Zeiller, 1878.

1877. *Diplothmema* Stur, Culm-Flora, II, p. 226 (pars).
1878. *Mariopteris* Zeiller, Bull. Soc. Géol. Fr., (3) VIII, p. 93.
1879. *Pseudopecopteris* Lesquereux, Coal Flora, Atlas, p. 6; text I (1880), p. 180 (pars).

MARIOPTERIS MURICATA (Schloth.) Zeill.

1804. *Polypodium stipite muricato* * * * Schlotheim, Fl. d. Vorwelt, pp. 58, 59, Pl. XII, figs. 21, 23.
1820. *Filicites muricatus* Schlotheim, Petrefactenkunde, p. 409.
1825. *Pecopteris muricata* (Schloth.) Sternberg, Versuch, I, Tent., p. xviii.
1832 or 1833. *Pecopteris muricata* (Schloth.) Stb., Brongniart, Hist. Vég. Foss., p. 352, Pl. XCV, figs. 3, 4; Pl. XCVII, fig. 1.
1848. *Pecopteris muricata* (Schloth.) Stb., Sauveur, Vég. foss. houill. Belg., Pl. XLIII, fig. 1; Pl. XLIV, fig. 2.
1865. *Pecopteris muricata* (Schloth.) Stb., Heer, Urwelt d. Schweiz, p. 14, fig. 14.
1825. *Pecopteris incisa* Sternberg, Versuch, I, Tent., p. xx; Vol. II, fasc. 5–6, Pl. XXII, fig. 3; fasc. 7–8 (Presl), p. 156.
1832 or 1833. *Pecopteris nervosa* Brongniart, Hist. Vég. Foss., p. 297, Pl. XCIV, Pl. XCV, figs. 1*, 2*.
1833. *Pecopteris nervosa* Brongn., Lindley & Hutton, Foss. Fl. Gt. Brit., II, Pl. XCIV*.
1848. *Pecopteris nervosa* Brongn., Sauveur, Vég. foss. houill. Belg., Pl. XLIV, fig. 1*.
1869. *Pecopteris nervosa* Brongn., Schimper, Traité, I, p. 513, Pl. XXX, figs. 6*, 7*.
1873. *Pecopteris nervosa* Brongn., Breton, Étude géol. Dourges, p. 59, Pl. V, fig. 1*.
1876. *Pecopteris nervosa* Brongn., Heer, Fl. Foss. Helv., p. 33, Pl. XV, fig. 1*, 2.
1879. *Pecopteris nervosa* Brongn., Heer, Urwelt d. Schweiz, 2d ed., p. 9, fig. 6.
1881. *Pecopteris nervosa* Brongn., Weiss, Aus d. Fl. d. Steinkohl., p, 16, Pl. XVI, fig. 98*.
1882. *Pecopteris nervosa* Brongn., Achepohl, Niederrh.-Westfäl. Steink., pp. 74, 76, 90, Pl. XXII, fig. 6*; Pl. XXIII, fig. 14*; Pl. XXVIII, fig. 10*, 14*.
1832 or 1833. *Pecopteris nervosa* var. *α. macrophylla* Brongniart, Hist. Vég. Foss., p. 297, Pl. XCV, fig. 1*.
1832 or 1833. *Pecopteris nervosa* var. *β microphylla* Brongniart, Hist. Vég. Foss., p. 297, Pl. XCV, fig. 2*.
1832 or 1833. *Pecopteris nervosa* var. *γ oblongata* Brongniart, Hist. Vég. Foss., p. 297, Pl. XCIV*.
1832 or 1833. *Pecopteris sauveurii* Brongniart, Hist. Vég. Foss., p. 299, Pl. XCV, fig. 5*.
1834. *Pecopteris laciniata* Lindley & Hutton, Foss. Fl. Gt. Brit., II, Pl. CXXII.
1836. *Alethopteris muricata* (Schloth.) Goeppert, Syst. Fil. Foss., p. 313.
1855. *Alethopteris muricata* (Schloth.) Goepp., Ettingshausen, Steinkohlenfl. Radnitz., p. 43, Pl. XIV, fig. 1.
1869. *Alethopteris muricata* (Schloth.) Goepp., Von Roehl, Foss. Fl. Steink. Westphalens, p. 78, Pl. XI, fig. 1.
1836. *Alethopteris nervosa* (Brongn.) Goeppert, Syst. Fil. Foss., p. 312*.
1855. *Alethopteris nervosa* (Brongn.) Goepp., Geinitz, Verst. Steink. Sachsen, p. 30, Pl. XXXIII, fig. 2*, 3*.
1869. *Alethopteris nervosa* (Brongn.) Goepp., Von Roehl, Foss. Fl. Steink. Westphalens, p. 77, Pl. XXXI, fig. 7*.
1871. *Alethopteris nervosa* (Brongn.) Goepp., Dawson, Geol. Struct. P. E. I., p. 44, Pl. II, fig. 18?*.
1881. *Alethopteris nervosa* (Brongn.) Goepp., Achepohl, Niederrh.-Westfäl. Steink., p. 53, Pl. XIV, fig. 13*, 19*; p. 57, Pl. XV, fig. 4*; p. 64, Pl. XVIII, figs. 15*, 16*.

*Appears to be referable to the variety *nervosa*.

1836. *Alethopteris sauveurii* (Brongn.) Goeppert, Syst. Fil. Foss., p. 311*.
1838. *Alethopteris lindleyana* Presl [non (Royle) Schimp.], in Sternberg: Versuch, II, fasc. 7-8, p. 145*.
1848. *Pecopteris heterophylla* Sauveur [nec (Goepp.) Schimp., nec (Ung.) Schimp.], Vég. terr. houill. Belg., Pl. XLVII*.
1860. *Pecopteris subnervosa* Roemer (non Gr'Ey.), Beitr. geol. Kenntn. n.-w. Harzgeb., p. 36, Pl. VIII, fig. 11*.
1869. *Pecopteris subnervosa* Roem., Von Roehl, Foss. Fl. Steink. Westphalens, p. 90, Pl. XIII, figs. 5*, 5*a*.
1869. *Pecopteris (Aspidides) nervosa* Brongn.; Schimper, Traité, I, p. 513*.
1876. *Sphenopteris muricata* (Schloth.) O. Feistmantel, Verst. böhm. Kohlenabl., p. 59 (281), Pl. XVI (LXV), fig. 3.
1877. *Diplothmema muricatum* (Schloth.) Stur, Culm-Flora, II, p. 230.
1885. *Diplothmema muricatum* (Schloth.) Stur, Farne d. Schatzlarer Sch., p. 393, Pl. XXI, figs. 1-5; Pl. XXII, figs. 1-5*; Pl. XXIII, figs. 1*-6.
1877. *Diplothmema nervosum* (Brongn.) Stur, Culm-Flora, II, p. 230*.
1885. *Diplothmema nervosum* (Schloth.) Stur, Farne d. Schatzlarer Sch., p. 384, Pl. XXIV, fig. 1*; Pl. XXV^b, fig. 2*.
1877. *Neuropteris heterophylla* Brongn., Lebour, Illustr., Pl. XIV.
1877. *Pecopteris (Alethopteris) aquilina* (Schloth.) Brongn., Lebour, Illustr., Pl. XVI*.
1877. "Neuropterid-Frond?" Lebour, Illustr., p. 31, Pl. XV.
1877. An *Pecopteris (Alethopteris) marginata* Goepp., Lebour, Illustr., p. 35, Pl. XVII?*
1878. *Mariopteris muricata* (Schloth.) Zeiller, Expl. carte géol. Fr., IV, Atlas, Pl. CLXVII, fig. 5; text (1879), p. 71.
1886. *Mariopteris muricata* (Schloth.) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XXI, fig. 1, 1^a; Pl. XXII, figs. 1, 2, 2^a; Pl. XXIII, figs. 1, 1^a, 1^b; Pl. XX, fig. 4; text (1888), p. 173.
1893. *Mariopteris muricata* (Schloth.) Zeill., Kidston, Foss. Fl. Kilmarnock, p. 323.
1878. *Mariopteris nervosa* (Brongn.) Zeiller, Bull. Soc. Géol. Fr., (3), VII, p. 97, Pl. V, figs. 1*, 2*.
1879. *Mariopteris nervosa* (Brongn.) Zeiller, Vég. foss. terr. houill. Fr., p. 69, Pl. CLXVII, figs. 1*-4*.
1879. *Pseudopecopteris muricata* (Schloth.) Lesquereux, Coal Flora, Atlas, p. 7, Pl. XXXVII, figs. 2, 2^a, 2^b; text, 1 (1880), p. 203.
1883. *Pseudopecopteris muricata* (Schloth.) Lesquereux, 13th Rept. Geol. Survey Ind., 2, Pl. XII, figs. 3, 3^a?.
1889. *Pseudopecopteris muricata* (Schloth.) Lx., Lesley, Dict. Foss. Penna., II, p. 800 (text-fig. ?).
1879. *Pseudopecopteris nervosa* (Brongn.) Lesquereux, Coal Flora, Atlas, p. 6, Pl. XXXIV, figs. 1*, 2*, 3*; text, 1 (1880), p. 197*.
1880. *Pseudopecopteris subnervosa* (Roem.) Lesquereux, Coal Flora, I, p. 198*.
1882. *Odontopteris britannica* Gutb., Achepohl, Niederrh.-Westfäl. Steink., p. 71, Pl. XXI, fig. 6. (23?).
1882. *Odontopteris reichiana* Gutb., Achepohl, Niederrh.-Westfäl. Steink., p. 84, Pl. XXVI, fig. 21; p. 93, Pl. XXXI, fig. 7; p. 95, Pl. XXXII, figs. 6*-9.*
1882. *Odontopteris*, Achepohl, Niederrh.-Westfäl. Steink., p. 93, Pl. XXXI, fig. 2;* Pl. XXXII, figs. 4,* 5.*
1882. *Odontopteris dentiformis* Achepohl, Niederrh.-Westfäl. Steink., p. 93, Pl. XXX, fig. 6.*
1883. *Alethopteris*, Achepohl, Niederrh.-Westfäl. Steink., Ergänzungsbl. III, fig. 33.
1883. *Alethopteris acuta* Achepohl [non (Brongn.) Mill.], Niederrh.-Westfäl. Steink., p. 118, Pl. XXXVI, fig. 6.*
1883. *Alethopteris conferta* Gutb., Achepohl, Niederrh.-Westfäl. Steink., p. 117, Pl. XXXV, fig. 10.*

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*Appears to be referable to the variety *nervosa*.

1885. *Diplothmema sauveurii* (Brongn.) Stur, Farne d. Schatzlarer Sch., p. 380, Pl. XXIV, figs. 2*–4.*

1885. *Diplothmema hirtum* Stur, Farne d. Schatzlarer Sch., p. 372, Pl. XXXIV, fig. 1.*

1886. *Mariopteris muricata* forma *typica* Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XX, figs. 2, 3, 2a; Pl. XX, figs. 1, 1a; Pl. XXIII, figs. 1, 1a–b.

1886. *Mariopteris muricata* forma *nervosa* (Brongn.) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XX, figs. 2,* 3;* Pl. XXII, figs. 1,* 2,* 2a.

1886. *Mariopteris muricata* forma *hirta* (Stur) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XX, fig. 4.*

1891. *Mariopteris muricata* var. *nervosa* (Brongn.) Kidston, Foss. Pl. Staffordsh. C. F., 2, p. 78.*

In the earlier American Paleozoic plant collections, most of which were labeled by the hand of Professer Lesquereux, we find in general that the name *Pseudopecopteris muricata* was applied to a species quite distinct from that to which the name *Ps. nervosa* was affixed. Among the great number of specimens referred to one or the other of these two species there are comparatively few—and these are from the Alleghany series—whose reference is doubtful or which can not on a close examination be with satisfaction assigned to either type as relatively distinct from the other. Accordingly, it has been not a little surprising to learn that the most distinguished among the active students of Paleozoic fossil plants in Europe are not only unable to find any specific differences between the *Pecopteris nervosa* of Brongniart and Schlotheim's *Filicites muricatus*, but also that they find every transitional stage between the two forms, even finding both forms in large segments of the same frond.

The important, and at first rather startling, bearing of this synthesis on the individuality and validity of the American types has led to a reexamination of the latter and their comparison with the earlier literature. This comparative examination, aided by the consultation of specimens from the British, French, and Silesian coal fields,[1] shows that the forms commonly known in this country as *Pseudopecopteris muricata* are in fact quite different from the type illustrated by Schlotheim, and that they can not properly be referred to the latter's species. The American fossils formerly referred to that type are for the most part confined to the Pottsville series in this country. They include several distinct forms, none of which is specifically identical with Schlotheim's type. One of them has been described and illustrated under a new name in unpublished manuscript by Professor Newberry. The comparatively few specimens whose former reference was doubtful come mostly from the lower part of the Alleghany series, and their close relation to the plant figured by Schlotheim naturally justified their identification therewith, although the very liberal and apparently misleading interpretation given of the *F. muricatus* by Brongniart led to the inclusion by Lesquereux of the Pottsville plants under the same name. The

*Appears to be referable to the variety *nervosa*.

[1] Examples in the Lacoe collection, U. S. National Museum.

form first published by Schlotheim appears to constitute a *Mariopteris* type, standing most closely to that branch of the genus represented by *M. latifolia* or *M. acuta*, though perhaps intermediate to *M. nervosa*. In our Coal Measures, possibly as well as in the European, it is difficult to draw a satisfactory or definite line between the true *muricata* phases and the *nervosa* phases, since the connecting links are so close and numerous. However, the observations thus far made in the floras of our coal fields go to show that the *muricata* phase is generally earlier and stratigraphically lower than the *nervosa* type, to which it leads, and between which and one of the types in the Pottsville group it appears to indicate a line of genesis. The Coal Measures type, in a broad sense, certainly exhibits a number of phases or variations, some of which are well marked and peculiar. But while the existence of intermediate forms which render their distinct specific definition impracticable is admitted, it appears that, far from occurring with other phases promiscuously in the same fronds, or even in the same beds, these forms are often well individualized both locally and stratigraphically. Certain phases of the *nervosa* type are found in connection with certain developments of the *muricata* type, but many of the more specialized variations have never yet, I believe, been found associated. In fact, the series of forms included in the *muricata-nervosa* group may be regarded as differentiations of a single Mariopteris stock. They thus constitute one of the best exhibits of modifications and variations in a somewhat definite and well-marked stock to be found among Paleozoic ferns. The fact that between a well-marked and perhaps later form and an earlier form, which, taken as an individual, is readily distinguishable from the former and possibly not found in the same beds, there exists a series of intervening forms, does not wholly destroy the stratigraphic value of the more marked forms, while it furnishes an interesting example of species modification or specific evolution.

It may not be incompatible with good systematic biology, while increasing in a higher decree the stratigraphical value of fossil plants, to give some sort of appellation or description to such of the forms of a comprehensive species as are found to be more peculiar to certain portions of the Coal Measures, indicating differences of time, or which are found in different regions.

Since, as has been noted above, the phases of the *muricata* type are in our Coal Measures generally characteristic of the beds older and lower than those with the *nervosa* type with its prevailingly broader, more robust, and connate pinnules, with very coarse nervation, it seems well for all reasons to retain a distinction, at least varietal in rank, between the two types or sections of *M. muricata* in its broad sense. I am therefore disposed to agree with Mr. Kidston in regarding the really typical *nervosa* as a valid variety, rather than as a mere form as proposed by Professor Zeiller. To this variety belongs most of the material published in this country as *Pseudopecopteris nervosa*, although a portion of the fossils are probably referable to the typical *muricata*.[1]

The specimens from the McAlester coal field appear to represent a small, rather delicate phase of the var. *nervosa* with narrow, unconstricted, rather thin, acute pinnules. A similar phase is found in the lower part of the Kanawha series, in northern West Virginia.

Locality.—Roof of the Grady coal, 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6703–6706.

MARIOPTERIS SPHENOPTEROIDES (Lx.) Zeill.

1879. *Odontopteris sphenopteroides* Lesquereux, Coal Flora, Atlas, p. 4, Pl. XXI, figs. 3, 4; text, 1 (1880), p. 139.
1881. An *Alethopteris nervosa* (Brongn.) Goepp., Achepohl, Niederrh.-Westfäl. Steink., p. 42, Pl. XI, fig. 16?
1883. *Sphenopteris nobilis* Achepohl, Niederrh.-Westfäl. Steink., Ergänzungsbl. III, fig. 5.
1886. *Mariopteris sphenopteroides* (Lx.) Zeiller, Fl. Foss. houill. Valenciennes, Atlas, Pl. XIX, figs. 3, 4; text (1888), p. 171.

This species, which is well represented in the Cherokee shales of Henry County, Missouri,[2] and which is also found at Mazon Creek, Illinois, appears to be very rarely present in small fragments from the McAlester coal field.

Localities.—One-half mile west of McAlester, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6753.

Two miles east of Krebs, Indian Territory, NW. ¼ sec. 12, T. 5 N., R. 15 E.; roof of the Grady coal. U. S. Nat. Mus. Reg. 6700.

MARIOPTERIS SILLIMANNI (Brongn.).

1835 or 1836. *Pecopteris sillimanni* Brongniart, Hist. Vég. Foss., 1, p. 353, Pl. XCVI, fig. 5, 5a.
1869. *Pecopteris* (*Aspidides*) *sillimanni* Brongn., Schimper, Traité, 1, p. 515.
1870. *Callipteris sillimanni* (Brongn.) Weiss, Zeitschr. d. deutsch. geol. Gesell., XXXII, p. 864.
1879. *Pseudopecopteris sillimanni* (Brongn.) Lesquereux, Coal Flora, Atlas, p. 7, Pl. XXXVII, fig. 3; text, 1 (1880), p. 206.

The plant from Zanesville, Ohio, published by Brongniart[3] as *Pecopteris sillimanni*, appears from the figure given in the "Histoire" to be close to, if not identical with, a single fern fragment from the Grady coal. The apparent differences include a rather more oblique position of the pinnules, which are proportionately a little longer and more markedly connate near the apex of the pinna and in the rather thinner nervation. The specimen from Indian Territory seems to agree in

[1] In the above synonymy the figures or descriptions that appear to represent the *nervosa* type are marked by an asterisk (*).

[2] The species has been fully illustrated in a monograph of the Flora of the Lower Coal Measures of Missouri (Mon. U. S. Geol. Survey, Vol. XXXVII).

[3] Hist. Vég. Foss., p. 353, Pl. XCVI, figs. 5, 5a.

some respects equally, if not more closely, nevertheless, with the example from Cannelton, Pennsylvania (No. 3508 of the Lacoe collection), illustrated by Lesquereux[1] as *Pseudopecopteris sillimanni.* The known variation in the pinnæ of Mariopteris, to which, on account of their relations to *M. pottsvillea* and others of the *muricata* group, I believe these plants to belong, make it seem probable that the collection of additional material in the McAlester coal fields will show the form and proportions of Brongniart's Zanesville specimens, though it may be necessary to compare material from the latter locality in order to satisfy the question of the difference in nervation.

Locality.—Mine No. 12, NW. ¼ of sec. 12, T. 5 N., R. 15 E., 2 miles east of Krebs, Indian Territory; roof of the Grady coal. U. S. Nat. Mus. Reg. 6716.

MARIOPTERIS OCCIDENTALIS n. sp.

Pl. LXVII, figs. 1-6, 1a, 4a.

Fronds rather small, compact. Divisions of the primary pinnæ open, close, ovate-lanceolate, acute, the inferior proximal segments being heteromorphous, the rachis broadly ventrally canaliculate, minutely lineate, and bordered by a very narrow decurring lamina. Penultimate pinnæ open at nearly a right angle, alternate, lanceolate, or linear-lanceolate, acute, or acuminate. Ultimate pinnæ open, alternate, or subalternate, rather close, small, somewhat rigid or slightly curved, oblong, or ovate-oblong in the earliest stage, becoming lanceolate, acute, with a very narrowly bordered, depressed rachis.

Pinnules small, somewhat polymorphous, open, usually nearly touching, often contiguous, especially near the apex of the pinna. The larger ones ovate-oblong, with slightly upturned, more or less acute apices, the bases being abruptly contracted by a deep and very narrow distal sinus and a slightly rounded sinus at the proximal angle. The lowest proximal pinnules often unequally or somewhat irregularly divided, or the succeeding pinnules broadly, compactly, and obliquely truncate-round-sublobate, with very narrow, shallow sinuses in passing into the pinnatifid stage, while the pinnules near the apex of the pinna become very small, oblique, close, usually touching, gradually connate in passing upward, with shallower, oblique, strongly decurrent sinuses, at first broadly oval, or obovate, or slightly cuneate, rounded, and gradually blended with the small ovate, faintly sublobate terminal pinnule. Lamina a little thick, obscuring the nervation somewhat on the ventral surface, glossy, depressed over the stronger primary nerves, very slightly arched at the border, and decurring by a narrow wing along the rachis.

Nervation generally distinct on the dorsal surface of the pinnule. Primary nerve of moderate strength, originating at a very acute angle,

[1] Coal Flora, Vol. I, p. 206, Pl. XXXVII, fig. 3.

but curving rapidly outward and passing with a slight upward curve toward the apex of the pinnule. Secondary nerves not very strong, distant, forking at a moderate, or sometimes a wide, angle near the base, one or both of the nervils forking usually again at a rather wide angle in arching, sometimes strongly, to the margin, which they touch, quite distantly, at less than a right angle.

The general aspect of the larger pinnæ of this species, which is represented by many specimens from McAlester, is very similar to that of *Neuropteris cordato-ovata* of Weiss,[1] recorded from the higher Coal Measures of the United States by Lesquereux[2] as *Pseudopecopteris cordato-ovata*. It will readily be seen, however, that the plant illustrated in Pl. LXVII, fig. 4, of this paper differs from that published by Weiss by the distinctly Mariopteroid heteromorphy of the inferior basal pinnules and the corresponding divisions of the pinnæ, as well as by the obviously distinct nervation, which is nearer the type seen in *Mariopteris mazoniana*. A further difference of minor importance lies in the size of the pinnæ and pinnules, only the very largest of which in *M. occidentalis* approach the proportions of those in the plant figured by Weiss, although the form in that case is so similar. In regard to this similarity in the form it will be noted that the largest pinnules of the McAlester fern are nearly as acute as those of the European type, although generally smaller and less obtuse than the plant from Wilkesbarre, Pennsylvania, figured by Professor Lesquereux. The latter differs from *M. occidentalis* as much in size and nearly as much in nervation as does the Old World type, though from the Mariopteroid form of the pinnules and development of the basal pinnules, as illustrated in the Coal Flora,[3] or seen in numerous specimens from the Coal Measures of the Mississippi Valley, I have little hesitation in transferring the Wilkesbarre plant to the genus Mariopteris, to which should also, in my judgment, be referred the *Odontopteris pachyderma* of Fontaine and I. C. White.[4] A small fragment of a fern similar to or perhaps identical with the plant described above is found on a specimen from Ottawa, Kansas, No. 2202 in the Lacoe collection of the U. S. National Museum.

Among other Coal Measures species of *Mariopteris* to which our plant is related *Diplothmema jacquoti* Zeiller[5] and *Pecopteris loschii* Brongniart[6] are perhaps most similar. The former appears to represent a much broader type, with broadly ovate, arched pinnules having a thickened border, and is comparable to some of the small species of Mariopteris near the top of the Pottsville series in this country, while the latter, described from Zanesville, Ohio, has its pinnules rather strongly narrowed at the base.

[1] Foss. Fl. jüngst. Steink. u. Rothl., p. 28, Pl. I, figs. 1, 1a.
[2] Coal Flora, Vol. I, p. 205, Pl. XXXVII, figs. 4, 5.
[3] Pl. XXXVII, figs. 4, 4a, 5.
[4] Permian Flora, p. 53, Pl. X, figs. 5-10.
[5] Fl. Foss. bassin houill. Valenciennes, Pl. XVIII, figs. 3-6.
[6] Hist. Vég. Foss., p. 355, Pl. XCVI, figs. 6, 6a.

Localities.—One-half mile west of McAlester, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6435. Cherryvale, Indian Territory, same horizon. U. S. Nat. Mus. Reg. 6603.

MARIOPTERIS OCCIDENTALIS VILLOSA n. var.

Pl. LXVII, figs. 8, 8*a*, 9.

Pinnules more robust and more obtuse than in normal form, close, or touching, strongly imbricated in the upper portions of the pinnæ, densely and somewhat irregularly rugose-striate in the direction of the nervation, which is almost wholly obscured.

The general aspect of the variety here described is similar to that of the species from McAlester, with the exception that the pinnules are compact, rather more robust, obtuse, assuming a slightly more oblong form. A close inspection, however, shows that, whereas the nervation of the normal type is fairly clear, the laminæ smooth and not very thick, the substance of the variety is thick and is rugose in somewhat irregular roughened or corrugated striæ, parallel in general to the direction of the nervation, which is scarcely visible.

The form as a whole is probably related to *Mariopteris incompleta* (Lx.), and *Pecopteris aspera* Brongn. It should, possibly, be recognized as a distinct species.

Locality.—Mine No. 12, NW. ¼ Sec. 12, T. 5 N., R. 15 E., 2 miles east of Krebs, Indian Territory; roof of Grady coal. U. S. Nat. Mus. Reg. 6748–6750.

MARIOPTERIS CAPITATA n. sp.

1893. *Mariopteris* (*Pseudopecopteris*) *decipiens* (Lx.) D. White, Bull. U. S. Geol. Survey No. 98, p. 47 (Excl. Syn.), Pl. 1, figs. 5–8, Pl. II, figs. 1–3.

Fronds large, dichotomous below, tripinnate or quadripinnate, spreading; primary rachis broad, flat, 2 to 7 millimeters or more in width, rather lax, somewhat flexuous, somewhat geniculate below, tapering rapidly toward the apex, irregularly striate, punctate, covered in portions by a thin, often shiny, epidermis, the upper portion bordered by narrow laminæ from the decurrent pinnules; primary pinnæ at right angles or oblique toward the apex, oval-lanceolate, somewhat contracted below, tapering above to a slightly obtuse apex; secondary rachis rather lax, finely punctate, often flexuous, usually sulcate or depressed above, round below, somewhat decurrent at the base; secondary pinnæ alternate, at right angles to the rachis, or oblique, the lower ones often curved backward, close, usually parallel, with margins close, generally touching or slightly overlapping, 1.5 to 6 centimeters or more in length, linear-lanceolate, 8 millimeters to 3 centimeters wide, obtuse, terminating in large, broad sub-lobate, oval, ovate, or deltoid pinnules with sinuate margins and rounded tip.

Pinnules slightly polymorphous, alternate, more or less oblique, close, generally nearly contiguous, sometimes slightly overlapping, thin, 3 millimeters to 2 centimeters long, 2 to 9 millimeters broad, the lowest ones broader, oval, ovate, or obovate, sometimes orbicular at the base of the pinnæ, occasionally oblong in the largest pinnæ and on the tip of the primary pinnæ, always rounded above, decurrent and more or less connate by the decurrent laminæ, the margins usually slightly thickened and marked by a shallow furrow on the upper side; those toward the lower end of the larger pinnæ contracted at the base, especially on the anterior margin, rounded below with a broad attachment to the rachis, connate by a narrow, decurring lamina; those higher up in the pinna oval or obovate, curving outward, rounded at the base above by a deep and narrow sinus, decurrent below; those still higher on the pinna not so deeply divided, becoming united somewhat below, and passing into the terminal pinnule, which is often nearly as broad as the pinna; pinnules of the upper secondary pinnæ less deeply separated, attached by the whole width; secondary pinnæ succeeded, in passing toward the apex of the primary pinnæ, by pinnatifid pinnules, lobed at the base, large oblong above, becoming entire with slightly sinuate margins in passing upward, then entire, oblong, ovate, or obovate, with broadening attachments to the rachis, as in the secondary pinnæ; lower pair of pinnules at the base of each secondary pinna usually shorter, more rounded at the base and broader than those succeeding; the one on the upper side of the pinna more or less orbicular or truncate above, the distal border often marked by a broad, shallow sinus or slight fissure in the more mature specimens; the pinnule on the lower side more or less triangular or alate, the longest side, opposite the attachment, bilobate, more or less deeply cleft in the more mature specimens, dividing the pinnule into two unequal lobes, the distal lobe usually longer and broader, the proximal lobe rounder and somewhat auriculate, or overlapping the rachis; pinnules of the lower secondary pinnæ becoming oblong, with slightly undulate margins, then lobed below, becoming, in passing downward, like those near the tip of the primary pinnæ, gradually pinnatifid, the terminal pinnule long, broad, and obtuse, and assuming the forms and proportions of the secondary pinnæ, the divisions corresponding to the lower basal pinnule of the secondary pinnæ, shorter, with anomalous pinnatifid divisions diverging from the attachment of the original pinnule.

Nervation generally obscure, except in the lower part of the pinnule; primary nerves rather strong, diverging from the rachis usually at a very narrow angle and arching more or less gradually into the pinnules, giving off branches at a narrow angle during their passage, and dissolving below the apex; primary bundles, often several, perhaps springing directly from the rachis in the smaller pinnules, and diverging somewhat flabellately toward the margins, branching several times, but only one becoming developed as a median nerve in each of the largest basally constricted pinnules, in which it is strong, depressed, and minutely punctate below, diminishing above by finer branches, arching slightly and branching repeatedly in passing to the margin, where the very slender and slightly flexuous nervils count about thirty-five to the centimeter; nerves of the basal pinnules of the pinnæ more or less flabellate from the broad entering band of nerves at the base, forking, and passing, arched, to the lateral margins, nearly straight, toward the top; fructification unknown.

Among the material from the Carboniferous outliers in the zinc and lead region of southwestern Missouri I found a large number of specimens, which, while failing to agree well with the various published figures and descriptions of *Pseudopecopteris decipiens* (Lx.), were nevertheless, "after much hesitation," referred to the latter species, since they appeared to agree with certain specimens in the collection of the U. S. National Museum labelled by Professor Lesquereux under that name.

Subsequently, however, the addition to the national collections of material from many sources, especially the accession of the types in the Lacoe collection, has brought together rich material, some of which is from type localities, for comparison. A study of this material, together with an examination of the types in the Lacoe collection, shows the plant published, with a careful description of the material from the Missouri outlier flora, to be quite distinct from the original type from the Shamokin Gap.[1] The latter, as shown by other specimens from the same series of the anthracite region, is again distinct from that later illustrated from the Paleozoic flora of Arkansas.[2] The latter is somewhat nearer the plant described above, though it differs by the shorter, more connate, irregular pinnules and the small terminal lobes. The aspect of the upper pinnæ of the plant from James Fork of the Poteau River in Arkansas is, like the original of Coal Flora Pl. LII, figs. 10, 10a (now No. 5008 of the Lacoe collection), closely similar to that of the fern illustrated by Lesquereux[3] as *Pseudopecopteris anceps.*

For a discussion of the characters of *Mariopteris capitata* the reader is referred to the remarks in my report on the flora of the Missouri outliers.[4] Several fragments from the collection under consideration appear to agree well with the types of that report.

Mariopteris capitata belongs to the group represented by *M. cordato-ovata* (Weiss), *M. pachyderma* (F. & W.), *M. occidentalis*, *M. lesquereuxii* (Newb.), and *M. sillimanni* (Brongn.), which, with Professor Zeiller's *Diplothmena jaquoti*, lead back to the *M. inflata* type and the Pottsville group, represented by *M. pottsvillea* or *M. muricata* (Schloth.) Zeill. It is probably nearest related to *M. sillimanni*, from which it is distinguished by its longer, more oblong, obtuse, constricted, less arched, and more connate pinnules, the terminal pinnule being larger and sublobate.

[1] Geol. Pa., Vol. II, 2, 1858, p. 862, Pl. XVIII, figs. 2, 2a.
[2] Rept. Geol. Surv. Ark., Vol. II, 1860, p. 312, Pl. V, figs. 1, 1a.
[3] Coal Flora, Atlas, p. 7, Pl. XXXVIII; text 1, p. 207.
[4] Bull. U. S. Geol. Survey No. 98, pp. 47–52.

Locality.—Roof of McAlester coal, one-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6514.

MARIOPTERIS sp.

The ironstone concretions from mine No. 12 contain two fragments of another species of this genus. The pinnules are large, dilated, obtusely rounded, and round sublobate. The fragments strongly suggest *Mariopteris speciosa* Lx. sp.[1]

Locality.—Roof of the Grady coal at mine No. 12, 2 miles southeast of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6754.

SPHENOPTERIDEAE.

SPHENOPTERIS Brongniart, 1822.

1822. *Filicites* sect. *Sphenopteris* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 233.
1826. *Sphænopteris* Sternberg, Versuch, 1, tent., p. xv.
1828. *Sphenopteris* Brongniart, Prodrome, p. 28.

SPHENOPTERIS LACOEI D. W.

1893. *Sphenopteris lacoei* D. White, Bull. U. S. Geol. Survey No. 98, p. 56, figs. 5, 6 (excl. fig. 5a).

The material of this species, described from a small Carboniferous outlying basin near Belleville, Jasper County, Missouri, agrees well with the type specimens. The species, for the description of which the reader is referred to the report on the latter,[2] is also present in the Des Moines series near Clinton, Missouri.

Locality.—One-half mile west of McAlester, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6447.

SPHENOPTERIS TAFFII n. sp.

Pl. LXVII, figs. 7, 7a; Pl. LXVIII, figs. 1?, 19?.

Penultimate pinnæ linear-lanceolate, or lanceolate, slightly contracted at the base, tapering above to a rather slender, acute point, the rachis being rather strong, lineate, and bordered by a relatively broad, even wing of the decurrent lamina. Ultimate pinnæ alternate, rather open, close, or a little distant, oblong-triangular, laterally asymmetrical, slightly subfalcate, oblong-triangular, or ovate-oblong, obtuse, short, and cut by narrow decurrent sinuses into 5 or more short, broad, nearly erect, truncate-rounded, faintly crenulate, extremely broadly cuneate, or slightly obovate, distally coalescent lobes, or, when larger or lower in the frond, becoming elongated, very open, linear, somewhat upward-turned, and acute.

Pinnules of the young pinnæ or in the pinnatifid stage as described above; those of the elongated pinnæ being small, close, inequilateral,

[1] Coal Flora, 1, p. 216, Pl. LI, fig. 1. *Pseudopecopteris speciosa* Lx.
[2] Bull. U. S. Geol. Survey, No, 98, 1893, pp. 56–58, Pl. II, figs. 5, 5a, 6.

short, alternate, ovate, round-obtuse, not contracted at the base, slightly connate around the narrow decurrent sinus, or becoming ovate, a little more distant, slightly constricted at the strongly decurrent base, and crenulate. Lamina thin, very minutely but distinctly rugose, and provided on any portion of its surface, even on the epidermis of the rachis, with small, slightly prominent, rounded, apparently glanduloid, not very distant dots, about .2 mm. in diameter, or slightly oval in a general direction parallel to the nervation, the low-rounded or flattened tops being often depressed, thus giving the dots a mammillate form.

Nervation rather strong, though usually hardly distinct. Primary nerve originating at a rather open angle, irregularly finely striate, forking generally at a moderately-wide angle, the nervils being few, rather broad, erect, or curving slightly upward, and simple or forking again in the larger lobes or pinnules.

The salient features of the above-described species are the relatively broadly alate rachis, the slightly subfalcate form of the ultimate pinnæ, the inequilateral crenulate decurrent pinnules and lobes, and the conspicuous dots scattered, as seen in Pl. LXVII, fig. 7, loosely about on all portions of the plant, including the epidermis of the rachis.[1] Although they are in general rather more numerous on the pinnules, there is so little difference in their distribution and they vary so little in size that, taking into account the fact that they are present in almost equal numbers on all fragments of the plant, I am disposed to regard them as of a glandular nature, instead of considering them as fungi similar to *Excipulites*, as they at first appear to be. The dots are not high, though the excellent preservation of the fern renders them quite evident. The general appearance of the individual is seen in the enlarged fig. 7*a*, Pl. LXVII.

The generic identity of this species, the mode of development of whose fronds is, unfortunately, not shown in the series before me, is uncertain. It has some characters in common with specimens which in this country have been referred to *Pseudopecopteris* (*Dicksonites*) *pluckenetii* (Brongn.) Lx., but its nearest relationship, judged from the fragments of pinnæ and pinnules, is with the cristate group of sphenopterids as represented by *Sphenopteris brittsii* Lx.,[2] whose slender pinnæ and inequilateral pinnules strongly resemble our form even to the occurrence of an occasional very small dot on the lamina, though the margin of the Missouri plant is distinctly denticulate, while the pinnules are more broadly ovate.

The form of the pinnatifid pinnules in the larger pinnæ and the crenulation of the margin are suggestive of the *Sphenopteris mediana* of Lesquereux[3] from the higher coals of the Southern Anthracite field.

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[1] They are clearly seen on a segment of a rachis 11 mm. wide in one of the specimens, the rounded or slightly mammillate protuberances being quite easily distinguishable from the punctations on the stems of the villous Pecopterids or the Sphenopterids of the Hoeninghausii group.

[2] Coal Flora, p. 277, Pl. LV., figs. 2, 2a–b.

[3] Geol. Pa., II, 1858, p. 862, Pl. VIII, figs. 8, 9, 9a. See fig. 8. Coal Flora, I, p. 271.

The latter species appears, however, to differ more conspicuously by the absence of the rachial wing, the more oblong pinnæ, and the smooth lamina.

To *Sphenopteris taffii* should probably be referred a specimen, No. 5046, of the Lacoe Collection, U. S. National Museum, from near the base of the Middle Coal Measures at Lansing, near Leavenworth, Kans.

Localities.—One-half mile west of McAlester, Indian Territory; roof of McAlester coal. U. S. Nat. Mus. Reg. 6440, 6441. Also from the same horizon at Savanna, Indian Territory. U. S. Nat. Mus. Reg. 6566.

SPHENOPTERIS sp. indet.

Besides the form described above, there are in the collection from McAlester two very small and obscure fragments which are too incomplete and too thoroughly macerated to reveal the outlines or the normal nervation. One of the fragments seems to represent a fertile, linear-lobed diplothmemoid form suggestive of Hymenotheca. The other belongs perhaps more properly to Oligocarpia, though it is too far destroyed to permit a satisfactory determination.

Locality.—One-half mile west of McAlester, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6442.

ALOIOPTERIS Potonié, 1894.

Jahrb. d. k. Pr. Geol. Landesanst. u. Bergakad., XIV (1893), Mittheil., p. xlviii. Abh. d. k. Preuss. Geol. Landesanst., N. F., No. 21, 1896, p. 24.

ALOIOPTERIS WINSLOVII D. W. Mss.

1843. Cf. *Pecopteris (Diplazites) cristatus* Gutbier, in Naumann, Cotta, and Geinitz, Gaea v. Sachsen, p. 80.

1848. Cf. *Pecopteris cristata* Gutb. (non Brongn.), Goeppert, in Bronn, Index Pal., p. 80.

1879. *Pecopteris cristata* Gutb., Lesquereux, Coal Flora, Atlas, p. 8, Pl. XLIV, fig. 2, 2*a*; text, 1 (1880), p. 256.

1854. An *Asplenites sternbergii* Ettingshausen, Beitr. Fl. Radnitz, p. 42 (pars), Pl. XX, fig. 2, 3, 4?

1855. An *Alethopteris cristata* (Gutb.) Geinitz, Verst. Steink. Sachsen, p. 29, Pl. XXXII, fig. 6?

1885. An *Saccopteris (Alethopteris) cristata* (Gutb.) Stur, Farne d. Carbon-Fl., p. 164.

1897. *Pecopteris* n. sp., D. White, Bull. Geol. Soc. Amer., VIII, p. 291.

This species, somewhat familiar to American paleontologists under the name of *Pecopteris cristata* Gutb., has been separated by the writer from the Old World species, after a thorough study and comparison of abundant material from the Des Moines series of Missouri,[1] on account of several characters of specific rank. The American plant, whose fertile form probably belongs to Corynepteris, has a wide distribution in the Coal Measures, it being not very rare among the plants from the Missourian of Kansas.

Locality.—One-half mile west of McAlester, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6465–6470.

[1] Mon. Flora Lower Coal Missouri, Mon. U. S. Geol. Surv., Vol. XXXVII.

ALOIOPTERIS sp.

The genus Aloiopteris is further represented in the collections by a solitary small fertile fragment from Cherryvale. In the proportions of the pinna the fragment strongly suggests *A. erosa* (Gutb.), as identified in numerous specimens from the Upper Coal Measures (Missourian) of Kansas. It is possible, however, that this fragment, which is too incomplete for identification, may be from the peripheral portion of the frond of *A. Winslovii.*

Locality.—Westernmost mine at Cherryvale, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6612.

PECOPTERIDEAE.

PECOPTERIS Brongniart, 1822.

1822. *Filicites* —— *sect. Pecopteris* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 233.
1826. *Pecopteris* Sternberg, Versuch, 1, tent., p. XVII (pars).
1828. *Pecopteris* Brongniart, Prodrome, p. 54.

PECOPTERIS DENTATA Brongn. (non Will.).

1828. *Pecopteris dentata* Brongniart, Prodrome, pp. 58, 170.
1834. *Pecopteris dentata* Brongniart, Hist. Vég. Foss., p. 346, Pl. CXXIII, CXXIV.
1835. *Pecopteris dentata* Brongn., Lindley and Hutton, Foss. Flora, II, Pl. CLIV.
1870. *Pecopteris dentata* Brongn., Lesquereux, Rept. Geol. Surv. Ill., IV, p. 404.
1876. *Pecopteris dentata* Brongn., Ferd. Roemer, Leth. geogn., 1, Atlas, Pl. LII, figs. 1*a*, *b*; text (1880), p. 176.
1878. *Pecopteris dentata* Brongn., Zeiller, Vég. foss. terr. houill., Atlas, Pl. CLXVIII, figs. 3, 4; text (1879), p. 86.
1879. *Pecopteris dentata* Brongn., Lesquereux, Coal Flora, Atlas, Pl. XLIV, figs. 4, 4a; text, I (1880), p. 240.
1880. *Pecopteris dentata* Brongn., Fontaine and I. C. White, Permian Flora, p. 66, Pl. XXII, figs. 1, 2 (3–5?).
1883. *Pecopteris dentata* Brongn., Renault, Cours Bot. Foss., III, p. 121, Pl. XXI, figs. 4, 5.
1887. *Pecopteris dentata* Brongn., Lesquereux, Proc. U. S. Nat. Mus., X, p. 25.
1893. *Pecopteris dentata* Brongn., D. White, Bull. U. S. Geol. Survey, No. 98, p. 60.
1828. *Pecopteris plumosa* (Artis?) Brongniart, Prodrome, pp. 58, 171.
1835 or 1836. *Pecopteris plumosa* (Artis?), Brongniart, Hist. Vég. Foss., p. 348, Pls. CXXI, CXXII.
1858. *Pecopteris plumosa* (Artis?) Brongn., Lesquereux, Geol. Pa., II, 2, p. 867.
1866. *Pecopteris plumosa* (Artis?) Brongn., Lesquereux, Rept. Geol. Surv. Ill., II, Pal., p. 442.
1869. *Pecopteris plumosa* (Artis?) Brongn., von Roehl, Foss. Fl. Steink. Westphalens, p. 58, Pl. XXXIII, fig. 4.
1881. *Pecopteris plumosa* (Artis?) Brongn., Weiss, Aus d. Fl. d. Steink., Pl. XVII, figs. 104, 104*a*.
1888. *Pecopteris plumosa* (Artis?) Brongn., Howse, Trans. N. H. Soc. Northumberland and Durham, X, 1, p. 89.
1828. *Pecopteris triangularis* Brongniart, Prodrome, pp. 58, 171.
1832. An *Sphenopteris caudata* Lindley and Hutton, Foss. Flora, I, Pl. XLVIII?

1833. *Cyatheites dentatus* (Brongn.) Goeppert, Systema, p. 325.
1855. *Cyatheites dentatus* (Brongn.) Goepp., Geinitz, Verst. Steink. Sachsen, p. 26 (pars), Pl. XXIX, figs. 10–12; Pl. XXX, figs. 1, 2.
1869. *Cyatheites dentatus* (Brongn.) Goepp., von Roehl, Foss. Fl. Steink. Westphalens, p. 87, Pl. XXXIII, fig. 6.
1876. *Cyatheites dentatus* (Brongn.) Goepp., Heer, Fl. foss. Helv., p. 30, Pls. XI, XII, figs. 1–5.
1838. *Pecopteris brongniartiana* Presl, in Sternberg, Versuch, II, 7 u. 8, p. 160.
1848. *Cyatheites plumosus* (Artis?) Goeppert, in Bronn, Index Palæont., p. 365.
1869. *Cyathocarpus dentatus* (Brongn.) Weiss, Foss. Fl. jüngst. Steink. u. Rothl. Saar-Rh. Geb., p. 86.
1869. *Pecopteris (Cyatheides) dentata* Brongn., Schimper, Traité, I, p. 508.
1877. *Senftenbergia dentata* (Brongn.) Stur, Culm-Flora, II, p. 187 (293).
1877. *Senftenbergia plumosa* (Artis?) Stur, Culm-Flora, II, p. 187 (293).
1885. *Senftenbergia plumosa* (Artis?) Stur, Farne d. Carbon-Fl., p. 92 (pars), Pl. LI, figs. 1, 2, 3.
1883. *Dactylotheca dentata* (Brongn.) Zeiller, Ann. Sci. Nat., (6) bot., XVI, p. 184, Pl. IX, figs. 12–15.
1888. *Dactylotheca dentata* (Brongn.) Zeiller, Fl. foss. houill. Valenciennes, p. 30, fig. 16 *a, b*.
1890. *Dactylotheca dentata* (Brongn.) Zeiller, Fl. foss. Autun et Épinac, I, p. 21, fig. 17 *a, b*.
1885. *Senftenbergia acuta* (Brongn.)., Stur, Farne d. Carbon-Fl., I, p. 96, Pl. LI, figs. 4, 5.
1886. *Pecopteris (Dactylotheca) dentata* Brongn., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XXVI, figs. 1, 1 *a, b*, 2, 2 *a–e*; Pl. XXVII, figs. 1, 1 *a, b*, 2, 2 *a*, 3, 3 *a*, 4; Pl. XXVIII, figs. 4, 5, 5 *a*; text (1888), p. 196.
1890. *Pecopteris (Dactylotheca) dentata* (Brongn.) Zeiller, Fl. foss. Autun et Épinac, I, p. 66, Pl. IX *a*, figs. 3, 3 *a*.
1887. *Dactylotheca plumosa* (Artis?) Kidston, Foss. Fl. Radstock Ser., p. 381.
1887. *Dactylotheca plumosa* Brongn. var. *dentata* (Brongn.) Kidston, Foss. Fl. Radstock Ser., p. 382.

The form represented in the collections belongs to the higher Coal Measures type of the species with large broad pinnules, in which the nerves fork at a wide angle, one or both of the nervilles sometimes forking again in the largest pinnules, in contradistinction to the basal Coal Measures forms represented by *P. acuta*, *P. plumosa*, or the very delicate simple-nerved type of the upper part of the Pottsville series seen in the *Aspidites silesiacus* Goepp., from the Waldenburg Series.

Localities.—One-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6448. Cherryvale, Indian Territory, westernmost mine. U. S. Nat. Mus. Reg. 6604. Savanna, Indian Territory. U. S. Nat. Mus. Reg. 6582. All from the roof of the McAlester coal.

PECOPTERIS UNITA Brongn.

1828. *Pecopteris unita* Brongniart, Prodrome, p. 58.
1833 or 1834. *Pecopteris unita* Brongniart, Hist. Vég. Foss., p. 342, Pl. CXVI, fig. 1–5, 1 *a–b*.
1838. *Pecopteris unita* Brongn., Presl, in Sternberg: Versuch, II, fasc. 7–8, p. 158.
1870. An *Pecopteris unita* Brongn., Unger, Sitzb. Akad. Wiss. Wien, Math.-nat. Cl., LX, 1, p. 785, pl. 1, figs 4, 5. ?
1877. *Pecopteris unita* Brongn., Grand'Eury, Fl. carb. Loire, p. 76, Pl. VIII, fig. 13.

1879. *Pecopteris unita* Brongn., Lesquereux, Coal Flora, Atlas, Pl. XL, fig. 1–7; text, 1 (1880), p. 223.
1883. *Pecopteris unita* Brongn., Lesquereux, 13th Rep't Geol. Surv. Ind., 2, Pl. XIII, fig. 3, 3 *b*.
1883. *Pecopteris unita* Brongn., Renault, Cours Bot. Foss., III, p. 119, Pl. XX, figs. 11-19.
1887. *Pecopteris unita* Brongn., Kidston, Foss. Fl. Radstock Ser., p. 367, Pl. XXIV, figs. 2–9.
1887. *Pecopteris unita* Brongn., Schmalhausen, Pfl. Artinsk. u. Perm. Abl., p. 29, Pl. II, fig. 13.?
1889. *Pecopteris unita* Brongn., Lesley, Dict. Foss. Pa., II, p. 610, text fig.
1890. *Pecopteris unita* Brongn., Grand'Eury, Géol. Paléont. houill. Gard, p. 278. Pl. V, fig. 1 (fertile), Pl. VI, fig. 24.
1828. *Pecopteris pectinata* Brongniart, Prodrome, p. 58.
1848. *Cyatheites unitus* (Brongn.) Goeppert, in Bronn: Nomenclator, p. 365.
1855. *Cyatheites unitus* (Brongn.) Goepp., Geinitz, Verst. Steink. Sachsen, p. 25, Pl. XXIX, figs. 4, 5.
1857. *Cyatheites unitus* (Brongn.) Goepp., Meneghini, Pal. Sardaigne, p. 160, Pl. D, f. II, 3, fig. VI, 4, 4*a*.
1849. *Pecopteris* (*Aplophlebis*) *unita* Brongniart, Tableau d. Genres, p. 25.
1865. *Aspidium brongniartii* Ettingshausen, Farrnkr. Jetzwelt, p. 200.
1869. *Pecopteris* (*Cyatheides*) *unita* Brongn., Schimper, Traité, 1, p. 505.
1869. *Cyathocarpus unitus* (Brongn.) Weiss, Foss. Fl. jüngste Steink. Rothl., p. 88, Pl. XII, figs. 5, 6.
1877. *Oligocarpia unita* (Brongn.) Stur, Culm-Flora, 11, p. 294.
1877. *Goniopteris unita* (Brongn.) Grand 'Eury, Fl. carb. Loire, Pl. VIII, fig. 13.
1879. *Stichopteris unita* (Brongn.) Schimper, in Zittel: Handb. Palaeont., II, p. 90, figs. 65, $_{6-8}$.
1879. *Pecopteris* (*Goniopteris*) *unita* Brongn., Lesquereux, Coal Flora, Atlas, p. 7, Pl. XLI, figs. 1–7.
1896. *Pecopteris* (*Goniopteris*) *unita* Brongn., Renault, Fl. foss. Autun et Épinac, II, p. 10.
1883. *Diplazites unitus* (Brongn.) Stur, Zur Morph. u. Syst. Culm. Carbon-Farne, p. 143.
1885. *Diplazites unitus* (Brongn.) Stur, Farne d. Schatzlarer Sch., p. 214.
1888. *Pecopteris* (*Ptychocarpus*) *unita* Brong., Zeiller, Fl. foss. houill. Commentry, I, p. 162, Pl. XVIII, figs. 1–5.
1890. *Pecopteris* (*Ptychocarpus*) *unita* Brongn., Zeiller, Fl. foss. Autun et Épinac, I, p. 63, Pl. VIII, figs. 11, 11*a*, p. 65, fig. 31, A–D.
1888. *Ptychocarpus unitus* (Brongn.) Zeiller, Fl. foss. houill. Valenciennes, p. 40, text-fig., 26 *a*, *b*.
1889. *Ptychocarpus unitus* (Brongn.) Zeill., Kidston, Fruct. Carb. Ferns, p. 23, Pl. II, fig. 22.
1890. *Ptychocarpus unitus* (Brongn.) Zeiller, Fl. foss. Autun et Épinac, I, p. 25, text-fig. 23.
1896. *Ptychocarpus unitus* (Brongn.) Zeill., Renault, Fl. foss. Autun et Épinac, II, pp. 9, 10, figs. 4, 5.

Much difference of opinion exists as to the validity of the differentiation of the plants described as *Pecopteris unita*, *P. longifolia* (non Stb.), *P. emarginata*, *Goniopteris oblonga*, and *G. elliptica*. Most of the living authorities on Paleozoic ferns agree in uniting several if not all of the above-enumerated forms in one species, *P. unita*. The decision to combine *P. unita*, *P. longifolia* (Brongn.), and *P. emarginata* is nearly unanimous among the paleobotanists of Europe, though several have, notwithstanding the avowed existence of complete transitions, recognized or suggested a number of "forms" or varieties.[1]

In general the writer has not been able to find even a satisfactory varietal distinction in most of the American material recorded as *P. unita* and *P. emarginata*. But between the plants described by Fontaine and I. C. White from the Monongahela series, on the one hand, and those identified by Lesquereux from the Allegheny series on the other, there is at least a varietal distinction, although the latter can not be said to agree with Brongniart's figures and illustrations more nearly than do the later forms.

The entire group of the American species, including also the material in *P. lanceolata*, *P. robusta*, *P. arguta*, *P. elegans*, and *P. hallii* is, in my opinion, in need of comparative examination and critical revision. The synonymy given above is but partial, only those names applied to the original types being quoted.

Among the specimens from the McAlester coal field, those from the horizon of the Grady coal appear to belong to a small early phase of the form with distinctly upward-turned nervils and broadly confluent pinnules, approaching in habit the familiar form found in most of the collections from Mazon Creek, Illinois, though not so large as that form. It conforms more nearly to the form *emarginata* as illustrated by Kidston.[2]

The fragments from the upper horizon in the Missouri, Kansas and Texas Railway cut are only provisionally referred to this species. They belong to a form with small, narrow, distinct pinnules, in which the nerves of the middle and upper portions are straight, or nearly straight, seldom arching perceptibly outward. This form is very close to one from Olyphant, Pennsylvania, and the Rhode Island coal field, described in our American literature[3] as *Pecopteris arguta* Brongn.[4] These examples from the railway cut, while approaching in size the *P. elliptica* F. & W.,[5] are in reality probably close to the phase illustrated by Brongniart.

Localities.—Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory, about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6659. A form very close to that of Brongniart's type is from a bed about 100 feet lower at the same locality. U. S. Nat. Mus. Reg. 6658.

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[1] See Zeiller: Fl. foss. bassin houill. et perm. d'Autun et Épinac, I, 1890, p. 63. Also Kidston: Foss. Fl. Radstock Ser., 1887, p. 367.

[2] Foss. Fl. Radstock Ser., Pl. XXIV.

[3] Coal Flora, I, p. 227, Pl. XLI, figs. 2, 3, 3*a*.

[4] The above-mentioned material is quite distinct from *Pecopteris arguta* Stb. (Tentamen, p. XIX), made by its author a synonym of *P. fœminæformis* (Schloth.) Zeiller (Schlotheim, Fl. d. Vorwelt, Pl. IX, fig. 16; Petrefactenkunde, p. 307).

[5] Permian Flora, p. 83, Pl. XXX, figs. 1, 1*a*.

PECOPTERIS (GONIOPTERIS) ELLIPTICA Font. and I. C. W.

1880. *Goniopteris elliptica* Fontaine and I. C. White, Permian Flora, p. 83, Pl. XXX, figs. 1, 1a.

The fragments of pinnæ which I refer to this species appear to agree in all respects with the fern described by Professor Fontaine and Dr. I. C. White from the roof of the Waynesburg coal at Cassville, West Virginia. The species is most closely connected with *P. unita*, of which it seems to be a diminutive descendant.

Locality.—Missouri, Kansas and Texas Railroad cut, one-half mile south of South McAlester, Indian Territory; about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6646.

PECOPTERIS RICHARDSONI n. sp.

Pl. LXVIII, figs. 2–4, 3*a*, 4*a*.

Frond tri-(quadri-?) pinnate, somewhat lax or flexuose, not dense, with loose, broad, irregularly but clearly lineate rachis. Penultimate pinnæ oblong-lanceolate, or linear-lanceolate, acute. Ultimate pinnæ alternate, or subalternate, open at an angle of 60° to 70°, a little distant, usually nearly one-third the width of the mature pinnæ apart, linear, or oblong-linear, the sides parallel in the lower and middle, converging rapidly near the apex, with a slight outward curve, to the slightly acute tip, hardly rigid, a little lax, somewhat decurrent at the point of origin, 1.2 (pinnatifid pinnules) to 8 centimeters or more in length, 3 to 15 millimeters in width, the rachis being rather broad, lax, loosely fibrous, and distinctly decurrent at the base.

Pinnules alternate, subalternate, or subopposite, a little distant, somewhat irregular in direction, very rarely touching, oblong, three or four times as long as broad, the sides nearly parallel, rounded at the top, with a tendency to curve slightly upward near the apex, distinct very nearly to the base, even in the smaller pinnæ, rather distant in the larger pinnæ, constricted in the distal angle by a narrow, decurrent sinus, and decurring in Alethopteroid form from a point very close to the rachis in a very narrow rachial wing. Lamina a little thick, smooth or extremely minutely granular, sometimes very shallowly and broadly depressed along the axis of the pinnule, slightly arched at the margin, and usually depressed between the coarse and very distant nerves, especially near the margin, where it becomes consequently slightly crenulate, often having the appearance of serration, the teeth coinciding with the apices of the nerves in number and position.

Nervation rather coarse and generally distinct, often quite conspicuous. Primary nerve rounded, of moderate strength, faintly lineate, passing, distinct, to just below the apex, and more or less clearly decurrent at the point of emergence from the loosely fibrous rachis, with which it often appears for a short distance to be only imperfectly joined. Secondary nerves alternate, or sometimes nearly opposite, coarse, very distant, often appearing nearly as large as the midrib, originating at an angle of 30 to 45°, and passing usually with a very slight, very rarely strong, outward curve, or often straight, or nearly straight, seldom forking, except occasionally in the largest pinnules which are about to become pinnatifid, to the border, where they count but 12 to 15 per centimeter.

Sporangia oval, or oblong, about 0.65 millimeter long, 0.25 millimeter wide, in a row about the pinnule, a single sporangium lying just within the margin of the pinnule, its longer axis parallel to each nervil to which it is attached, similar to the habit of *Dactylotheca*, to which genus it is apparently referable.

The most conspicuous feature of this species is the prominence of the nervation, especially near the margin of the fertile pinnules, and the relatively small number of the nerves, which very rarely fork except in the largest pinnules, counting only 12 to 15, usually about 13, to the centimeter at the border. Whenever the nerves fork—i. e., when the pinnule approaches the pinnatifid stage—the forking is usually halfway or more from the midrib to the margin, the division being at a rather wide angle and the two nervils tending to curve upward. A young pinna, fig. 4, Pl. LXVIII, illustrates the form and details of the small pinnules in the newly developed pinnæ. It will be observed that the pinnules of the plant are not large for the genus, though a little long in proportion to the width. Aside from a slight laxness and consequent irregularity they are further notable for their separation, which in the larger pinnæ becomes somewhat Alethopteroid, with an extremely narrow decurrent wing passing down by the sinus on the distal side of the base of the pinnule next below.

None of the fertile specimens are so preserved as to show the characters of the fructification with sufficient clearness for absolute diagnosis. From the traces of the sporangia, and especially from their impression through the limb in several specimens, it appears that they are oval, or possibly a little pointed, about 0.6 millimeter long and .25 millimeter wide, a single sporangium being borne, parallel on the upper part of each nerville. Thus they add to the distinctness of the distant nerves, especially where the lamina is strongly depressed in the intervals. The form of the sporangia and their occurrence seem to indicate a generic reference to Dactylotheca. The proportions of the sporangia suggest the fertile pinnæ of *P. pennæformis*.

Pecopteris richardsoni evidently belongs to the group of long-pinnuled, simple-nerved species of the genus characteristic in general of the Upper Coal Measures or Permo-Carboniferous. Its general aspect is somewhat similar to that of the form of the Upper Coal Measures of Kansas and the Anthracite series recorded in our American literature as *P. aspidioides* Brongn.[1] The latter has its pinnules proportionately

[1] Lesquereux, Coal Flora, III, p. 756.

a little longer, closer, the nerves more frequently forking. *Pecopteris lesquereuxii* D. W., the nerves of which are simple and rather distant, has a punctate rachis, more acute pinnæ, and close, proportionately much longer pinnules, in which the nerves fork more frequently, while the fructification, probably Asterotheca, nearly covers the surface of the pinnule.

Localities.—One-half mile west of McAlester, Indian Territory, McAlester coal. U. S. Nat. Mus. Reg. 6423, 6426, 6427. Also in the same horizon at the westernmost mine, near Cherryvale, Indian Territory. U. S. Nat. Mus. Reg. 6605.

PECOPTERIS LESQUEREUXII D. W.

1880. *Pecopteris arborescens* (Schloth.) Brongn., Lesquereux, Coal Flora, I, p. 230 (pars, excl. fig. et syn.).

1884. An *Pecopteris aspidioides* Brongn., Lesquereux, Coal Flora, p. 756?.

1893. *Pecopteris (Asterotheca) lesquereuxii* D. White, Bull. U. S. Geol. Survey No. 98, p. 65, Pl. II, fig. 4.

The most important character of this species is the relatively great length of the pinnule, which is close and very slightly connivent and round-obtuse, while a few of the nervils in the larger pinnules are found to fork. The distinctions between it and *Pecopteris hemitelioides* and others of that group are pointed out in connection with the original description of the species.

The specimens from the McAlester coal field have the pinnules rather shorter proportionately than is the case in the types from the zinc and lead region of southwestern Missouri.

Locality.—Missouri, Kansas and Texas Railway cut, about one-half mile south of South McAlester, Indian Territory. Horizon in blue shales, about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6648–6652.

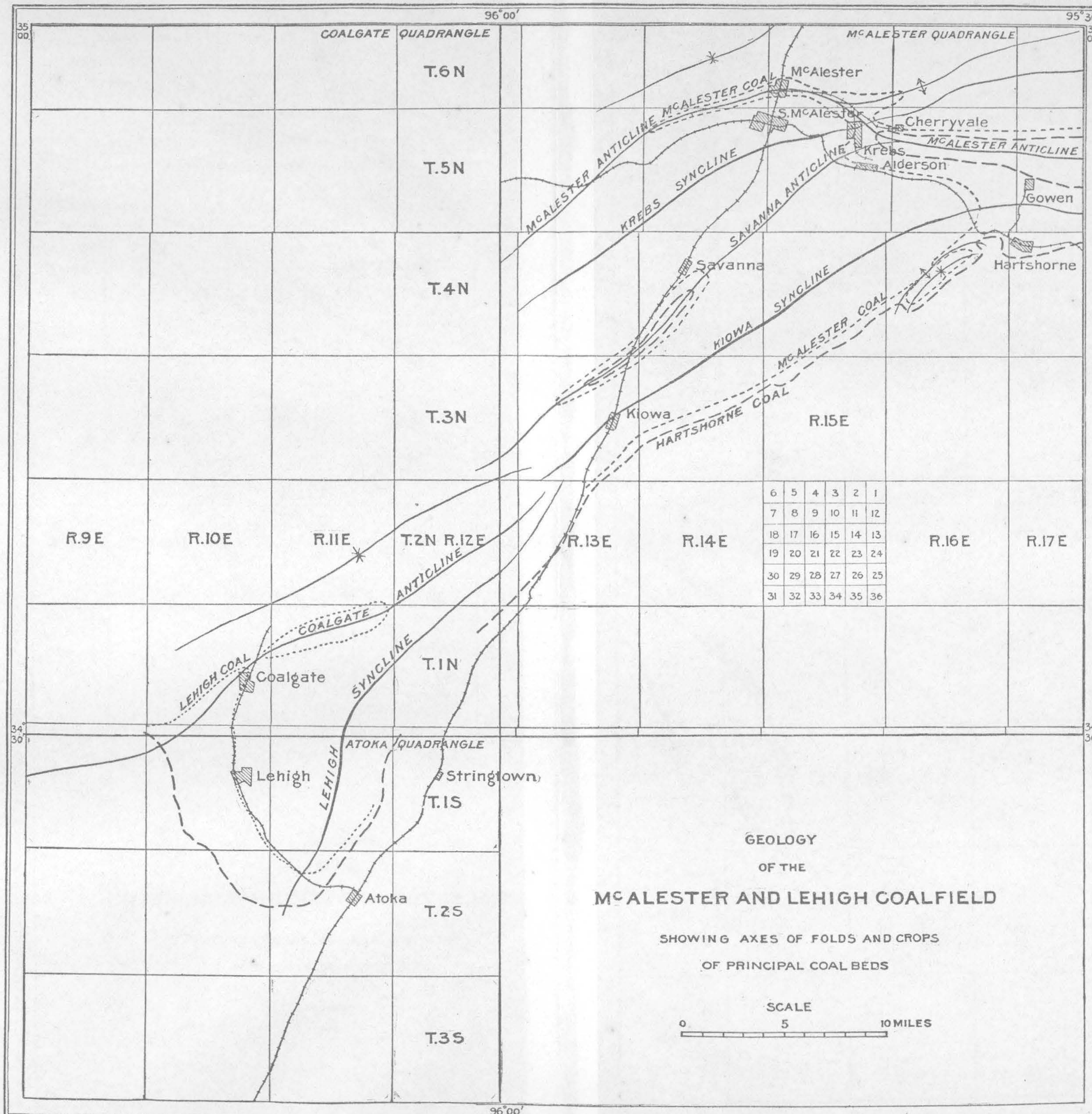
PECOPTERIS (ASTEROTHECA) SQUAMOSA LX.

1870. *Pecopteris squamosa* Lesquereux, Rept. Geol. Surv. Ill., IV, p. 400, Pl. XII, figs. 1–4, Pl. XIII, figs. 10, 11.

1879. *Pecopteris squamosa* Lesquereux, Coal Flora, Atlas, p. 7, Pl. XXXIX, figs. 12, 13, 13*a*; text, 1 (1880), p. 235.

The sporangia of this species, which is best known from Cannelton, Pennsylvania, are referable to the genus Asterotheca. The sterile fronds, although included in the densely villous group, are apparently related to the arborescens or simple-nerved group.

Localities.—Mine No. 11, Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6319. Also, from Savanna, Indian Territory. U. S. Nat. Mus. Reg. 6583. Horizon of the roof of the McAlester coal.


96°00'
95°30'
35 00
COALGATE QUADRANGLE
McALESTER QUADRANGLE
T.6N
T.5N
T.4N
T.3N
T.2N
T.1N
T.1S
T.2S
T.3S
R.9E
R.10E
R.11E
R.12E
R.13E
R.14E
R.15E
R.16E
R.17E
McAlester
S.McAlester
Cherryvale
Krebs
Alderson
Gowen
Hartshorne
Savanna
Kiowa
Coalgate
Lehigh
Stringtown
Atoka
McALESTER ANTICLINE
McALESTER COAL
KREBS SYNCLINE
SAVANNA ANTICLINE
McALESTER ANTICLINE
KIOWA SYNCLINE
McALESTER COAL
HARTSHORNE COAL
ANTICLINE
COALGATE
LEHIGH COAL
SYNCLINE
LEHIGH
ATOKA QUADRANGLE
34 30
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
GEOLOGY
OF THE
McALESTER AND LEHIGH COALFIELD
SHOWING AXES OF FOLDS AND CROPS
OF PRINCIPAL COAL BEDS
SCALE
0
5
10 MILES

PECOPTERIS CANDOLLIANA Brongn.

1828. *Pecopteris candolliana* Brongniart, Prodrome, p. 56.
1833 or 1834. *Pecopteris candolliana* Brongniart, Hist. Vég. Foss., p. 305, Pl. C, figs. 1, 1*a*.
1833 or 1834. *Pecopteris affinis* Brongniart [non (Schloth.) Stb.], Hist. Vég. Foss., p. 306, Pl. C, figs. 2, 3.
1883. *Pecopteris affinis* Brongn., Renault, Cours. Bot. Foss., III, p. 109, Pl. XVII, fig. 6.
1836. *Cyatheites candollianus* (Brongn.) Goeppert, Systema, p. 321.
1855. *Cyatheites candollianus* (Brongn.) Goepp., Geinitz, Verst. Steink. Sachsen, p. 24, Pl. XXVIII, figs. 12, 13.
1857. *Cyatheites candollianus* (Brongn.) Goepp., Meneghini, Pal. Sardaigne, p. 156, Pl. D, fig. V, 4.
1869. *Cyatheites candollianus* (Brongn.) Goepp., von Roehl, Foss. Fl. Steink. Westphalens, p. 83, Pl. XII, fig. 3*b*?.
1876. *Cyatheites candollianus* (Brongn.) Goepp., Heer, Fl. foss. Helv., p. 28, Pl. VIII, figs. 9? 9*b*?.
1853. *Pecopteris candolleana* Brongn., Andrä, in Germar: Verst. Steinkohlenf. Wettin u. Löbejün, p. 108, Pl. XXXVIII, figs. 1–3?.
1877. *Pecopteris candolleana* Brongn., Grand' Eury, Fl. carb. Loire, p. 69, Pl. VIII, fig. 8.
1880. *Pecopteris candolleana* Brongn., Fontaine and I. C. White, Permian Flora, p. 63, Pl. XX, figs. 1–3?.
1883. *Pecopteris candolleana* Brongn., Renault, Cours. Bot. Foss. III, p. 109, Pl. XVII, figs. 7, 8, 8 bis.
1869. *Pecopteris* (*Cyatheides*) *candolleana* Brongn., Schimper, Traité, I, p. 500.
1869. *Cyathocarpus candolleanus* (Brongn.) Weiss, Foss. Fl. jüngst. Steink. u. Rothl. Saar-Rh. Geb., p. 85.
1879. *Pecopteris candollei* Brongn., Zeiller, Vég. foss. terr. houill., p. 84.
1883. *Scolecopteris candolleana* (Brongn.) Stur, Zur Morph. System Culm- u. Carbonfarne, p. 123.
1888. *Pecopteris* (*Asterotheca*) *candollei* Brongn., Zeiller, Fl. foss. houill. Commentry, I, p. 128, Pl. XI, fig. 3.
1890. *Pecopteris* (*Asterotheca*) *candollei* Brongn., Zeiller, Fl. foss. houill. perm. Autun et Épinac, I, p. 47, Pl. VIII, figs. 5, 6.

The small collection of fossil plants from Savanna contains a few fragments which I am unable to distinguish from this very rare species from our Coal Measures.

Locality.—Savanna, Indian Territory, roof of the McAlester coal. U. S. Nat. Mus. Reg. 6578.

PECOPTERIS VESTITA Lx.

1879. *Pecopteris vestita* Lesquereux, Coal Flora, Atlas, p. 8, Pl. XLIII, figs. 1–4, 6, 7; text 1 (1880), p. 252 (pars).
1883. *Pecopteris vestita* Lesquereux, 13th Rept. Geol. Surv. Ind., 2, Pl. XIV, figs. 1, 1*a*.
1889. *Pecopteris vestita* Lx., Lesley, Dict. Foss. Pa., II, p. 612, text fig.

PECOPTERIS VESTITA Lx. var. MINOR n. var.

The form here designated seems to possess all the essential characters, including the tapering acute pinnæ of the normal form of *P. vestita*, although it is more delicate, and its pinnules are considerably smaller than is usual in that densely villous species.

Localities.—Two miles east of Krebs, Indian Territory, roof of the Grady coal. U. S. Nat. Mus. Reg. 6702. It is also found at the same horizon at mine No. 12, a little farther south. U. S. Nat. Mus. Reg. 6698.

PECOPTERIS cf. VILLOSA Brongn.?

1834. An *Pecopteris villosa* Brongniart, Hist. Vég. Foss., p. 316, Pl. CIV, fig. 3?
1880. An *Pecopteris villosa* Brongn.? Lesquereux, Coal Flora, I, p. 253?

To this species is tentatively referred a form that seems identical with the densely villous Pecopteris so common at Mazon Creek, Illinois, and at Cannelton, Pennsylvania. Much doubt appears to exist among European paleobotanists as to the true characters and specific validity of the plant imperfectly described and illustrated by Brongniart. If, as some authorities appear to believe, Brongniart's description is based on fragments of *Pecopteris oreopteridia*, the American plant, cited as *P. villosa* with a query by Lesquereux, should bear some other designation.

Locality.—Roof of the McAlester coal at McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6463.

PECOPTERIS cf. SERPILLIFOLIA Lx.

1870. *Pecopteris flavicans* (Presl)? Lesquereux, Rept. Geol. Surv. Ill., IV, p. 404.
1879. *Pecopteris serpillifolia* Lesquereux, Coal Flora, Atlas, p. 8, Pl. XLVI, figs. 1-3, *3a-d*; text, 1 (1880), p. 237.

The several specimens which I refer to this species appear to conform to the types illustrated in figs. 1 and 2, Pl. XLVI, of the atlas to the Coal Flora. The nervils of the larger pinnules sometimes fork once, as is to be seen in the type of figure 2, now in the Lacoe Collection, U. S. National Museum. In fact, the largest pinnules that I assign provisionally to *P. serpillifolia* are close to the fern identified by Professor Lesquereux, from Ottawa, Kansas, as *P. aspidioides* Brongn.

Locality.—Roof of the McAlester coal at mine No. 11, near Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6356.

PECOPTERIS OREOPTERIDIA (Schloth.) Stb.

1804. "*Cum* POLYPODIO OREOPTERIDE *magnam habet affinitatem*," Schlotheim, Fl. d. Vorwelt, p. 36, Pl. VI, fig. 9.
1820. *Filicites oreopteridius* Schlotheim, Petrefactenkunde, p. 407.
1825. *Pecopteris Oreopteridis* (Schloth.) Sternberg, Versuch, 1, Tent, p. XIX.
1833. *Pecopteris Oreopteridis* (Schloth.) Sternberg, Versuch, fasc. 5-6, Pl. XXII, fig. 4; fasc. 7-8 (Presl), 1838, p. 149.
1828. *Pecopteris oreopteridius* (Schloth.) Stb., Brongniart, Prodrome, p. 56.
1834. *Pecopteris oreopteridius* (Schloth.) Stb., Brongniart, Hist. Vég. Foss., p. 317, Pl. CIV, fig. 2, (fig. 1?), Pl. CV, fig. 1, 2, 3.
1836. *Cyatheites Oreopteridis* (Schloth.) Goeppert, Systema Fil. Foss., p. 323.
1855. *Cyatheites Oreopteridis* (Schloth.) Goepp., Ettingshausen, Steinkohlenfl. Radnitz, p. 43 (non Pl. XV, fig. 2?).
1838. *Alethopteris Oreopteridis* (Schloth.) Presl, in Sternberg, Versuch, fasc. 7-8, p. 145.
1848. *Alethopteris oretopterides* (Schloth.) Presl, Goeppert, in Bronn, Nomencl., p. 24.

1848. *Cyatheites oreopteroides* (Schloth.) Goeppert, in Bronn, Nomencl., p. 364.
1855. *Cyatheites oreopteroides* (Schloth.) Goepp., Geinitz, Verst. Steink. Sachsen, p. 25, Pl. XXVIII, fig. 14.
1869. *Pecopteris* (*Cyatheides*) *oreopteridia* (Schloth.) Stb., Schimper, Traité, 1, p. 502.
1871. An *Pecopteris oreopteroides*? (Schloth.) Stb., Dawson, Geol. Struct. P. E. I., p. 44, Pl. II, fig. 17?
1876. *Cyatheites oreopteridius* (Schloth.) Goepp., Heer, Fl. foss. Helv., p. 30 (Pl. VIII, figs. 8, 8a?).
1879. *Pecopteris oreopteridis* (Schloth.) Stb., Lesquereux, Coal Flora, Atlas, p. 7, Pl. XLI, fig. 8; text, 1 (1880), p. 238.
1881. *Pecopteris oreopteroides* (Schloth.) Stb., Weiss, aus d. Fl. d. Steink., p. 16, Pl. XVII, fig. 102.
1883. *Pecopteris Oreopteridia* (Schloth.) Stb., Renault, Cours Bot. Foss., III, p. 110, Pl. XVIII, figs. 5, 5*b*, Pl. XIX, figs. 7-12.
1883. *Grand'eurya renaulti* Stur, Zur Morph. u. Syst. Culm u. Carbon-Farne, p. 46, fig. 12*c*.
1885. *Grand'eurya renaulti* Stur, Farne d. Schatzlarer Sch., p. 104, fig. 16*c*.
1887. *Pecopteris oreopteridia* (Schloth.) Stb., Kidston, Foss. Fl. Radstock Ser., p. 371, Pl. XXVII, figs. 3, 4, Pl. XXVIII, figs. 1, 2.
1888. *Pecopteris* (*Asterotheca*) *oreopteridia* (Schloth.) Stb., Zeiller, Fl. Foss. Bassin Houill. Commentry, p. 136, Pl. XV, figs. 6-8.

The specimens here included are all small and fragmentary, and the identification is therefore not without doubt. The examples from Krebs represent a villous form, whose nerves, forking once and rather close, pass to the margin more directly than is characteristic of the species. The sporangia, moreover, of the *Asterotheca* type are in fours, somewhat elongated, acute, the outer and inner pairs being sometimes unequal. The sori are in a row a little within the margin, and in compressed or flattened fragments the sporangia lie nearly at a right angle to the midrib, thus strongly resembling in both form and proportions the illustrations of *Pecopteris cyathea* given by Zeiller in the Commentry flora.[1]

Locality.—Roof of the McAlester coal at mine No. 11, Krebs, Indian territory. U. S. Nat. Mus. Reg. 6355. Also at Savanna, Indian Territory. U. S. Nat. Mus., Reg. 6579.

PECOPTERIS POLYMORPHA Brongn.

1828. *Pecopteris polymorpha* Brongniart, Prodrome, p. 56.
1834. *Pecopteris polymorpha* Brongniart, Hist. Vég. Foss., p. 331, Pl. CXIII.
1858. *Pecopteris polymorpha* Brongn., Lesquereux, in Rogers, Geol. Pa., II, 2, p. 866.
1866. *Pecopteris polymorpha* Brongn., Lesquereux, Rept. Geol. Surv. Ill., II, p, 469.
1877. *Pecopteris polymorpha* Brongn., Grand'Eury, Fl. Carb. Loire, p. 74, Pl. VIII, figs. 10, 11.
1878. *Pecopteris polymorpha* Brongn., Zeiller, Vég. foss. terr. houill. Fr., p. 91, Pl. CLXIX, figs. 1, 2, 3.
1883. *Pecopteris polymorpha* Brongn., Renault, Cours Bot. Foss., III, pp. 35, 116, Pl. XX, figs. 1-10.
1834. *Pecopteris miltoni* Brongniart, Hist. Vég. Foss., p. 333 (pars), Pl. CXIV, figs. 1-7 (non f. 8) [fide Zeiller].

[1] Fl. Foss. bassin houill. Commentry, 1, Pl. XIII, fig. 1*a*.

1886. *Pecopteris miltoni* Brongn., Sterzel, Fl. Rothl. n.-w. Sachsen, p. 6 (240), syn. *P. polymorpha* (non Pl. I, figs. 1–7).
1850. *Cyatheites polymorphus* (Brongn.) Heer, Mitth. naturf. Gesell., Zürich, II, p. 149.
1857. *Hemitelites trevirani* Goepp., Kimball, Fl. Appalach. C. F., p. 13, Pl. I, fig. 4 (excl. syn).
1869. *Pecopteris* (*Cyatheides*) *polymorpha* Brongn., Schimper, Traité, 1, p. 506.
1870. *Pecopteris* (*Cyatheites*) *polymorpha* Brongn., Unger, Sitz. Akad. Wiss. Wien, Math.-Nat. Cl., LX, 1, p. 786, Pl. I, fig. 2.
1876. *Cyatheites miltoni* (Artis?) Heer, Fl. Foss. Helv., p. 28 (pars), Pl. VIII, fig. 5 (6?), Pl. IX, Pl. X, figs. 1, 2, Pl. XX, fig. 6 (7?)
1877. *Scolecopteris conspicua* Grand 'Eury, Fl. Carb. Loire, p. 74, Pl. VIII, figs. 10–11.
1879. *Acitheca polymorpha* (Brongn.) Schimper, in Zittel: Handb. Palæont., II, p. 91, figs. 66, $^{9-12}$.
1880. *Pecopteris elliptica* Bunby., Lesquereux, Coal Flora, I, p. 245, Pl. XXXIX, figs. 4, 5 (6?).
1883. *Scolecopteris polymorpha* (Brongn.) Stur, Zur Morph. u. Syst. Culm u. Carbon-Farne, p. 107, figs. 21 *a*, *b*.
1885. *Scolecopteris polymorpha* (Brongn.) Stur, Farne d. Schatzlarer Sch., p. 198, fig. 25^{a}, ^{b}.
1887. *Scolecopteris polymorpha* (Brongn.) Stur, Solms-Laubach, Einl. Paläophytol., p. 147, fig. 12^{d}.
1888. *Scolecopteris polymorpha* (Brongn.) Stur, Schenk, Foss. Pflanzenreste, p. 23, fig. 25.
1888. *Scolecopteris polymorpha* (Brongn.) Stur, Zeiller, Fl. foss. houill. Valenciennes, p. 32, fig. 25^{b}.
1889. *Scolecopteris polymorpha* (Brongn.) Stur, Kidston, Fruct. Struct. Carb. Ferns, p. 20, Pl. II, fig. 20^{a-c}.
1890. *Scolecopteris polymorpha* (Brongn.) Stur, Zeiller, Fl. foss. Autun et Épinac, I, p. 24 fig. B.
1891. *Scolecopteris polymorpha* (Brongn.) Stur, Solms-Laubach, Foss. Botany, p. 145, fig. 13^{d}.
1883. *Hawlea bosquetensis* Stur, Zur. Morph. u. Syst. Culm u. Carbon-Farne, p. 54.
1885. *Hawlea bosquetensis* Stur, Farne d. Schatzlarer Sch., p. 111.
1888. *Pecopteris* (*Scolecopteris*) *polymorpha* Brongn., Zeiller, Fl. foss. houill. Commentry, I, p. 59, Pl. VIII, figs. 8, 8^{a}.
1890. *Pecopteris* (*Scolecopteris*) *polymorpha* Brongn., Zeiller, Fl. foss. houill. Commentry, I, p. 155, Pl. XVI, figs. 5, 6.

A few fragments, though small, appear safely referable to the *Pecopteris polymorpha* of Brongniart. In small specimens the chief distinction between this species and *P. oreopteridia* is that in the latter the nervilles fork but once, while in mature pinnules of the former they fork twice.

To *Pecopteris polymorpha* is to be referred the large form from Olyphant, Pennsylvania, described by Professor Lesquereux[1] as *P. elliptica* Bunby, since Professor Zeiller, to whom were sent specimens identified by the former in the Lacoe collection, has had the kindness to compare the American examples with type material, thus definitely ascertaining their specific identity. Corroboration, though hardly needed, is found by a comparison of the excellent specimens from the Grande Combe and Correze, sent in exchange by Professor Zeiller.

[1] Coal Flora, I, p. 245.

Locality.—Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory. Horizon about 2,000 feet above that of the McAlester coal. U. S. Nat. Mus. Reg. 6662.

PECOPTERIS sp.

Several other very small fragments in the collections represent two species of Pecopteris, neither of which is determinable in the material at hand. The first form is a segment of a pinnatifid pinna, the pinnatifid pinnules being very lax, rather broad at the base, and decurring. The lobes are large, rounded, coherent most of their length, and a little irregular, as is also the nervation. The latter is rather thick, striate, a little flexuose, very oblique, the nervils often forking once. The general aspect of the fragment is like that figured by Geinitz as *Cyatheites villosus* in Pl. XXIX, fig. 7, of the "Versteinerungen." It is possible that the plant from Indian Territory stands close to the original type of the somewhat confused species *P. serpillifolia* Lx.,[1] from Mazon Creek, though the pinnæ of the latter seem to be less decurrent. The other form of Pecopteris mentioned above is seen only in a very small fruiting fragment showing rather long, slender pinnules, deeply cut with thick, striated rachis and midrib. The sporangia are rather long and appressed at right angle to the midrib, strongly resembling the mode of preservation sometimes seen in *Asterotheca;* for example, *A. euneura* Schimp. or *A. cyathea* Brongn.

Locality.—Roof of the McAlester coal at McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6708, 6710.

MEGALOPTERIDEAE.

ALETHOPTERIS Sternberg, 1826.

Versuch einer Flora d. Vorw., 1, Tent., p. xxi.

ALETHOPTERIS SERLII (Brongn.) Goepp.

1804. ——— ——— Parkinson, Organic Rem., I, Pl. IV, fig. 6.
1828. *Pecopteris serlii* Brongniart, Prodrome, p. 57 (nomen nudum).
1832 or 1833. *Pecopteris serlii* Brongniart, Hist. Vég. Foss., p. 292, Pl. LXXXV.
1837. *Pecopteris serlii* Brongn., Lindley and Hutton, Fossil Flora, III, Pl. CCII.
1840. *Pecopteris serlii* Brongn., Jackson, Rept. Geol. and Agricult. R. I., 1839, p. 288, Pl. III, fig. 6.
1876. *Pecopteris serlii* Brongn., Heer, Fl. foss. Helv., p. 32, Pl. XII, fig. 8.
1836. *Alethopteris serlii* (Brongn.) Goeppert, Systema Fil. Foss., p. 301, Pl. XXI, figs. 6, 7.
1840. *Alethopteris serlii* (Brongn.) Goepp., Teschemacher, Bost. Jour. Nat. Hist., V, p. 380, Pl. XXXV, figs. *a a*.
1860. *Alethopteris serlii* (Brongn.) Goepp., F. A. Roemer, Beitr. z. Kenntn. n.-w. Harzgeb., p. 32, Pl. VIII, fig. 9.
1861. *Alethopteris serlii* (Brongn.) Goepp., Lesquereux, 4th Rept. Geol. Surv. Ky., p 433. (Plate I, figs. 3, 3*a*, not published.)

[1] Coal Flora, Pl. XLVI, fig. 1.

1869. *Alethopteris serlii* (Brongn.) Goepp., von Roehl, Foss. fl. Steinkohlenf. Westphalens, p. 76, Pl. X, figs. 8, 9 *b*.

1869. *Alethopteris serlii* (Brongn.) Goepp., Schimper, Traité, I p. 555.

1876. *Alethopteris serlii* (Brongn.) Goepp., Ferd. Roemer, Lethaea. geogn., Pal., Atlas, Pl. LII, figs. 2 *a*, 2 *b*; text (1880), p. 181.

1878. *Alethopteris serlii* (Brongn.) Goepp., Zeiller, Vég. foss. terr. houill. Fr., Atlas, Pl. CLXIII, figs. 1, 2; text (1879), p. 75.

1879. *Alethopteris serlii* (Brongn.) Goepp., Lesquereux, Coal Flora, Atlas, Pl. XXIX, figs. 1–5; text (1880), I, p. 176.

1881. *Alethopteris serlii* (Brongn.) Goepp., Weiss, Aus. d. Fl. d. Steinkohl., p. 15, Pl. XVI, fig. 97.

1883. *Alethopteris serlii* (Brongn.) Goepp., Renault, Cours. Bot. Foss., III, p. 157, Pl. XXVII, fig. 7.

1883. *Alethopteris serlii* (Brongn.) Goepp., Lesquereux, 13th Rept. Geol. Surv. Ind., Pl. XII, fig. 2.

1886. *Alethopteris serlii* (Brongn.) Goepp., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XXXVI, figs. 1, 2; Pl. XXXVII, figs. 1, 1 *a*; text (1888), p. 234.

1889. *Alethopteris serlii* (Brongn.) Goepp., Lesley, Dict. Foss. Pa., Vol. I, p. 14, text figs.

1848. *Alethopteris hannonica* Sauveur, Vég. foss. terr. houill. Belg., Pl. XXXVIII.

1854. *Alethopteris sternbergii* Goepp., Ettingshausen, Steink.-fl. Radnitz, p. 42, Pl. XVIII, fig. 4.

1865. *Pteris serlii* (Brongn.) Ettingshausen, Farrnkräuter d. Jetzw., p. 109.

1879. *Alethopteris lonchitica* (Schloth.). Brongn., Schimper, in Zittel, Handb. Pal., II, p. 118, figs. 93, 1, 1 *b*.

This common species of the Alleghany series (Lower Productive Coal Measures) is the most abundant form in the roof shales of the McAlester coal. The specimens represent the robust phase of the species which is familiar in coal E or F of the anthracite series.

The form with somewhat elongated, a little distant, pinnules, which will in due time be described as the variety *missouriensis* in the "Flora of the Lower Coal Measures of Missouri," appears also to be present in one of the collections, though the fragments in the latter possibly represent only inrolling of the lamina in the large pinnules of the normal form.

Localities.—Roof of the McAlester coal, at (1) one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6407); (2) mine No. 11, near Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6387); (3) Cherryvale, Indian Territory (U. S. Nat. Mus. Reg. 6600); (4) west mine at Alderson, Indian Territory (U. S. Nat. Mus. Reg. 6736).

The species, apparently in good form, is found at a stage about 2,000 feet above the McAlester coal, in the Missouri, Kansas and Texas Railway cut one-half mile south of South McAlester, Indian Territory, the specimens from the upper bed being U. S. Nat. Mus. Reg. 6629.

In the collections from the Grady coal, examples apparently referable to this species were found 2 miles east of Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6689), and at Johnsville, Indian Territory (U. S. Nat. Mus. Reg. 6555).

CALLIPTERIDIUM Weiss, 1870.

Zeitschr. d. deutsch. geol. Gesell., XXII, pp. 858, 876.
Lesquereux, Coal Flora, I, 1880, p. 164.

CALLIPTERIDIUM INÆQUALE Lx.

1879. *Callipteridium inæquale* Lesquereux, Coal Flora, Atlas, Pl. XXXIII, figs. 2-5; text, I (1880), p. 168.

The distinction between this species and the following species, both originally described from the same locality, Cannelton, Pennsylvania, is not always clear, even in the typical material labeled by Professor Lesquereux. There is, however, not the slightest doubt as to the presence of two valid species, one of which, *C. inæquale*, is distinctly alethopteroid, with strong midribs and open, though irregular, nerves. The other, *C. mansfieldi*, is odontopteroid, with thin midrib and generally fine, oblique nerves.

The reference of the fragments from Krebs to this species is but provisional, since they may represent a new species, though the material is too incomplete to permit a good identification and comparison with other known types, or a diagnosis. The portions of pinnæ have much in common with *C. grandini* Brongn. sp.

Localities.—One-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6415); mine No. 11, Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6314); both lots in the roof of the McAlester coal.

CALLIPTERIDIUM MANSFIELDI Lx.

1879. *Callipteridium mansfieldi* Lesquereux, Coal Flora, Atlas, p. 5, Pl. XXVII, figs. 1, 2; text, I (1880), p. 166.

This fine species has not before been found outside of the type locality, Cannelton, Pennsylvania. The distinction between it and *C. inæquale* Lx. is pointed out in the notes on the latter species. Portions of the pinnæ of *C. gigas* (Gutb.), as well as certain specimens identified as *C. grandini* (Brongn.), strongly resemble the larger pinnæ of *C. mansfieldi* in form, though the nervation is different.

Localities.—Several specimens from Cherryvale, Indian Territory, probably belong to this species (U. S. Nat. Mus. Reg. 6596). It is perhaps present also from the mine one-half mile west of McAlester, Indian Territory, although the fragments are too deformed to be identified with certainty (U. S. Nat. Mus. Reg. 6413). Both lots are from the stage of the McAlester coal.

CALLIPTERIDIUM SULLIVANTII (Lx.) Weiss.

1854. *Callipteris sullivantii* Lesquereux, Bost. Jour. Nat. Hist., VI, No. 4, p. 423.
1858. *Callipteris sullivantii* Lesquereux, Geol. Pa., II, 2, p. 866, Pl. V, fig. 13.
1881. *Callipteris sullivantii* Lx., C. A. White, Rept. Geol. Surv. Ind., 1880, p. 153, Pl. IX, fig. 4.

1881. *Callipteris sullivantii* Lx., Calvin, Pop. Sci. Mo., XVIII, p. 619, fig. 1.
1883. *Callipteris sullivantii* Lx., Chamberlain, Geol. Wis., I, p. 216, fig. 67 *c*.
1889. *Callipteris sullivantii* Lx., Lesley, Dict. foss. Pa., I, p. 108, text fig.
1891. *Callipteris sullivantii* Lx., Le Conte, Elements Geol., p. 363, fig. 472.
1869. *Alethopteris sullivanti* (Lx.) Schimper, Traité, I, p. 561.
1870. *Callipteridium sullivanti* (Lx.) Weiss, Zeitschr. d. deutsch. geol. Gesell., XXII, p. 876, Pl. XXI, figs. 1-3.
1880. *Callipteridium sullivantii* (Lx.) Weiss, Lesquereux, Coal Flora, I, p. 164.
1883. *Callipteridium sullivantii* (Lx.) Weiss, Lesquereux, 13th Rept. Geol. Surv. Ind., p. 210, Pl. XII, fig. 1.
1889. *Callipteridium sullivantii* (Lx.) Weiss, Miller, N. Am. Geol. Pal., p. 111, fig. 22.
1889. *Callipteridium sullivantii* (Lx.) Weiss, Lesley, Dict. foss. Pa., I, p. 107, text fig.

The specimens which are here referred to the above species have their pinnules hardly so round and close as in the examples from the Lower Coal Measures of Illinois or Missouri. They agree more closely with the form found in coals E or F of the northern anthracite field or at the penitentiary shaft near Leavenworth, Kansas.

Locality.—Westernmost mine near Cherryvale, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6598.

CALLIPTERIDIUM sp.?

Under the above doubtful generic reference record is made of a terminal fragment of a pinna which is comparable in some respects to *C. neuropteroides* Lx. It is, however, possibly an Odontopteris.

Locality.—Mine "6½," sec. 2, T. 1 S., R. 10 E., Atoka quadrangle, Indian Territory. U. S. Nat. Mus. Reg. 6675.

ODONTOPTERIS Brongniart, 1822.

1822. *Filicites*—sect. *Odontopteris* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 234.
1826. *Odontopteris* Sternberg, Versuch, I, tent., p. xxi.
1828. *Odontopteris* Brongniart, Prodrome, p. 60.
1870. *Mixoneura* et *Xenopteris* Weiss, Zeitschr. d. deutsch. geol. Gesell., XXII, pp. 864, 865.

ODONTOPTERIS WORTHENI Lx.

1866. *Odontopteris wortheni* Lesquereux, Rept. Geol. Surv. Ill., II, p. 432, Pl. XXXVI, figs. 1, 1*b*.
1879. *Odontopteris wortheni* Lesquereux, Coal Flora, Atlas, p. 5, Pl. XXII, figs. 1, 1*a*; text, I (1880), p. 130.
1891. *Odontopteris wortheni* Lx., Le Conte, El. Geol., p. 364, fig. 478.
1870. *Xenopteris wortheni* (Lx.) Weiss, Zeitschr. d. deutsch. geol. Gesell., XXII, p. 867, Pl. XXI *a*, figs. 1, 1*b* (copied from Lesquereux).

The specimen which I provisionally refer to this species is of precisely the same type as other rather small forms from Cape Breton and elsewhere, identified by Professor Lesquereux under the above name. As in other similar cases, in which we have to deal with pinnules conforming to the hirsute group of Neuropteris in their basal portion, but more or less irregularly deeply lobed in the apices, the specimen from Johnsville shows, in my opinion, merely a heteromorphous development of a pinnule of one of the Neuropteris group represented by *N. scheuchzeri* Hoffm.

Locality.—Johnsville, Indian Territory; roof of a coal supposed to be the McAlester coal. U. S. Nat. Mus. Reg. 6546, 6547.

NEUROPTERIS Brongniart, 1822.

Mém. Mus. Hist. Nat., VIII, p. 333.

NEUROPTERIS FASCICULATA Lx. ?

1870. *Neuropteris fasciculata* Lesquereux, Rept. Geol. Surv. Ill., IV, p. 381, Pl. V, figs. 1–4.
1879. *Neuropteris fasciculata* Lesquereux, Coal Flora, Atlas, p. 5, Pl. XXIV, figs. 5, 6; text, I (1880), p. 93.

The fragments referred, with much doubt, to this species have the nerves more open and lax than is characteristic of the type.

Locality.—Roof of Grady coal, 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6695.

NEUROPTERIS JENNEYI D. W.

1893. *Neuropteris jenneyi* D. White, Bull. U. S. Geol. Survey No. 98, p. 82, Pl. I, figs. 7*a*, 7*b*, Pl. II, figs. 7–12, Pl. III, figs. 1–6, 6*a*, 7–10.

This interesting composite type of neuropteroid fern has hitherto been known only from the outlying Carboniferous basin near Belleville, Missouri. As was remarked in connection with its original detailed description, the species appears to be intermediate between Neuropteris and Odontopteris. Certain of its lobate pinnules would naturally be placed in the latter genus. It is, I believe, a somewhat polymorphous species derived from or most closely related to the *N. griffithii* or *N. clarksoni* of Lesquereux.

Locality.—Roof of the McAlester coal at mine No. 11, near Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6307.

NEUROPTERIS SCHEUCHZERI Hoffm.

1826. *Neuropteris scheuchzeri* Hoffmann, in Keferstein, Teutschland, IV, p. 157, Pl. 1*b*, figs. 1–4.
1830. *Neuropteris scheuchzeri* Hoffm., Brongniart, Hist. Vég. Foss., p. 230, Pl. LXIII, fig. 5.
1840. *Neuropteris scheuchzeri* Hoffm., Jackson, Rept. Geol. Agricult. Surv. R. I., 1839, p. 288, Pl. V, fig. 10.
1857. *Neuropteris scheuchzeri* Hoffm., Kimball, Fl. Appal. Coal Field, p. 9, Pl. I, fig. 1.
1886. *Neuropteris scheuchzeri* Hoffm., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XLI, figs. 1, 1*a*, 2, 3; text (1888), p. 251.
1887. *Neuropteris scheuchzeri* Hoffm., Kidston, Foss. Fl. Radstock Ser., p. 356, Pl. XXIII, figs. 1, 1*a*, 2.
1893. *Neuropteris scheuchzeri* Hoffm., D. White, Bull. U. S. Geol. Survey, No. 98, p. 69.
1830. *Neuropteris angustifolia* Brongniart, Hist. Vég. Foss., p. 231, Pl. LXIV, figs. 3, 4.
1869. *Neuropteris angustifolia* Brongn., Geinitz, Dyas, II, p. 139, Pl. XXVII, fig. 9?

1869. *Neuropteris angustifolia* Brongn., von Roehl, Foss. Fl. Steinkohlenf. Westphalens, p. 33, Pl. XIV, fig. 7.
1879. *Neuropteris angustifolia* Brongn., Lesquereux, Coal Flora, Atlas, Pl. VIII, figs. 2, 3, 6, 8, 10; text, I (1880), p. 89.
1883. *Neuropteris angustifolia* Brongn., Lesquereux, 13th Rept. Geol. Surv. Ind., 2, p. 52, Pl. X, fig. 1.
1884. *Neuropteris angustifolia* Brongn., Lesquereux, Coal Flora, III, p. 734.
1889. *Neuropteris angustifolia* Brongn., Lesley, Dict. Foss. Pa., II, p. 451, text fig.
1832. *Neuropteris cordata* Brongn., Lindley and Hutton, Fossil Flora, I, p. 119, Pl. XLI.
1847. *Neuropteris cordata* Brongn., Bunbury, Quart. Jour. Geol. Soc., III, p. 423, Pl. XXI, fig. 1, 1*a*–f.
1865. *Neuropteris cordata* Brongn., Goeppert, Foss. Fl. Perm. Form., p. 100, Pl. XI, fig. 1? 2?
1878. *Neuropteris cordata* Brongn., Dawson, Acad. Geol., 3d ed., p. 446, fig. 166*b*?
1880. *Neuropteris cordata* Brongn., Lesquereux, Coal Flora, I, p. 91 (pars).
1888. *Neuropteris cordata* Brongn., Dawson, Geol. Hist. Pl., p. 126, fig. 51*b*.
1889. *Neuropteris cordata* Brongn., Lesley, Dict. foss. Pa., II, p. 452, text fig.
1836. ——— ——— Morton, Am. Jour. Sci., XXIX, Pl. XI, fig. 26.
1847. *Neuropteris cordata* Brongn. var. *angustifolia* (Brongn.) Bunbury, Quart. Jour. Geol. Soc., III, p. 424.
1866. *Neuropteris cordata* Brongn. var. *angustifolia* (Brongn.) Bunb., Dawson, Quart. Jour. Geol. Soc., XXII, p. 154.
1854. *Neuropteris hirsuta* Lesquereux, Boston Jour. Nat. Hist., VI, 4, p. 417.
1857. *Neuropteris hirsuta* Lesquereux, Rept. Geol. Surv. Ky., III, pp. 434, 556, Pl. VI, fig. 4.
1858. *Neuropteris hirsuta* Lesquereux, Geol. Pa., II, 2, p. 857, Pl. III, fig. 6; Pl. IV, figs. 1–16.
1869. *Neuropteris hirsuta* Lx., Schimper, Traité, I, p. 445.
1875. *Neuropteris hirsuta* Lx., Dana, Manual Geol., 2d Ed., p. 327, fig. 635.
1879. *Neuropteris hirsuta* Lesquereux, Coal Flora, Atlas, Pl. VIII, figs. 1, 4, 5, 7, 9, 12; text, I (1880), p. 88.
1880. *Neuropteris hirsuta* Lx., Fontaine and White, Permian Flora, p. 47, Pl. VIII, figs. 7, 8.
1881. *Neuropteris hirsuta* Lx., C. A. White, Rept. Geol. Survey Ind., 1879–80, p. 152, Pl. IX, figs. 1, 2, 3.
1882. *Neuropteris hirsuta* Lx., Le Conte, Geol., p. 365, fig. 473.
1883. *Neuropteris hirsuta* Lx., Chamberlain, Geol. Wis., I, p. 216, fig. 67[b].
1889. *Neuropteris hirsuta* Lx., Lesley, Dict. Foss. Pa., II, pp. 460–462, text figs. 1–16.
1889. *Neuropteris hirsuta* Lx., Miller, Geol. Pal. N. Am., p. 128, fig. 54.
1857. *Neuropteris rogersii* Kimball (non Lx.), Fl. Appal. Coal Field, p. 10, Pl. I, fig. 1.
1884. *Neuropteris angustifolia* Brongn. var. *hirsuta* Lesquereux, Coal Flora, III, p. 885.

This common and characteristic species of the Coal Measures is well represented at the stage of the Grady coal by the smaller, narrower, and more acute phase, which I have found to be in general more particulary confined to the basal portion of the Lower Productive Coal Measures (Allegheny series) in the northeastern bituminous coal fields.

The specimens of pinnules from Johnsville are very much larger, lingulate, clearly hirsute, and somewhat more dilated, though the bases are not very round, nor are the midribs as broad and strong as in the very late forms of the species. In fact, if the early, narrow, acute, and usually faintly hirsute type is recognized by the varietal appellation, *angustifolia*, as was done by Lesquereux, the common form in hand, which is considerably larger than the types figured by Hoffmann and

Brongniart might continue to bear the special designation *hirsuta*, since they conform entirely to the type to which that term in specific rank was applied by Lesquereux.

The latest known phase of the *Neuropteris scheuchzeri* type is a dilated, obtusely lingulate, often very large and slightly polymorphous form, with distinct pedicels, broad, ribbon-like, lax midribs, dilated auricles, smoother lamina, with very short hairs very rarely found except near the midrib in the upper part of the pinnule. To this form, on which the very short, bristle-like hairs are so seldom seen, the varietal term *nuda* may be applied. It is represented by numerous specimens in the Lacoe collection, U. S. National Museum.

Localities.—The typical *hirsuta* form comes from Johnsville, Indian Territory; stage of McAlester coal (U. S. Nat. Mus. Reg. 6528). The smaller, narrower form is present in the roof of the Grady coal, 2 miles east of Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6699).

NEUROPTERIS GRIFFITHII Lx.

1884. *Neuropteris griffithii* Lesquereux, Coal Flora, III, p. 737, Pl. XCV, figs. 3–8.

NEUROPTERIS GRIFFITHII Lx. OCCIDENTALIS n. var.

The pinnules included under the above varietal division differ from those of the normal form, as described by Professor Lesquereux, chiefly in their much closer ultimate nervilles and the rather sinuous border. In the size and irregularity of their form, as well as their texture and mode of secondary nervation, they are extremely close to the plant from the Anthracite series at Port Griffith, in northeastern Pennsylvania. While the nervils of the latter count only about 30 to 35 to the centimeter at the border, the variety from Indian Territory shows about 45 to 50 per centimeter, the nerves forking four or five times in arching gradually toward the margin, just before reaching which they occasionally fork again in the larger pinnules. As a minor difference, may also be noted a slightly less broad overlap, on the average, in the two sides of the base.

Neuropteris griffithii is most nearly related to *Neuropteris clarksoni* Lx., which Kidston has found to be specifically identical with the type specimens described and remarkably figured by Brongniart as *N. macrophylla.*[1] It differs from the other, however, by the generally smaller, less elongated, and acute pinnules, the thin texture, coarse nervation proportionately more open near the midrib and less strongly arched in passing to the border. The pinnules are in general more pronouncedly enlarged at the base in round, never nearly equal, often overlapping lobes.

This type of plant, which is extremely rare below coal E in the Anthra-

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[1] While waiving the discussion in this place of the existence of two forms corresponding to the types described by Brongniart and Lesquereux, respectively, it may here be noted that among the specimens from the Radstock coal field now in the Lacoe collection in the U. S. National Museum there are many which are specifically inseparable from the plant described by Professor Lesquereux.

cite series, is thought to have been found in a new specimen at Mazon Creek, Illinois, and at Cannelton, Pennsylvania.

Locality.—One-half mile west of McAlester, Indian Territory; roof of McAlester coal. U. S. Nat. Mus. Reg. 6508, 6509.

NEUROPTERIS RARINERVIS Bunb.?

1847. *Neuropteris rarinervis* Bunbury, Quart. Jour. Geol. Soc., III, p. 425, Pl. XXII, figs. 1, 1*a-b*.
1858. *Neuropteris rarinervis* Bunb., Lesquereux, Geol. Pa., II, 2, p. 859.
1863. *Neuropteris rarinervis* Bunb., Dawson, Can. Nat., VIII, p. 443.
1866. *Neuropteris rarinervis* Bunb., Lesquereux, Rept. Geol. Surv. Ill., II, p. 428, Pl. XXXIII, figs. 1–5; Pl. XXXIV, figs. 1, 1*a*.
1869. *Neuropteris rarinervis* Bunb., Schimper, Traité, I, p. 440.
1870. *Neuropteris rarinervis* Bunb., Lesquereux, Rept. Geol. Surv. Ill., IV, p. 386, Pl. VIII, fig. 1–6.
1871. *Neuropteris rarinervis* Bunb., Dawson, Rept. Geol. Struct. P. E. I., p. 44, Pl. II, fig. 19.
1879. *Neuropteris rarinervis* Bunb., Lesquereux, Coal Flora, Atlas, p. 4, Pl. XV, fig. 2–5; text, I (1880), p. 109.
1881. *Neuropteris rarinervis* Bunb., Lesquereux, Rept. Geol. Surv. Ind., 1879–80, p. 152, Pl. X, figs. 1, 2, 3.
1886. *Neuropteris rarinervis* Bunb., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. XLV, figs. 1, 1*a*, 2, 3, 4, 4*a*; text (1888), p. 268.
1893. *Neuropteris rarinervis* Bunb., D. White, Bull. U. S. Geol. Survey No. 98, p. 85, Pl. V, figs. 7?, 6?.
1878. *Neuropteris heterophylla* Brongn., Zeiller, Vég. foss. terr. houill., Atlas, Pl. CLXIV, fig. 2; text (1879), p. 49.

The fragments here included appear to represent the species, though they are too small and poorly preserved to warrant a definite specific determination. The presence of this fern at the stage of the McAlester coal field designated below is, therefore, somewhat doubtful.

Locality.—Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory; horizon about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6631.

NEUROPTERIS HARRISI n. sp.

Pl. LXVIII, figs. 5–7, 9 (8 × 2).

Pinnæ small, delicate, the very small, narrow terminal pinnule connivent with the close or imbricated subjacent pinnules. Rhachis rather slender.

Pinnules small, alternate, open nearly at a right angle, or somewhat oblique, close, usually slightly imbricated, oblong, narrowing upward, elongated when mature, or ovate-triangular when young, obtuse or slightly pointed, sometimes slightly dilated at the unequally cordate base. Those near the apex of the pinna becoming reduced, rounded, or often slightly obovate or sphenopteroid, obliquely imbricated in passing into the small terminal. Lamina rather thin.

Nervation clear, though not very coarse. Midrib of moderate strength, distinct for three-fourths or more of the length of the pinnule, or sometimes vanishing quickly in the uppermost pinnules. Nerves not very strong, originating at a very narrow angle from the midrib, forking three or four times, the major upper division sometimes forking again while curving gently toward the border which they reach at less than a right angle, the nervils counting 30 to 35 per centimeter.

Among some specimens collected by Mr. Gilbert D. Harris in the vicinity of Russellville and Atkins, Arkansas, are a number of examples of a species of Neuropteris whose terminal portions strongly resemble the *N. desorii* of Lesquereux,[1] while the larger or lower pinnules strikingly suggest the related species, *N. rarinervis* Bunby. These specimens have lain in the Lacoe collection, in the National Museum, unidentified and undescribed until the present, when the examination of the collections made by Mr. Taff revealed the presence of the same form.

Neuropteris harrisi is a small and rather delicate thin species whose salient features are the narrow, often slightly pointed form of the lower pinnules, which are unequally cordate at the rounded base, and the coalescent sphenopteroid or callipteroid form often assumed by the uppermost pinnules, such as Pl. LXVIII, fig. 6 (2668), while the small terminal is sublobate and sinuate-margined. In fact, the terminal portions might easily be mistaken for *Neuropteris desorii* Lx. A comparison, however, of the latter species, which is well represented in the Lacoe collection, shows it to differ by the greater distance of the pinnules, the lowest only of which are fully constricted at the base, the uniformly sinuate margins in all pinnules, the strongly decurrent midrib, and the flexuous nerves, which are more distant and open near the midrib. From *Neuropteris rarinervis* Bunby., which some of the larger pinnules and occasional terminals resemble, the *N. harrisi* is distinguished by the more elongated, slightly pointed pinnules, the thin texture, the finer, more oblique nerves and the crowded pinnules, which only in this largest stage become somewhat dilated at the base. The nervation of the species in hand is closer and more regular and oblique than that of some of the specimens from Cape Breton that have been referred to the former species.

The types, probably from near Russellville, Arkansas, of this species are Nos. 2667 to 2670 of the Lacoe collection in the U. S. National Museum.

Locality.—Two miles east of Krebs, Indian Territory, NW. ¼ of sec. 12, T. 5 N., R. 15 E.; roof of Grady coal. U. S. Nat. Mus. Reg. 6684.

NEUROPTERIS MISSOURIENSIS Lx.,

1879. *Neuropteris missouriensis* Lesquereux, Coal Flora, Atlas, p. 3, Pl. VII, figs. 5, 6, 6*a*; text, 1 (1880), p. 104.

This common species in the coal-bearing shales of Henry County, Missouri, has many of the features of *N. flexuosa* Stb., from which its

[1] Coal Flora, I, p. 112, Pl. XIV, Pl. XV, fig. 1.

larger isolated pinnules are often only with difficulty distinguished, while the smaller pinnules frequently simulate the *N. rarinervis* Bunby. *Neuropteris missouriensis* is most closely related to the former, from which it is separated by its large oblong, obtuse terminal pinnules, the rather more rounded base, and the thickened nerves near the midrib. The species will be illustrated and described in detail in the memoir on the Flora of the Lower Coal Measures of Missouri.[1]

Localities.—The specimens from the following points, all at the horizon of the McAlester coal, appear to be referable to the normal form, though the identifications from small fragments and isolated pinnules are not wholly satisfactory. One-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6402); mine No. 11, Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6306); westernmost mine at Cherryvale, Indian Territory (U. S. Nat. Mus. Reg. 6602). The presence of this species in the collections from this locality is far from certain, although the small pinnule (the only fragment of the genus found) appears to agree with some of the pinnules of the Missouri fern. More material is indispensable for a proper indentification. Savanna, Indian Territory; U. S. Nat. Mus. Reg. 6563.

Fragments possibly referable to this species, although close to certain examples from Cape Breton referred to *N. rarinervis* Bunby, are present from mine No. 6½, sec. 2, T. 1 S., R. 10 E., Atoka quadrangle, Indian Territory. The larger pinnules are, however, very close to the Missouri fern. Hence its doubtful reference thereto. U. S. Nat. Mus. Reg. 6669.

NEUROPTERIS MISSOURIENSIS LX. NERVOSA n. var.

The nodular fragments from Johnsville contain abundant pinnules and portions of pinnæ, which seem to differ but slightly from the species typically found in Henry County, Missouri.[2] To this Indian Territory form I give the above distinctive varietal designation. The form is distinguished from the normal type by its rather more triangular and more acute terminal pinnules, the frequently rather more elongated and more pointed lateral pinnules, and the more conspicuous nervation, which usually counts about 28–30 per centimeter at the margin. Occasionally, especially in the smaller pinnules, the nervation strongly resembles that of *Neuropteris rarinervis* Bunby, and may, in fact, be as close to that species as are some of the specimens identified therewith.

The variety *nervosa* presents an intermediate form that binds *N. missouriensis* Lx. to the *N. flexuosa* Stb. and the *N. tenuifolia* Brongn., with the latter of which it is specially comparable, on account of the markedly cordate bases of the pinnules and the general habit of the

[1] Mon. U. S. Geol. Survey, Vol. XXXVII.
[2] Coal Flora, Atlas, 1879, Pl. VII, fig. 5, 6; Flora Lower Coal Measures of Missouri, Mon. U. S. Geol. Surv., Vol. XXXVII, Pl. XIII, fig. 4.

nervation, while the longer pinnules sometimes continue the similarity, though the terminals approach more closely to *N. flexuosa*.

Locality.—Johnsville, Indian Territory; roof of coal supposed to be the McAlester coal. U. S. Nat. Mus. Reg. 6526.

NEUROPTERIS CAUDATA D. W.

1893. *Neuropteris caudata* D. White, Bull. U. S. Geol. Survey No. 98, p. 87, Pl. IV, figs. 1–9.

This peculiar member of the group of *Neuropteris* species, represented by *N. ovata* Hoffm.,[1] is nearest related to the species from the Coal Measures referred by Professor Lesquereux to *N. loschii* Brongn.[2] While in the general aspect of its pinnæ, the callipteroid upper pinnules, the thick lamina, and the close, hair-like nervation it strongly resembles the Lower Coal Measures phase of *N. ovata* in this country, its larger pinnules being suggestive of the pinnules of *N. plicata*, as labelled by Lesquereux, it has, in general, its pinnules more pointed, and is specially marked by the elongated, spur-like projection of the proximal basal angle.

Locality.—Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester; horizon about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6620.

NEUROPTERIS sp. indet.

Under this caption references may be given to several fragments from various localities, the plant remains being too incomplete for even tentative reference. First of these may be mentioned a portion of a cyclopterid pinnule, with thin lamina, and very rarely forking nearly parallel nerves. It suggests the American plant from Cannelton, whose Cyclopteris pinnules are figured[3] as *N. trichomanoides* Brongn. This fragment, probably from the stage of the McAlester coal, was collected at Johnsville, Indian Territory. U. S. Nat. Mus. Reg. 6649.

Another lot, from mine "Six and one half" in the Atoka quadrangle, contains portions of two pinnules of one of the long-pinnuled species of *Neuropteris*. Not enough is preserved to warrant further comparisons. U. S. Nat. Mus. Reg. 6673.

A third form, which is comparable to *Neuropteris tenuifolia* Brongn., is present in the collection from the McAlester coal at Savanna, Indian Territory. U. S. Nat. Mus. Reg. 6560. It is not practicable to attempt to determine this species, which is somewhat unsatisfactorily differentiated in our Carboniferous flora, with no other material than a few detached pinnules.

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[1] Keferstein, Teutschland geogn.-geol. dargestellt, IV, 1828, p. 158, Pl. 1*b*, figs. 5, 6, 7.

[2] The comparison of the material with Hoffmann's figure and description, which were unknown to Lesquereux, or with Kidston's republication of *N. ovata* (Foss. Flora Radstock Ser., p. 359, Pl. XXII, fig. 1) shows the greater number of the specimens to belong to the latter. The type of Brongniart's *N. loschii* is considered by European botanists as belonging to *N. heterophylla* Brongn.

[3] Coal Flora, Atlas, Pl. IV, fig. 4.

Another indeterminable portion of a cyclopterid (U. S. Nat. Mus. Reg. 6732) comes from the same stage at mine No. 12, 2 miles southeast of Krebs, Indian Territory.

DICTYOPTERIS Gutbier. 1835.

1835. *Dictyopteris* Gutbier, Abdrücke, p. 62.
1838. *Linopteris* Presl, in Sternberg: Versuch, II, fasc. 7-8, p. **167**.

DICTYOPTERIS CARRII (LX.).

1884. *Neuropteris carrii* Lesquereux, Coal Flora, III, p. 731 (pars), Pl. XCIV, fig. 4-7.

The examination of the types[1] described by Professor Lesquereux as *Neuropteris carrii* reveals a far greater tendency toward anastomosis than is indicated in the drawings or inferred from the description. The specimens from Kingston show frequent anastomoses, as well as pseudo-anastomoses, even near the midrib, the meshing being sometimes nearly as close as in *Dictyopteris rubella* Lx. Hence the species is here referred to the latter genus. Unfortunately there are no pinnæ sufficiently complete to determine the presence or absence of the typical *Dictyopteris* form of the pinnæ and disposition of the pinnules. The *Dictyopteris* type of pinnation is also illustrated in the *Neuropteris gigantea* Stb., and the *N. zeilleri* of Potonié. If classified by the pinnation, both of these species would be referable to *Dictyopteris*, and such a reference would find support also in the reported occasional anastomoses of the nerves in both.[2]

A portion of the specimens from Mazon Creek, Illinois, referred to *Neuropteris carrii* have the nervation closer, more regular, without anastomosis, and are therefore to be retained in the latter genus.

The identification of *Dictyopteris carrii* in the McAlester coal field is not without doubt, on account of the paucity of material. It is probably present, however, in a single large pinnule, from Johnsville, resembling fig. 6, Pl. XCIV, of the Coal Flora, in form and proportions, though the secondary nervilles are a little closer near the middle of the pinnule.

Locality.—Johnsville slope, near Johnstown, Indian Territory, supposed horizon of the McAlester coal. U. S. Nat. Mus. Reg. 6548.

DICTYOPTERIS GILKERSONENSIS D. W. MSS.

This species, described in manuscript of the Flora of the Lower Coal Measures of Missouri,[3] is not rare in the clay ironstones at Gilkerson's Ford, in Henry County of that State. Its form is most comparable to the *Dictyopteris münsteri* (Eichw.) Schimp.,[4] though differing from the

[1] 1385, 1386, 1387, and 1392 in the Lacoe Collection, U. S. National Museum.
[2] Potonié, Jahrb. d. k. Pr. Geol. Landesanst. u. Bergakad., Vol. XII, 1891 (1893), p. 31.
[3] Mon. U. S. Geol. Surv., Vol. XXXVII.
[4] Eichwald, Urwelt Russlands, Hft. 1, p. 87, Pl. III, fig. 2; Kidston, Foss. Fl. Radstock Ser., p. 361, Pl. XXI, fig. 6.

latter chiefly by its narrower, straight pinnules and finer nerve meshes near the margin.

The pinnules from the McAlester coal that I refer to this species are in general rather more closely nerved near the midrib than is found to be the case in the type material from Missouri.

Localities.—From the roof of the McAlester coal, one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6421), and at Savanna, Indian Territory (U. S. Nat. Mus. Reg. 6567). From the stage of the Grady coal, 2 miles east of Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6696).

EQUISETINEÆ.

CALAMARIEAE.

CALAMITES Suckow, 1784.

Acta Acad. Theod. Palat., V, p. 357.
Schlotheim, Petrefactenkunde, 1820, p. 398.

CALAMITES CANNÆFORMIS Schloth.[1]

1818. *Phytolithus sulcatus* Steinhauer, Foss. Reliquæ, p. 297 (pars), Pl. VI, fig. 2 (non fig. 1).
1820. *Calamites cannæformis* Schlotheim, Petrefactenkunde, p. 398, Pl. XX, fig. 1.
1828. *Calamites cannæformis* Schloth., Brongniart, Hist. Vég. Foss., p. 131, Pl. XXI, figs. 1-5.
1832. *Calamites cannæformis* Schlotheim, Merkw. Verst., p. 10, Pl. XX, fig. 1.
1833. *Calamites cannæformis* Schloth., Lindley and Hutton, Foss. Fl. Gt. Brit., II, p. 217, Pl. LXXIX.
1835. *Calamites cannæformis* Schloth., Gutbier, Abdrücke, p. 22, Pl. II, figs. 7, 7*a*.
1848. *Calamites cannæformis* Schloth., Sauveur, Vég. foss. houill. Belg., Pl. XII, fig. 2.
1854. *Calamites cannæformis* Schloth., Geinitz, Hainichen-Ebersd. Sch., p. 32, Pl. XIV, fig. 16 (18?, non figs. 17, 19).
1855. *Calamites cannæformis* Schloth., Geinitz, Verst. Steink. Sachsen, p. 5, Pl. XIV, figs. 1-4 (non fig. 5, non Pl. XIII, fig. 8).
1869. *Calamites cannæformis* Schloth., Schimper, Traité, I, p. 316, Pl. XX, figs. 1-3.
1869. *Calamites cannæformis* Schloth., Von Roehl, Foss. Fl. Steink. Westphalens, p. 12 (pars), Pl. I, fig. 2, Pl. II, f. 1 (non Pl. I, fig. 5, Pl. II, fig. 3, Pl. X, fig. 3, Pl. XXII, fig. 1).
1877. *Calamites cannæformis* Schloth., Grand'Eury, Fl. carb. Loire, p. 21, Pl. III, figs. 1, 2.
1879. *Calamites cannæformis* Schloth., Lesquereux, Coal Flora, Atlas, p. 2, Pl. I, fig. 1; text, I (1880), p. 24.
1883. *Calamites cannæformis* Schloth., Lesquereux, 13th Rept. Geol. Surv. Ind., 2, Pl. V, fig. 2.
1889. *Calamites cannæformis* Schloth., Lesley, Dict. Foss. Pa., I, p. 104, text fig.
1890. *Calamites cannæformis* Schloth., Renault, Fl. foss. houill. Commentry, II, p. 392, Pl. XLIV, figs. 6, 7.
1890. *Calamites cannæformis* Schloth., Grand'Eury, Géol. Paléont. houill. Gard., p. 209, Pl. XIV, figs. 11, 12.
1887. *Stylocalamites* (*Calamites*) *cannæformis* (Schloth.) Kidston, Foss. Fl. Radstock Ser., p. 342.

[1] The synonymy of this species is incomplete, few other than those figures published under the above name being cited.

The material which I provisionally refer to this species comprises three very imperfect fragments showing portions only of as many nodes, but not a complete internode. The residue of the cortical or woody tissue of the trunk forms a perceptible carbonaceous scale, which is rather thicker than is characteristic of the species. The medullary cast seems nevertheless to be very close to *C. cannæformis*.

Locality.—Roof of the McAlester coal at Cherryvale, Indian Territory. U. S. Nat. Mus. Reg. 6609.

CALAMITES sp. indet.

Another species of *Calamites*, belonging to a thin-walled type, appears to be represented by several fragments. They are comparable to *C. suckowii*.

Locality.—Roof of the McAlester coal at mine No. 11, near Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6673.

CALAMODENDRON Brongniart, 1849.

Tableau d. Genres, p. 50.

CALAMODENDRON APPROXIMATUM (Schloth.) Brongn.

1820. *Calamites approximatus* Schlotheim, Petrefactenkunde, p. 399.
1825. *Calamites approximatus* Schloth., Artis, Antedil. Phytology, p. 4, Pl. IV.
1832. *Calamites approximatus* Schlotheim, Merkw. Verst., p. 32.
1828. *Calamites approximatus* Schloth., Brongniart, Hist. Vég. Foss., p. 133, Pl. XV, figs. 7, 8.
1879. *Calamites approximatus* Schloth., Lesquereux, Coal Flora, Atlas, Pl. I, fig. 5; text, I (1880), p. 26.
1883. *Calamites approximatus* Schloth., Lesquereux, 13th Rept. Geol. Surv. Ind., Pl. V, fig. 6.
1820. *Calamites interruptus* Schlotheim, Petrefactenkunde, p. 400, Pl. XX, fig. 2.
1832. *Calamites interruptus* Schlotheim, Merkw. Verst., p. 10, Pl. XX, fig. 2.
1849. *Calamodendron approximatum* (Schloth.) Brongniart, Tableau, p. 50.
1884. *Calamodendron approximatum* (Schloth.) Brongn., Lesquereux, Coal Flora, III, p. 914, Pl. LXXIV, fig. 16.
1884. *Calamitina approximata* (Schloth.) Weiss, Steinkohlen-Cal., II, p. 81, Pl. XXV, fig. 1.
1887. *Calamitina approximata* (Schloth.) Weiss, Kidston, Foss. Fl. Radstock Ser., p. 414.
1893. *Calamitina approximata* (Schloth.) Weiss, Kidston. Foss. Pl. Kilmarnock, p. 311, Pl. II, figs. 5, 6.
1890. *Arthropitus approximata* (Schloth.) Renault, Fl. foss. houill. Commentry, II, p. 434, Pl. LII, f. 6, 7, Pl. LIII, f. 1.

The study of the internal structure and mode of growth of the Calamitean trunks whose medullary casts are familiar as *Calamites* (or *Calamodendron*) *approximatus* of the early authors has led not only to a differentiation and refinement of species, but also to strong disagreements as to the systematic positions of the several genera to which they have been referred.[1]

[1] In the synonymy given above no attempt is made to include the many and sometimes slightly complicated more recent references of the forms described by the early paleobotanists.

Renault describes and figures both the pith-casts and the structure of the wood of the stems, which he refers, on account of the histological characters, to Goeppert's genus *Arthropitys*. Although the material from Indian Territory represents a thick carbonaceous residue enveloping a portion of a medullary cast in complete agreement with the examples figured by Renault,[1] as well as with the type figure given by Schlotheim, the difficulty involved in the attempt to distinguish *Calamodendron* from *Arthropitys* when dealing only with crushed and carbonized examples in which the form of the pith is obliterated is at once apparent. The outer surface of the bright coaly residue of the woody zone is nearly smooth.

Locality.—Roof shale of the Grady coal at Gowan, Indian Territory. U. S. Nat. Mus. Reg. 6588.

CYCLOCLADIA Lindley and Hutton, 1834.

1834. *Cyclocladia* Lindley and Hutton, Foss. Fl. Gt. Brit., II, p. 137, Pl. CXXX.
1868. *Cyclocladia* L. & H., K. Feistmantel, Abt. K. böhm. Ges., (6) II, No. 6, p. 5, Pl. I.
1874. *Cyclocladia* L. & H., O. Feistmantel, Verst. böhm. Kohlen-Abl., I, 1874, p. 95, Pl. I, fig. 8.
1869. *Macrostachya* Schimper, Traité Pal. Vég., I, p. 333 (trunks only).
1876. *Calamitina* Weiss, Steinkohlen-Calamarien, I, p. 126.

CYCLOCLADIA sp.

This genus is represented by a single fragment from the roof of the Grady coal. The internodes are very short, but the specimen is so small that it is impossible to determine the periodicity of the nodes or the presence or absence of branch scars.

Locality.—Roof of the Grady coal, about 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6729.

ASTEROPHYLLITES Brongniart, 1822.

1822. *Asterophyllites* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 210 (pars).
1828. *Asterophyllites* Brongniart, Prodrome, p. 159.
1820. *Casuarinites* Schlotheim, Petrefactenkunde, p. 397 (pars).
1823. *Schlotheimia* Sternberg, Versuch, I, 2, p. 32.
1823. *Myriophyllites* Sternberg, Versuch, I, 3, p. 39 (pars).
1826. *Bornia* Sternberg, Versuch, I, 4, Tent., p. XXVIII (pars).
1826. *Bruckmannia* Sternberg, Versuch, I, 4, Tent., p. XXIX (pars).
1826. *Bechera* Sternberg, Versuch, 1, 4, Tent., p. XXX (pars).
1836. *Hippurites* Lindley and Hutton, Foss. Fl. Gt. Brit., III, p. 105 (pars).
1869. *Calamocladus* Schimper, Traité, I, p. 323.
1880. *Asterophyllum* Schimper, in Zittel: Handb. Palæont., II, p. 175.

ASTEROPHYLLITES EQUISETIFORMIS (Schloth.) Brongn.

1723. ——— ——— Scheuchzer, Herb. Dil., Pl. I, fig. 3, Pl. II, fig. 1.
1804. ——— ——— Schlotheim, Fl. d. Vorw., Pl. I, fig. 2, Pl. II, fig. 3.
1820. *Casuarinites equisetiformis* Schlotheim, Petrefactenkunde, p. 397.

[1] Fl. foss. bassin houill. Commentry, II, 1890, Pl. LIII, fig. 1.

1825. *Bornia equisetiformis* (Schloth.) Sternberg, Versuch, I, fasc. 4, Tent., p. XXVIII.
1841. *Bornia equisetiformis* (Schloth.) Stb., Steininger, Geogn. Beschr., Nachtr., p. 12, fig. 13.
1828. *Asterophyllites equisetiformis* (Schloth.) Brongniart, Prodrome, p. 159.
1837. *Asterophyllites equisetiformis* (Schloth.) Brongn., Germar, Isis, col. 428, Pl. II, fig. 3.
1841. *Asterophyllites equisetiformis* (Schloth.) Brongn., Hitchcock, Geol. Mass., II, p. 541, Pl. XXI, fig. 2.
1845. *Asterophyllites equisetiformis* (Schloth.) Brongn., Germar, Verst. Steink. Wettin Löbejün, p. 21, Pl. VIII.
1846. *Asterophyllites equisetiformis* (Schloth.) Brongn., Teschemacher, Foss. Veg. Amer., p. 380.
1855. *Asterophyllites equisetiformis* (Schloth.) Brongn., Geinitz, Verst. Steink. Sachsen, p. 8, Pl. XVII, fig. 1.
1861. *Asterophyllites equisetiformis* (Schloth.) Brongn., Lesquereux, Rept. Geol. Surv. Ky., IV, p. 436, (Pl. IV, fig. 1, 1*a* not published).
1864. *Asterophyllites equisetiformis* (Schloth.) Brongn., Goeppert, Foss. Fl. Perm. Form., p. 36, Pl. I, fig. 3.
1869. *Asterophyllites equisetiformis* (Schloth.) Brongn., von Roehl, Foss. Fl. Steink. Westphalens, p. 22, Pl. III, fig. 5.
1871. *Asterophyllites equisetiformis* (Schloth.) Brongn., O. Feistmantel, Steinkohlenf. Kralup, p. 17, Pl. I, fig. 1.
1871. *Asterophyllites equisetiformis* (Schloth.) Brongn., Weiss, Foss. Fl. jüngst. Steink. u. Rothl., p. 126, Pl. XII, fig. 2 (?).
1873. An *asterophyllites equisetiformis* (Schloth.) Brongn., O. Feistmantel, Zeitschr. deutsch. Geol. Gesell., XXV, p. 471, Pl. XIV, fig. 6.?
1874. *Asterophyllites equisetiformis* (Schloth.) Brongn., O. Feistmantel, Verst. böhm. Ablag., I, p. 116, Pl. X, fig. 1, 2; Pl. XI, Pl. XII, fig. 2.
1876. *Asterophyllites equisetiformis* (Schloth.) Brongn., Heer, Fl. foss. Helv., p. 48, Pl. XIX, fig. 1, 2.
1879. *Asterophyllites equisetiformis* (Schloth.) Brongn., Saporta, Monde d. Plantes, p. 175, figs. 11, [3, 4]
1879. *Asterophyllites equisetiformis* (Schloth.) Brongn., Zeiller, Vég. foss. terr. houill., p. 19, Pl. CLIX, fig. 3.
1879. *Asterophyllites equisetiformis* (Schloth.) Brongn., Heer, Urw. d. Schweiz, 2d ed., p. 16, fig. 1a.
1880. *Asterophyllites equisetiformis* (Schloth.) Brongn., Lesquereux, Coal Flora, Atlas (1879), p. 1, Pl. II, fig. 3, 3a; Pl. III, fig. 5-7; Text, I, p. 35.
1880. *Asterophyllites equisetiformis* (Schloth.) Brongn., Ferd. Roemer, Leth. Geogn., Pal., p. 146, Pl. L, fig. 4.
1881. *Asterophyllites equisetiformis* (Schloth.) Brongn., Weiss, Aus d. Fl. d. Steink., p. 9, Pl. IX, fig. 45.
1882. *Asterophyllites equisetiformis* (Schloth.) Brongn., Renault, Cours Bot. Foss., II, p. 122, Pl. XVIII, fig. 1; Pl. XIX, fig. 3.
1883. *Asterophyllites equisetiformis* (Schloth.) Brongn., Schenk, in Richthofen: China, IV, p. 235, Pl. XXXVII, fig. 2, 3.
1883. *Asterophyllites equisetiformis* (Schloth.) Brongn., Lesquereux, 13th Rept. Geol. Surv. Ind., 2, Pl. VI, fig. 1, 2.
1886. *Asterophyllites equisetiformis* (Schloth.) Brongn., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LVIII, figs. 1-7; text (1888), p. 368.
1889. *Asterophyllites equisetiformis* (Schloth.) Brongn., Lesley, Dict. Foss. Pa., I, p. 46, text fig.
1890. *Asterophyllites equisetiformis* (Schloth.) Brongn., Renault, Fl. foss. houill. Commentry, II, p. 409, Pl. XLVIII, figs. 3, 4, 5.

1893. *Asterophyllites equisetiformis* (Schloth.) Brongn., Grand' Eury, Géol. Pal. houill. Gard, pp. 156, 173, Pl. XVII, fig. 4.
1893. *Asterophyllites equisetiformis* (Schloth.) Brongn., Potonié, Fl. Rothl. Thüringen, p. 176, Pl. XXIV, fig. 8.
1836. *Hippurites longifolia* Lindley & Hutton, Foss. Fl., III, Pls. CXC, CXCI.
1844. *Asterophyllites Neumannianus* Goeppert, in Wimmer: Fl. v. Schlesien, II, p. 199.
1848. *Asterophyllites Lindleyanus* Goeppert, in Bronn: Index, pal., p. 122.
1851. *Calamites Cistii* Brongn., Ettingshausen, Fl. d. Vorw., p. 75 (ex parte syn.).
1865. *Calamites Cistii* Brongn., Heer, Urwelt d. Schweiz, p. 8, fig. 4*c*.
1855. *Asterophyllites grandis* L. & H., Geinitz, Verst. Steink. Sachsen, Pl. XVII, fig. 5.
1855. *Calamites equisetiformis* (Schloth.) Ettingshausen, Steinkohlenfl. Radnitz, p. 28.
1869. *Calamocladus equisetiformis* (Schloth.) Schimper, Traité, I, p. 324, Pl. XX, figs. 1-3, 4.
1869. *Annularia calamitoides* Schimper, Traité, I, p. 349, Pl. XXII. fig. 4.
1876. *Calamocladus binervis* Boulay, Terr. houill. nord Fr., p. 22, Pl. II, fig. 1.
1876. *Calamostachys germanica* Weiss? Steinkohlen-Cal., I, p. 47, Pl. XVI, figs. 3, 4.
1883. *Calamostachys germanica* Weiss, Schenk, in Richthofen: China, IV, p. 233, Pl. XXXVI, fig. 5.
1878. *Calamostachys equisetiformis* (Schloth.) [Bigsby?], Bigsby, Thesaurus Dev.-Carb., p. 145.
1880. *Asterophyllum equisetiformis* (Schloth.) Schimper, in Zittel: Handb. Pal., II, pp. 174, 175, fig. 131.
1881. *Asterophyllites annularioides* Crepin, in Mourlon: Géol. Belgique, II, p. 59.

The representatives of this species in the McAlester flora are typical in form and well developed, indicating a stage above the base of the coal measures. The earlier and stratigraphically lower forms approach *A. erectifolius* Andr. It seems more than possible that the latter comprise branchlets of an ancestral type.

Localities.—Mine No. 11, near Krebs, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6368. Also found in the Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory; stage about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6663.

ANNULARIA Sternberg, 1823.

Versuch einer Flora d. Vorwelt, I, fasc. 3, p. 36.

ANNULARIA STELLATA (Schloth.) Wood.

PL. LXVIII, FIG. 10?

1699. *Apparinæ densius foliatæ* Luidius, Lithophyl. Brit., p. 12, Pl. V, fig. 201.
1723. *Apparinæ densius foliatæ*, Scheuchzer, Herb. Diluv., p. 19, Pl. III, fig. 3.
1723. *Galium album vulgare* Tourn., Scheuchzer, Herb. Diluv., p. 63, Pl. XIII, fig. 3.
1771. *Galium album latifolium* Rupp., Knorr, in Walch: Naturgesch. Verst., III, p. 117, Pl. ω, fig. 2.
1804. ——— ———, Schlotheim, Flora Vorw., Pl. I, fig. 4.
1804. *Equisetum?* Parkinson, Organic Rem., p. 428, Pl. V, Fig. II.
1809. An *Phytolithus stellatus* Martin, Petrifacta Derb., Pl. XX, fig. 4?.
1820. *Casuarinites stellatus* Schlotheim, Petrifactenkunde, p. 397.
1832. *Casuarinites stellatus* Schlotheim, Merkrwürdige Verst., p. 5, Pl. I, fig. 4.
1823. *Annularia spinulosa* Sternberg, Versuch, 1, fasc. 2, pp. 28, 32, Pl. XX, fig. 4; tent., p. XXXI.

1826. *Bornia stellata* (Schloth.), Sternberg, Versuch, I, tent., p. XXVIII.
1826. *Annularia fertilis* Sternberg, Versuch, 1, fasc. 4, p. 43, Pl. LI, fig. 2; Tent., p. XXXI.
1837. *Annularia fertilis* Stb., Bronn, Lethæa Geogn., p. 44, Pl. VIII, fig. 8.
1859. *Annularia fertilis* Stb., Eichwald, Lethæa Rossica, p. 187, Pl. XIV, fig. 9.
1828. *Annularia longifolia* Brongniart, Prodrome, p. 156.
1845. *Annularia longifolia* Brongn., Germar, Verst. Wettin u. Löbejün, p. 25, Pl. IX, figs. 1-3.
1852. *Annularia longifolia* Brongn., Ettingshausen, Steinkohlenfl. Stradonitz, p. 8. Pl. I, fig. 4.
1855. *Annularia longifolia* Brongn., Geinitz, Verst. Steink. Sachsen, p. 10, Pl. XIX, figs. 3-5.
1866. *Annularia longifolia* Brongn., Lesquereux, Geol. Surv. Ill., II, Pal., p. 444.
1869. *Annularia longifolia* Brongn., Schimper, Traité, 1, p. 348 (pars), Pl. XXII, fig. 5, Pl. XXVI, figs. 2, 3, 4.
1869. *Annularia longifolia* Brongn., Von Roehl, Foss. Fl. Steink. Westphalens, p. 28, Pl. IV, fig. 6.
1870. *Annularia longifolia* Brongn., Unger, Sitzb. Akad. Wiss. Wien, Math.-Nat. Cl., LX, 1, p. 783, Pl. I, fig. 8.
1874. *Annularia longifolia* Brongn., O. Feistmantel, Verst. böhm. Ablag., 1, p. 127, Pl. XV, fig. 3, Pl. XVI, fig. 1.
1876. *Annularia longifolia* Brongn., Ferd. Roemer, Lethæa geogn., 1, Atlas, pl. 2, fig. 8; text (1880), p. 150.
1876. *Annularia longifolia* Brongn., Heer, Fl. foss. Helv., p. 51, Pl. XIX, figs. 4, 5.
1879. *Annularia longifolia* Brongn., Lesquereux, Coal Flora, Atlas, p. 2, Pl. II, figs. 1, 2, *2a;* text (1880), 1, p. 45.
1881. *Annularia longifolia* Brongn., Lesquereux, Rept. Geol. Surv. Ind., 1879-80, p. 153, Pl. XI, fig. 1.
1882. *Annularia longifolia* Brongn., Renault, Cours. Bot. Foss., II, p. 126, Pl. XX, fig. 1.
1883. *Annularia longifolia* Brongn., Lesquereux, 13th Rept. Geol. Surv. Ind., pt. 2, p. 44, Pl. VII, figs. 1, 2.
1883. *Annularia longifolia* Brongn., Schenk, in Richthofen: China, IV, p. 232, Pl. XXXIX.
1884. *Annularia longifolia* Brongn., Lacoe, in Lesquereux: Coal Flora, III, p. 706.
1889. *Annularia longifolia* Brongn., Lesley, Dict. Foss. Pa., I, p. 26, text fig.
1834. *Asterophyllites equisetiformis* (Schloth.) Brongn., Lindley & Hutton, Foss. Fl. Gt. Brit., II, Pl. 124.
1835. *Equisetum stellifolium* Harlan, Trans. Geol. Soc. Pa., I, p. 260, Pl. XIV, fig. 4.
1836. *Asterophyllites?* Morton, Am. Jour. Sci., XXIX, p. 151, Pl. IX, fig. 30.
1840. *Asterophyllites*, Jackson, Rept. Geol. Surv. R. I., 1839, p. 288, Pl. VI.
1841. *Annularia*, Hitchcock, Final Rept. Geol. Mass., II, pp. 542, 754, fig. 266, Pl. XXII, fig. 3, Pl. XXIII, fig. 1 (center).
1860. *Annularia stellata* (Schloth.) Wood, Proc. Acad. Nat. Sci. Phil., XII, p. 236.
1878. *Annularia stellata* (Schloth.) Wood, Zeiller, Vég. foss. terr. houill., Atlas, Pl. CLX, figs. 2, 3; text (1879), p. 26.
1886. *Annularia stellata* (Schloth.) Wood, Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXI, figs. 4-6; text (1888), p. 398.
1887. *Annularia stellata* (Schloth.) Wood, Kidston, Foss. Fl. Radstock Ser., p. 343.
1887. *Annularia stellata* (Schloth.) Wood, Stur, Calamar. Carbon-Fl., p. 55, Pl. XIII b, fig. 3.
1890. *Annularia stellata* (Schloth.) Wood, Renault, Fl. foss. houill. Commentry, II, p. 398, Pl. XLV, figs. 1-7, Pl. XLVI, figs. 1-6.
1891. *Annularia stellata* (Schloth.) Wood, Raciborski, Permokarb. Fl. Karmiowick. Wapienia, p. 7, Pl. V, figs. 17-19.
1892. *Annularia stellata* (Schloth.) Wood, Potonié, Naturw. Wochenschr., VII, No. 51, p. 520, figs. 1, 2.

1893. *Annularia stellata* (Schloth) Wood, Potonié, Fl. Rothl. Thüringen, p. 162, Pl. XXIV, fig. 1-6.
1893. *Annularia stellata* (Schloth.) Wood, D. White, Bull. U. S. Geol. Survey No. 98, p. 25.
1868. *Asterophyllites longifolius* (Brongn.) Binney, Obs. Struct. Foss. Pl. Carb., 1, p. 28, Pl. VI, fig. 3.
1870. *Annularia* sp., Ferd. Roemer, Geol. v. Oberschlesien, p. 117, Pl. IX, fig. 9.
1883. *Annularia mucronata* Schenk, in Richthofen: China, IV, p. 226, Pl. XXX, fig. 10.
1887. *Annularia Geinitzii* Stur, Calamar. Schatzlarer Sch., p. 215, Pl. XVI *b*, figs. 1, 2, 3.
1887. An *Annularia westphalica* Stur, Calamar. Schatzlarer Sch., p. 213, Pl. XIII *b*, fig. 2?
1887. *Asterophyllites westphalicus* Stur, Calamar. Schatzlarer Sch., p. 216, Pl. IV *b*, fig. 4.

FRUCTIFICATION.

1826. *Bruckmannia tuberculata* Sternberg (Pars?), Versuch, 1, fasc. 4, Tent., p. XXIX, Pl. XLV, fig. 2.
1882. *Bruckmannia tuberculata* Stb., Renault, Cours. Bot. Foss., II, p. 129, Pl. XXI, fig. 1-6, 6*bis*.
1828. *Asterophyllites tuberculata* (Stb.) Brongn., Prodrome, p. 159.
1876. *Annularia longifolia* Brongn., Ferd. Roemer, Lethaea Geogn., 1, Atlas, Pl. L, fig. 9; text (1880), p. 150.
1877. *Annularia longifolia* Brongn., Grand' Eury, Fl. Carb. Loire, p. 44, Pl. VI, fig. 4.
1879. *Annularia longifolia* Brongn., Heer, Urwelt d. Schweiz, p. 16, fig. 22.
1879. *Annularia longifolia* Brongn., Lesquereux, Coal Flora, Atlas, p. 2, Pl. III, fig. 10 (non 11, 12).
1882. *Annularia longifolia* Brongn., Renault, Cours Bot. Foss., II, p. 126, Pl. XXXI, figs. 1-7.
1883. *Annularia longifolia* Brongn., Schenk, in Richthofen, China, IV, p. 232, Pl. XXXIV, figs. 4-7; Pl. XXXV, fig. 7; Pl. XXXVI, fig. 1-4; Pl. XXXIX, Pl. XLI, fig. 6.
1876. *Stachannularia tuberculata* (Stb.) Weiss, Steinkohlen-Cal., 1, p. 17, Pl. I, figs. 2-4; Pl. II, figs. 1-3; Pl. III, figs. 3-10, 12.
1879. *Asterophyllites* fruit, Lesquereux, Coal Flora, Atlas, p. 2, Pl. III, fig. 10.
1884. *Calamostachys tuberculata* (Stb.) Weiss (non Lx.) Steinkohlen-Cal., II, p. 178.
1886. *Annularia stellata* (Schloth.) Wood, Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXI, figs. 3, 3*a*; text (1888), p. 398.
1890. *Annularia stellata* (Schloth.) Wood, Renault, Fl. foss. houill. Commentry, II, p. 398, Pl. XLV, fig. 1-3, Pl. XLVI, fig. 4-6.
1893. *Annularia stellata* (Schoth) Wood, Sterzel, Fl. Rothl. Plauensch. Grund, p. 99, Pl. IX, fig. 9.

This species, which is common in the eastern and northern bituminous coal fields, is not very rare in the roof of the McAlester coal.

The sporangia figured in Pl. LXVIII, fig. 10, probably belong to this species. The description of the fructification has been given by Weiss, cited in the above synonymy.

Localities.—One-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6472. Also found at an horizon about 2,000 feet above the McAlester coal in the Missouri, Kansas and Texas Railway cut south of South McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6636.

ANNULARIA SPHENOPHYLLOIDES (Zenk.) Gutb.

1699. *Rubeola mineralis* Luidius, Lithophyl. Brit., p. 12, No. 202.
1771. *Rubia sylvestris* Volkmann, Walch, Naturgesch. Verst., III, p. 117, Pl. ω, fig. 1.
1804. *Rubia sylvestris* Volk., Parkinson, Org. Rem., p. 428, Pl. V, fig. 3.
1828. *Annularia brevifolia* Brongniart, Prodrome, p. 156.
1849. *Annularia brevifolia* Brongniart, Tableau, p. 53.
1853. *Annularia brevifolia* Brongn., Newberry, Annals Science, Cleveland, Vol. I, p. 97.
1876. *Annularia brevifolia* Brongn., Heer, Fl. Foss. Helv., p. 51, Pl. XIX, fig. 6–9.
1880. *Annularia brevifolia* Brongn., Ferd. Roemer, Lethaea geogn., I, p. 150, fig. 7.
1880. *Annularia brevifolia* Brongn., Schimper, in Zittel: Handbuch Paläont., II, p. 167, fig. 127.
1883. *Annularia brevifolia* Brongn., Schenk, in Richtofen: China, IV, p. 233, Pl. XL.
1887. *Annularia brevifolia* Brongn., Stur, Calamar. Schatzlar. Fl., p. 223, Pl. XVI*b*, figs. 3, 4.
1833. *Galium sphenophylloides* Zenker, N. Jahrb. f. Min., p. 398, Pl. V, figs. 6–9.
1837. *Annularia sphenophylloides* (Zenk.) Gutbier, Isis, v. Oken, col. 436.
1854. *Annularia sphenophylloides* (Zenk.) Gutb., Lesquereux, Bost. Jour. Nat. Hist., VI, p. 415.
1855. *Annularia sphenophylloides* (Zenk.) Gutb., Geinitz, Verst. Steinkohl. Sachsen, p. 11, Pl. XVIII, fig. 10.
1858. *Annularia sphenophylloides* (Zenk.) Gutb., Lesquereux, Geol. Pa., II, 2, p. 852, Pl. I, figs. 5, 5*a*.
1860. *Annularia sphenophylloides* (Zenk.) Gutb., Roemer, Palæontogr., IX, p. 21, Pl. XI, fig. 1.
1869. *Annularia sphenophylloides* (Zenk.) Gutb., Schimper, Traité, 1, p. 347, Pl. XVII, figs. 12, 13.
1870. *Annularia sphenophylloides* (Zenk.) Gutb., Unger, Sitzb. Acad. Naturw. Wien, Math.-Nat. Cl., LX, Pt. I, p. 783, Pl. I, fig. 8.
1874. *Annularia sphenophylloides* (Zenk.) Gutb., O. Feistmantel, Verst. böhm. Ablag., 1, p. 129, Pl. XVII, figs. 5, 6.
1878. *Annularia sphenophylloides* (Zenk.) Gutb., Zeiller, Vég. terr. houill., Atlas, Pl. CLX, fig. 4; text (1879), p. 25.
1879. *Annularia sphenophylloides* (Zenk.) Gutb., Lesquereux, Coal Flora, Atlas, p. 2, Pl. II, figs. 8, 9; text, 1, (1880), p. 48.
1881. *Annularia sphenophylloides* (Zenk.) Gutb., Weiss, Aus d. Fl. d. Steink., Pl. IX, fig. 47.
1882. *Annularia sphenophylloides* (Zenk.) Gutb., Renault, Cours Bot. Foss., II, p. 133, Pl. XX, fig. 3.
1882. *Annularia sphenophylloides* (Zenk.) Gutb., Sterzel, Zeitschr. d. Deutsch. geol. Gesell., XXXIV, p. 685, Pl. XXVII, figs. 1–10.
1883. *Annularia sphenophylloides* (Zenk.) Gutb., Lesquereux, 13th Ann. Rept. Geol. Surv. Ind., pt. 2, p. 45, Pl. VII, figs. 3, 4, 5.
1886. *Annularia sphenophylloides* (Zenk.) Gutb., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LX, figs. 5, 6; text (1888), p. 388.
1888. *Annularia sphenophylloides* (Zenk.) Gutb., Dawson, Geol. Hist. Pl., p. 122, fig. 45*b*.
1889. *Annularia sphenophylloides* (Zenk.) Gutb., Lesley, Dict. Foss. Pa., I, p. 28; 5 text-figs.
1889. *Annularia sphenophylloides* (Zenk.) Gutb., Miller. Geol. Pal. N. Am., p. 106, fig. 7.
1890. *Annularia sphenophylloides* (Zenk.) Gutb., Renault, Fl. foss. houill. Commentry, II, Atlas, Pl. XLVI, figs. 7–9.
1893. *Annularia sphenophylloides* (Zenk.) Gutb., D. White, Bull. U. S. Geol. Survey, No. 98, p. 30.
1860. *Annularia microphylla* Ferd. Roemer (non Sauveur), Palæontogr., IX, p. 21, Pl. V, fig. 1.
1887. *Annularia sarepontana* Stur, Calamar. d. Carbon-Fl., p. 221, Pl. XIII*b*, fig. 1.

FRUCTIFICATION.

1882. *Annularia sphenophylloides* (Zenk.) Gutb., Sterzel, Zeitschr. d. Deutsch. geol. Gesell., XXXIV, p. 685, Pl. XXVIII, figs. 1-4.
1876. An *Stachannularia calathifera* Weiss (?), Steinkohlen-Cal., 1, p. 27, Pl. III, fig. 11.
1880. An *Stachannularia calathifera* Weiss, Ferd. Roemer, Lethaea Geogn., 1, p. 157?
1884. *Calamostachys* cf. *calathifera* Weiss, Steinkohlen-Cal., II, p. 178.

In our American coal measures *Annularia sphenophylloides* is, so far as known, confined strictly to the supra-Pottsville beds. Its first observed occurrence in the northeastern areas is in the lower part of the Alleghany series. In the Kanawha series, as in the European coal fields, it does not make its appearance for a long distance above the Pottsville (millstone grit) series. In general it does not appear quite so low as does *A. stellata.* The species is, I believe, derived from the *A. Dawsoni* or *A. latifolia* of the upper part of the Pottsville series and the basal portion of the Kanawha series.

Localities.—Roof of McAlester coal, one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6473); also at Savanna, Indian Territory (U. S. Nat. Mus. Reg. 6584), and at Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory, about 2,000 feet above the horizon of the McAlester coal (U. S. Nat. Mus. Reg. 6667).

ANNULARIA SPHENOPHYLLOIDES (Zenk.) Gutb. var. INTERMEDIA Lx.

Lesquereux, Coal Flora, III, 1884, p. 724.

The examination of the collections of Coal Measures plants from this country show in general that the earlier specimens of *Annularia sphenophylloides* are small, the later examples, as in Rhode Island or in the middle veins of the Anthracite fields being larger, while the latest forms seen, as, for example, in the roof of the Waynesburg coal, Dunkard Creek series, are very large and lax, approaching *A. stellata* in size, although preserving the very obtuse, cuneate character of the normal form of *A. sphenophylloides.* This later enlarged form or phase of the species deserves formal distinction, since it possesses great stratigraphical value. For such distinction I employ the varietal term used by Professor Lesquereux, though the form is probably connected by every transitional earlier phase to the normal form.

Locality.—About 2,000 feet above the McAlester coal in the Missouri, Kansas and Texas Railway cut, about one-half mile south of South McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6635.

MACROSTACHYA Schimper, 1869.

Traité, I, p. 333 (strobili).

MACROSTACHYA COMMUNIS Lx.

1879. *Macrostachya*, cones of, Lesquereux, Coal Flora, Atlas, p. 2, Pl. III, fig. 17, 18 (non fig. 19).
1880. *Macrostachya infundibuliformis* (Bronn) Schimp., Lesquereux, Coal Flora, 1, p. 60 (pars, excl. syn.), Pl. III, figs. 17, 18 (non. fig. 19).
1884. *Macrostachya communis* Lesquereux, Coal Flora, III, p. 828, Pl. III, fig. 17, 18.
1890. *Macrostachya communis* Lx., Grand 'Eury, Géol. Paléont. bassin houill. Gard, p. 205.

The form of the strobilus and the characters of the bracts appear to agree with the species as seen in numerous specimens from Cannelton, Pennsylvania.

Locality.—Mine No. 11, near Krebs, Indian Territory; roof of the McAlester coal. U. S. Nat. Mus. Reg. 6377.

MACROSTACHYA sp. indet.

A single fragment of a flattened and carbonized cone in a fragment of "bone" from the Grady coal is not specifically identifiable.

Locality.—Mine No. 12, 2 miles southeast of Krebs, Indian Territory; roof of the Grady coal. U. S. Nat. Mus. Reg. 6681.

SPHENOPHYLLINEÆ.

SPHENOPHYLLEAE.

SPHENOPHYLLUM Brongniart, 1828.

1822. *Sphænophyllites* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 209.
1822. *Sphenophyllites* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 234.
1823. *Rotularia* Sternberg, Versuch, I, 2, p. 33; Tent., 1825, p. XXXII.
1828. *Sphenophyllum* Brongniart, Prodrome, p. 65.
1871. *Bowmannites* Binney, Obs. Struct. Foss. Pl. Carb. Str., II, p. 59.

SPHENOPHYLLUM CUNEIFOLIUM (Stb.) Zeill.

1823. *Rotularia asplenioides* Sternberg, Versuch, I, 2, p. 30, Pl. XXVI, fig. 4a,b.
1823. *Rotularia cuneifolia* Sternberg, Versuch, I, 2, p. 33, Pl. XXVI, fig. 4a,b.
1826. *Rotularia pusilla* Sternberg, Versuch, I, 4, Tent., p. XXXII.
1826. *Rotularia polyphylla* Sternberg, Versuch, I, 4, p. 42, Tent., p. XXXII, Pl. L, fig. 4.
1828. *Sphenophyllum fimbriatum* Brongniart, Prodrome, p. 68.
1828. *Sphenophyllum dentatum* Brongniart, Prodrome, p. 68.
1850. *Sphenophyllum dentatum* Brongn., Unger, Gen. et species, p. 70.
1855. *Sphenophyllum dentatum* Brongn., Phillips, Manual Geol., p. 234, fig. 110.
1831. *Sphenophyllum erosum* Lindley and Hutton, Foss. Flora, I, Pl. XIII.
1847. *Sphenophyllum erosum* L. & H., Bunbury, Quart. Jour. Geol. Soc., III, p. 430, Pl. XXIII, figs. 3a, 3b.
1864. *Sphenophyllum erosum* L. & H., Coemans and Kickx, Mon. Sphen., p. 149, Pl. I, figs. *5a, b, c*.

1868. *Sphenophyllum erosum* L. & H., Dawson, Acad. Geol., 3d ed., p. 444, fig. 165[c].
1869. *Sphenophyllum erosum* L. & H., Schimper, Traité, I, p. 341.
1869. *Sphenophyllum erosum* L. & H., Von Roehl, Foss. Fl. Steink. Westphalens, p. 30, Pl. IV, fig. 19.
1880. *Sphenophyllum erosum* L. & H., Lesquereux, Coal Flora, I, p. 55.
1881. *Sphenophyllum erosum* L. & H., Weiss, Aus d. Fl. d. Steink., Pl. X, figs. 57, 57[a].
1888. *Sphenophyllum erosum* L. & H., Dawson, Geol. Hist. Pl., p. 122, fig. 45[c].
1891. *Sphenophyllum erosum* L. & H., Newberry, Jour. Cincin. Soc. N. H., p. 215, Pl. XIX, figs. 1–4.
1836. *Rotularia erosa* (L. & H.) Goeppert, Foss, Farrnkr., p. 431.
1848. *Sphenophyllum pusillum* (Stb.) Sauveur, Vég. foss. terr. houill. Belg., Pl. LXIV, fig. 4.
1848. *Sphenophyllum saxifragæfolium* (Stb.) Goeppert, in Bronn: Index Pal., I, p. 1166.
1854. *Sphenophyllum saxifragæfolium* (Stb.) Goepp., Geinitz, Fl. Hain.-Ebersdorf., p. 37, Pl. XIV, figs. 7–10.
1869. *Sphenophyllum saxifragæfolium* (Stb.) Goepp., Von Roehl, Foss. Fl. Steink. Westphalens, p. 31, Pl. IV, fig. 17.
1878. *Sphenophyllum saxifragæfolium* (Stb.) Goepp., Zeiller, Vég. foss. terr. houill., Pl. CLXI, figs. 4, 5; text (1879), p. 31 (pars.).
1848. *Sphenophyllum multifidum* Sauveur, Vég. foss. terr. houill. Belg., Pl. LXIV, figs. 1, 2.
1852. *Sphenophyllum schlotheimii* Brongn. var. *β dentatum* et var. *ζ erosum* Ettingshausen, Steinkohlenfl. Stradonitz, p. 6, Pl. 6, fig. 6.
1855. *Sphenophyllum schlotheimii* Brongn. var. *β dentatum* et var. *ζ erosum* Ettingshausen, Steinkohlenfl. Radnitz, p. 30, Pl. XI, figs. 1–3.
1854. *Sphenophyllum trifoliatum* Lesquereux, Boston Jour. N. H., VI, No. 4, p. 415.
1858. *Sphenophyllum trifoliatum* Lesquereux, Geol. Pa., II, 2, p. 853, Pl. I, fig. 7.
1855. *Sphenophyllum schlotheimii* Brongn., Geinitz, Verst. Steink. Sachsen, Pl. XX, fig. 6.
1864. *Sphenophyllum erosum* L. & H. var. *saxifragæfolium* (Stb.) Coemans and Kickx, Monogr. Sphen., p. 151, Pl. 1, figs. 6*a–d*.
1869. *Sphenophyllum erosum* L. & H. var. *saxifragæfolium* (Stb.) C. & K., Schimper, Traité, 1, p. 342, Pl. XXV, figs. 10, 11–14.
1880. *Sph nophyllum erosum* L. & H. var. *saxifragæfolium*, (Stb.) C. & K., Schimper, in Zittel: Handb. Paläont., II, p. 179, figs. 135[3], [4].
1874. *Sphenophyllum emarginatum* Brongn., O. Feistmantel, Verst. böhm. Ablag., I, p. 134, Pl. XVIII, figs. 2, 5?, 6?.
1874. *Sphenophyllum emarginatum* Brongn. var. *saxifragæfolium* (Stb.) C. & K., O. Feistmantel, Verst. böhm. Ablag., I, p. 134, Pl. XVIII, fig. 4.
1877. *Sphenophyllum dichotomum* (Germ. & Kaulf.) Ung., Stur, Culm-Flora, II, p. 119, (225).
1887. *Sphenophyllum dichotomum* (Germ. & Kaulf.) Ung., Stur. Calamar. d. Carbon-Fl., p. 223, f. 43, Pl. XV, f. 5*a*, *b*, *c*, Pl. XII b, fig. 2.
1878. *Sphenophyllum cuneifolium* (Stb.) Zeiller, Vég. foss. terr. houill., Pl. CLXI, fig. 1; text (1879), p. 30 (pars.).
1882. *Sphenophyllum cuneifolium* (Stb.) Zeill., Renault, Cours bot. foss., II, p. 87, Pl. XIII, fig. 10.
1886. *Sphenophyllum cuneifolium* (Stb.) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXIII, figs. 1–3, 6, 7, (3, 4, 5, 10, fruit); text (1888), p. 413.
1893. *Sphenophyllum cuneifolium* (Stb.) Zeill., D. White, Bull. U. S. Geol. Survey No. 98, p. 36.
1893. *Sphenophyllum cuneifolium* (Stb.) Zeiller, Mém. Soc. Géol. Fr., Pal., IV, No. 11, p. 12, Pl. I, Pl. II, figs. 1–3, Pl. III, figs. 1–2.
1894. *Sphenophyllum cuneifolium* (Stb.) Zeill., Potonié, Ber. d. deutsch. bot. Gesell., XII, 4, p. 99, fig. 3*a*, *b* (fig. 1, fruit).

1886. *Sphenophyllum cuneifolium* (Stb.) Zeill. var. *saxifragæfolium* (Stb.) Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXII, fig. 1, Pl. LXIII, figs. 4, 5, 9, 10; text (1888), p. 413.

1893. *Sphenophyllum cuneifolium* (Stb.) Zeill. var. *saxifragæfolium* (Stb.) Zeill., D. White, Bull. U. S. Geol. Survey No. 98, p. 37.

This species is not rare in the upper portion (Sewanee division) of the Pottsville series and the lower portion of the succeeding Coal Measures on the Kanawha River in West Virginia. The typical form is, however, rare in the supra-Pottsville beds in the northern or northeastern area, even near the base of the series, although not infrequently specimens of *S. emarginatum* with dissected leaflets are so preserved as to be only with difficulty distinguished from the earlier form.

The fructification of this species, *Volkmannia* (*Bowmanites*) *dawsoni*, has been the subject of a most valuable study by Professor Zeiller.[1]

Locality.—Roof of the Grady coal, about 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6707.

SPHENOPHYLLUM SUSPECTUM n. sp.

PL. LXVIII, FIGS. 11, 12

Branchlets very slender, delicate, somewhat curved, with slender axis much enlarged at the nodes. Nodes close, 5 millimeters to 7 millimeters distant, especially enlarged on the proximal side, to which the very oblique leaves are joined, at least in a young stage, in an extremely narrow wing.

Leaves usually nine to the verticil, symmetrically arranged, linear, slightly spatulate, 7 millimeters to 10 millimeters long, 1.5 millimeters wide a little above the middle; the sides slightly convex, narrowed gently toward the base, a little contracted, with convex border, toward the apex, which is round-crenulate, or more or less distinctly obtusely round-bidentate, dorsally slightly convex, especially near the apex. Bases of the leaves continuous in direction at their slightly buttressed point of origin at the upper end of the internode, arching out obliquely, then turning upward nearly parallel to the axis, forming a deep cup-shaped verticil, 6 millimeters to 8 millimeters in diameter. Lamina rather thin, but minutely rugose by rows of scale-like epidermal cells parallel in general to the nervation.

Nervation distinct, coarse, continuous upward from the ribs of the axis, simple for from one-half to three-fourths of the distance up the leaf, when each nerve forks at a very narrow angle, the two nervils arching outward and upward, parallel or a little convergent, one of them extremely rarely forking again, the two nervils nearly meeting in the apex of the leaf when the latter is rounded, or entering the somewhat irregular or ill-defined teeth.

[1] Sur la constitution des épis de fructification du *Sphenophyllum cuneifolium*: Comptes Rendus, CXV, 1892, pp. 141–144.

Étude sur la constitution de l'appareil fructificateur des *Sphenophyllum*: Mém. Soc. Géol. Fr., Paléont., IV, 1893, No. 11, pp. 1–39, Pl. I–III.

The general aspect of the branchlets of this species is essentially that of *Asterophyllites* and, until the enlargements of the nodes or the bifurcation of the nerve is seen, it may easily be mistaken for one of the species of the latter genus with erect verticils, the leaves being as broad as those of *A. foliosus*. One of the fragments is shown in Pl. LXVIII, fig. 11, while the base of a slightly compressed verticil is seen in fig. 12. The swollen distal ends of the ribs at the nodes are continuous with the leaves, which soon curve outward and then upward again, the axis of the verticil being coincident with the stem.

As was remarked in the description, the nerve is always simple for more than half way up the leaf, but it forks once before reaching the top, the two nervils gradually divergent at first, then bending around to a parallel or even convergent position before reaching the apex, which is often irregularly rounded, crenate, or indistinctly bidentate. All the fragments represent a rather small plant, and I was at first disposed to regard them as perhaps the terminal portions of some other species of this genus. However, the uniformity of the characters, the proportions, and the lack of transition forms lead me after further consideration to regard it as a distinct species.

The closest relationship of *Sphenophyllum suspectum* is with either *Asterophyllites fasciculatus* Lx. or the plant from Missouri recorded by Professor Lesquereux as *S. oblongifolium* Germ. In my examination of all the plant collections from Henry County, Missouri,[1] it was found that the leaves of *Asterophyllites fasciculatus* are often bifurcated, while the external characters of the stem and leaf bases are essentially those of *Sphenophyllum*, to which genus the species should, in my judgment, be referred. The leaves of that plant are, however, very small, short, and strongly curved outward, except in the upper branchlets. *Sphenophyllum lesquereuxii*[2] (*S. oblongifolium* Germ.-Lx.), has its nerves single at the base, forking near the middle, and usually presents a distinctly bidentate, somewhat cuneate leaf. The leaves of this species, which is probably nearest the plant from Indian Territory, are open, less delicate, proportionately larger, of thin texture, the verticils irregular or asymmetrical, and the nerves forking lower in the leaf. The difference in the form alone of the leaf is at once recognizable.

Among other related species, such as *S. oblongifolium* Germ, *S. tenuifolium* F. & W., or *S. filiculme* Lx., our species is easily distinguished by the form of the verticils, the nervation, and the distal margin of the leaf.

Locality.—One-half mile west of McAlester, Indian Territory; roof of McAlester coal. U. S. Nat. Mus. Reg. 6431, 6747.

[1] Mon. U. S. Geol. Survey, Vol. XXXVII, Fossil Flora of the Lower Coal Measures of Missouri.
[2] Op. cit.

SPHENOPHYLLUM EMARGINATUM Brongn.

1822. *Sphenophyllites emarginatus* Brongniart, Classif. Vég. Foss., p. 234, Pl. II, figs. 8, 8a, b.
1822. *Rotularia marsileæfolia* Sternberg, Versuch, I, fasc. 2, p. 33 (in part).
1825. *Rotularia marsileæfolia* Sternberg, Versuch, I, Tent., p. XXXII (in part).
1828. *Rotularia marsileæfolia* Stb., Bronn, in Bischoff: Kryptogäm., Gewächse, p. 89, Pl. XIII, fig. 1a, b.
1838. *Rotularia marsileæfolia* Stb., Presl, Verh. Gesell. Mus. Böhmen, p. 29, Pl. II, figs. 2–4.
1828. *Sphenophyllum emarginatum* Brongniart, Prodrome, p. 68.
1835. *Sphenophyllum emarginatum* Brongn., Bronn, Leth. Geogn., I, p. 32, Pl. VII, fig. 10.
1855. *Sphenophyllum emarginatum* Brongn., Geinitz, Verst. Steink. Sachsen, p. 12, Pl. XX, figs. 1–4 (5–7?), Pl. XXXIV, fig. 4 (?).
1864. *Sphenophyllum emarginatum* Brongn., Coemans and Kickx, Mon. Sphen., p. 144, Pl. I, fig. 2, (Pl. II figs. 1–3?).
1869. *Sphenophyllum emarginatum* Brongn., von Roehl, Foss. Fl. Steinkohlenf. Weshphalens, p. 30 (in part), Pl. IV, fig. 12 (?).
1869. *Sphenophyllum emarginatum* Brongn., Schimper, Traité, p. 339, (Pl. XXV, fig. 18?).
1874. *Sphenophyllum emarginatum* Brongn., O. Feistmantel, Verst. böhm. Ablag., I, p. 134 (pars), (Pl. XVIII, figs. 2, 5, 6?).
1876. *Sphenophyllum emarginatum* Brongn., Heer, Fl. foss. Helv., p. 53, Pl. XIX, fig. 15.
1879. *Sphenophyllum emarginatum* Brongn., Heer, Urwelt d. Schweiz, 2d ed., Pl. I, fig. 10 (?).
1880. *Sphenophyllum emarginatum* Brongn., Lesquereux, Coal Flora, I, p. 53.
1880. *Sphenophyllum emarginatum* Brongn., Schimper, in Zittel: Handb. Palæont., II, p. 179, fig. 135.[5]
1880. *Sphenophyllum emarginatum* Brongn., Ferd. Roemer, Leth. Geogn., Pal., p. 153, Pl. L, fig. 6.
1881. *Sphenophyllum emarginatum* Brongn., Saporta and Marion, Évol. Rég. Vég., Crypt., p. 198, fig. 82, A[1] (a, c?).
1881. *Sphenophyllum emarginatum* Brongn., Weiss, Aus d. Fl. d. Steinkohl., Pl. X, fig. 58.
1886. *Sphenophyllum emarginatum* Brongn., Sterzel, Fl. Rothl. n.-w. Sachsen, p. 23 (pars), pp. 26, 27, figs. 18, 19?, Pl. XXIII (III), figs. 2–5 (?).
1886. *Sphenophyllum emarginatum* Brongn., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXIV, figs. 3–5; text (1888), p. 409.
1891. *Sphenophyllum emarginatum* Brongn , Raciborski, Permokarb. Fl., p. 26 (378) (pars).
1893. *Sphenophyllum emarginatum* Brongn., Zeiller, Mém. Soc. Géol. Fr., Pal., IV No. 11, p. 24, Pl. II (IV) figs. 4, 4a.
1832. *Sphenophyllum schlotheimii* Brongn., Lindley & Hutton, Foss. Fl., I, Pl. XXVII, figs. 1, 2.
1848. *Sphenophyllum schlotheimii* Brongn., Sauveur, Vég. foss. terr. houill. Belg., Pl. LXIV, fig. 3.
1876. *Sphenophyllum schlotheimii* Brongn., Ferd. Roemer, Leth. Geogn., I, Atlas, Pl. L, fig. 6.
1880. *Sphenophyllum schlotheimii* Brongn., Lesquereux, Coal Flora, I, p. 52 (pars).
1890. *Sphenophyllum schlotheimii* Brongn., Lesley, Dict. Foss. Pa., III, p. 980, text fig.
1860. *Sphenophyllum osnabrugense* F. A. Roemer, Beitr. z. Kenntn. n.-w. Harzgeb., p. 21, Pl. V, fig. 2a, b.

1864. *Sphenophyllum emarginatum* Brongn. var. B. *brongniartianum* Coemans and Kickx, Mon. gen. Sphen., p. 144, Pl. I, fig. 3.
1863. *Sphenophyllum emarginatum* Brongn. var. B. *brongniartianum* C. & K., Schimper, Traité I, p. 340, Pl. XXV, figs. 15, 16, 17.
1869. *Sphenophyllum emarginatum* Brongn. var. B. *brongniartianum* C. & K., von Roehl, Foss. Fl. Steinkohlenf. Westphalens, p. 30, Pl. XXVI, fig. 2, Pl. XXXII, fig. 6 A.
1879. *Sphenophyllum cuneifolium* (Stb.) Zeill., Vég. foss. terr. houill., p. 3 (pars).
1882. An *Sphenophyllum truncatum* Brongn., Renault, Cours. Bot. Foss., II, p. 87, Pl. XIII, figs. 5, 9?

The average specimens of this species from the McAlester coal are not very large, but they are rather fragile and the leaves are often rounded at the corners, or appear to be rounded slightly by reason of the shriveling or curling of the corners. For this reason the form in hand has sometimes been mistaken for *Sphenophyllum schlotheimii* Brongn., to which it is more closely related than is any other of our American Sphenophylla.

The teeth of the plant from Indian Territory are, however, distinct, though rather blunt and often buried in the matrix. Many of the verticils and fragments strongly suggest that figured by Sterzel[1] from the Saxon Permian.

Localities.—Roof of the McAlester coal, one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6445); mine No. 11, near Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6372); Savanna, Indian Territory (U. S. Nat. Mus. Reg. 6587). It is also present in the roof of the Grady coal at a mine 2 miles east of Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6693). Also from Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory; horizon about 2,000 feet above the McAlester coal (U. S. Nat. Mus. Reg. 6628).

INCERTÆ SEDIS.

RADICITES Potonié, 1893.

1825. *Hydatica* Artis (pars), Antediluvian Phytology, Pl. I, Pl. V.
1834. *Pinnularia* Lindley and Hutton, Foss. Fl. Gt. Brit., II, p. 81, Pl. CXI.
1847. ? *Rhizolithes* Braun, Flora, N. R., V, No. 6, p. 86.
1893. *Radicites* Potonié, Flora Rothl. Thüringen, p. 260.

RADICITES cf. CAPILLACEUS (L. & H.) Pot.

Specimens of rootlets referable to the familiar type known as *Pinnularia* L. & H. are not uncommon in the roof of the McAlester coal. They are, however, rather coarser and branch more freely than does the typical *Pinnularia capillacea* of Lindley and Hutton.[2] On the other hand, they are more regular in their method of branching than is *Radi-*

[1] Fl. Rothl. n.-w. Sachsen, 1886, p. 23, Pl. III, fig. 2.
[2] Foss. Fl. Gt. Brit., II, Pl. CXI. Lesquereux, in Rogers: Geol. Pa., II, 2, p. 878, Pl. XVII, fig. 22.

cites palmatifidus (Lx.),[1] but the divisions are less parallel than in *R. horizontalis* Lx. sp.[2]

The generic term *Pinnularia* having been preoccupied for a group of diatoms, *Radicites* has been proposed in substitution by Dr. Potonié.

Localities.—Roof of McAlester coal at Cherryvale, Indian Territory. U. S. Nat. Mus. Reg. 6611. Also one-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6474.

LYCOPODINEÆ.

LEPIDODENDREÆ.

Remains of this great family of Paleozoic plants are in the collections in hand confined (1) to cortical fragments of two species; (2) to rather small, slender linear-lanceolate leaves closely resembling those of *Lepidodendron Brittsii* Lx.; and (3) to fragments of cones or bracts (*Lepidophyllum*) of three species, one of which is also represented by its spore case (*Lepidocystis*). It is probable that further collecting in the McAlester region will reveal portions of trunks of other species of Lepidodendron. The presence of several extremely broad Lepidodendroid leaves similar to that which in the flora of the Des Moines series[3] I have referred to *Lepidophloios* justifies the anticipation that the latter genus, present in an unknown stage in the Atoka quadrangle, will also be found near the McAlester coal.

LEPIDODENDRON Sternberg, 1820.

1820. *Lepidodendron* Sternberg, Versuch, I, 1, p. 25; Tent. (1825), p. x.
1822. *Sagenaria* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 239.

Lepidodendron modulatum Lx.

1856. *Lepidodendron modulatum* Lesquereux, Proc. Bost. Soc. Nat. Hist., VI, p. 428.
1858. *Lepidodendron modulatum* Lesquereux, in Rogers: Geol. Pa., II, 2, p. 874, Pl. XV, fig. 1.
1860. *Lepidodendron modulatum* Lesquereux, Rept. Geol. Surv. Ark., II, p. 310, Pl. III, figs. 1, 1[a].
1870. *Lepidodendron modulatum* Lesquereux, Rept. Geol. Surv. Ill., IV, p. 430, Pl. XV, fig. 1.
1879. *Lepidodendron modulatum* Lesquereux, Coal Flora, Atlas, p. 12, Pl. LXIV, figs. 13, 14; text, II (1880), p. 385.
1881. *Lepidodendron modulatum* Lx., Calvin, Pop. Sci. Mo., XVIII, p. 611, fig. 1.
1889. *Lepidodendron modulatum* Lx., Lesley, Dict. Foss. Pa., I, p. 318, text fig.
1891. *Lepidodendron modulatum* Lx., LeConte, Elem. Geol., p. 366, fig. 489.
1834. *Lepidodendron obovatum* Stb., Mammatt, Geol. Facts, p. 96, Pl. LIV (Pl. A 13, fig. 2?).
1848. *Lepidodendron clathratum* Sauveur, Vég. terr. houill. Belg., Pl. XLI, fig. 4?.
1848. *Lepidodendron crenatum* Stb., Sauveur, Vég. terr. houill. Belg., Pl. LXIII, fig. 2?.
1848. *Lepidodendron aculeatum* Stb., Sauveur, Vég. terr. houill. Belg., Pl. LXIII, fig. 4.

[1] Rept. Geol. Surv. Ark., II, 1860, p. 313, Pl. V, fig. 9. Coal Flora, Atlas, p. 16, Pl. LXXV, fig. 9
[2] Geol. Pa., II, 2, 1858, p. 878, Pl. XVII, fig. 21.
[3] Foss. Flora Lower Coal Measures Missouri, Mon. U. S. Geol. Survey, Vol. XXXVII.

1877. *Lepidodendron aculeatum* Stb., Fairchild, Trans. N. Y. Acad. Sci., I, 3, p. 82 (excl. syn.), Pl. V, figs. 1-4, Pl. VI, figs. 1-5 (nec fig. 6 necque Pls. VII, VIII, IX).
1886. *Lepidodendron aculeatum* Stb., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXV, figs. 3, 7 (4?, 5?); text (1888), p. 435 (pars).
1854. An *Lepidodendron conicum* Lesquereux, Proc. Bost. Soc. N. H., VI, p. 428?.
1858. *Lepidodendron conicum* Lesquereux, in Rogers: Geol. Pa., II, 2, p. 874, Pl. XV, fig. 3?.
1860. *Lepidodendron mekiston* Wood, Proc. Acad. N. S. Phila., XII, p. 239, Pl. V, fig. 3.
1860. *Lepidodendron bordæ* Wood, Proc. Acad. N. S. Phila., XII, p. 240, Pl. VI, fig. 3.
1869. An *Lepidodendron caudatum* Stb., Von Roehl, Foss. Fl. Steink. Westphalens, p. 130, Pl. VIII, fig. 7? (non Pl. VI, fig. 7).
1869. An *Lepidodendron uræum* Wood, Trans. Am. Phil. Soc., XIII, p. 343, Pl. IX, fig. 5?.
1881. *Lepidodendron dichotomum rhombiforme* Achepohl, Niederr.-Westfäl. Steink., p. 67, Pl. XX, fig. 3.
1882. *Lepidodendron dichotomum transiens* Achepohl, Niederr.-Westfäl. Steink., p. 92, Pl. XXX, fig. 4.
1882. *Aspidaria* sp., Achepohl, Niederr.-Westfäl. Steink., p. 93. Pl. XXXI, fig. 8.
1883. An *Lepidodendron lamellosum* Achepohl, Niederr.-Westfäl. Steink., p. 134, Pl. XL, fig. 15.
1893. *Lepidodendron aculeatum* Stb. forma *modulatum* (Lx.) Kidston, Foss. Pl. Kilmarnock, p. 337.
1894. *Lepidodendron aculeatum* Stb. forma *modulatum* (Lx.) Kidston, Foss. Fl. S. Wales C. F., p. 602.

The type of trunk described by Lesquereux as *Lepidodendron modulatum* is one of the most common and widely distributed Lepidodendroid forms in our American Coal Measures. Although it is not yet typically found in the Pottsville series, it is not infrequent in the lower part of the Allegheny series, while its upper limit is not yet fixed. It seems probable, however, that it will be found in the lower part of the Monongahela series; but it is not known in the well-studied floras of the Dunkard Creek series, and the collections yet obtained show it to be most abundant in and to some extent characteristic of the Lower Productive Coal Measures (Allegheny series).

The presence of the precise form typical of *L. modulatum* in the Old World Coal Measures is evidenced by numerous good illustrations, showing the differentiative characters, mostly under the name of *Lepidodendron aculeatum*, in which *L. modulatum* is believed by most European paleobotanists to belong. After painstaking and critical studies on the part of Professor Fairchild[1] in this country and Professor Zeiller[2] in France, the conclusion is reached by both that the two types are but phases of the development or preservation of the same tree. An examination of many American specimens leads the writer to admit the difficulty in distinguishing in many cases the *L. modulatum* from the *L. aculeatum*,[3] both of which, as interpreted by Professor Lesquereux, are somtimes found at the same locality. Usually, however, the two forms are found in separate localities. Furthermore, the bolster borders, resembling twisted rope, characteristic of the *L. modulatum*,

[1] Trans. N. Y. Acad. Sci., I, 3, 1877, p. 82.
[2] Fl. Foss. bassin houill. Valenciennes, p. 435.
[3] Coal Flora, Vol. II, p. 371, Pl. LXIV, fig. 1.

are usually clear even in young branches on which the bolsters are but a few millimeters in length.[1] Hence, although the difference may be not more than varietal in rank, the writer is disposed to continue the name employed by Lesquereux until the American specimens with slightly less oval bolsters recorded as *L. aculeatum* may be further compared with European material. I anticipate that the differentiation of the fossils with the "ropy" borders will serve a utilitarian purpose, although the actual distinction from *L. aculeatum* may be less than varietal in importance.

Locality.—Roof of the McAlester coal, at mine No. 11, Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6378.

LEPIDODENDRON CHOCTAVENSE n. sp.

Pl. LXVIII, figs. 14, 14*a*.

Bolsters rhomboidal, or nearly square, somewhat protuberant, with very narrow sulcate borders, destitute of caudæ, the lower portion smoothly rounded or slightly transversely corrugated, perhaps as the result of pressure, the ligular pit in the extreme apex small and oval, the longer axis vertical.

Leaf scar extremely large, covering nearly one-half the area of the bolster, transversely rhomboidal, laterally acute, extremely obtuse below, the lower margins being nearly straight, the upper angle somewhat rounded, the upper margins circumflex. Cicatricules in a row, very close to the lower margin of the scar, the vascular trace small, rounded or oval, the transpiration traces small and relatively close.

The conspicuous features of this species are the noncarinate squarrose form of the bolsters and the proportionately extremely large leaf scar in which the cicatricules are placed near the lower angle. It is very poorly represented in the collection, the best fragment having been nearly destroyed inadvertently on account of the very soft and friable nature of the matrix. It is possible that the transverse corrugations of the lower field, which is otherwise gently rounded, are due to the flattening of the specimens. Faint and somewhat uncertain traces of roundish appendages, transpiratory vents, are apparently visible in some cases.

Among the species of *Lepidodendron* that resemble *L. choctavense* may be cited *L. andrewsii* Lx.[2] from Mazon Creek, Illinois, and *L. sigillaroides* Lx., described from Summit Lehigh in the Eastern Middle Anthracite field.[3] The latter, however, has its small scars near the upper angle of the bolster while the former has its bolsters of the same size apparently more strongly protuberant, as evidenced by the strong deformation, while the leaf scars are proportionately much smaller, the

[1] Rept. Geol. Surv. Ark., II, 1860, Pl. III, fig. 1.
[2] Coal Flora, p. 389, Pl. LXIV, fig. 6.
[3] Geol. Penn., II, 2, p. 875, Pl. XV, fig. 6.

cicatricules proportionately very much nearer the lateral angles. An examination of the type of the species from Mazon Creek (No. 5430, Lacoe collection, U. S. Nat. Mus.), shows a distinct though not prominent keel in the lower part of some of the bolsters.

Locality.—One-half mile south of South McAlester, Indian Territory, about 2,000 feet above the McAlester coal. U. S. Nat. Mus. Reg. 6752.

LEPIDODENDRON sp.

The fragments of leafy twigs from the roof of the Grady coal are not well enough preserved to show else than the leaves. The general aspect of the branchlets is somewhat like that of foreign specimens described as *Lepidodendron sternbergii* or *L. elegans*. It is not so densely foliate as the latter, nor are the leaves so rigid and uncinate as those of the Pottsville form, to which the name *L. sternbergii* was applied by Lesquereux.

Localities.—Roof of the Grady coal at Hartshorne, Indian Territory. U. S. Nat. Mus. Reg. 6564.

LEPIDOPHYLLUM Brongniart, 1828.

1822. *Filicites* sect. *Glossopteris* Brongniart, Mém. Mus. Hist. Nat., VIII, p. 232.
1828. *Lepidophyllum* Brongniart, Prodrome, p. 87.

LEPIDOPHYLLUM BREVIFOLIUM Lx.

Pl. LXVIII, figs. 15–18.

1854. *Lepidophyllum brevifolium* Lesquereux, Proc. Bost. Soc. N. H., VI, p. 439.
1858. *Lepidophyllum brevifolium* Lesquereux, in Rogers: Geol. Pa., II, 2, p. 876, Pl. XVII, fig. 6.
1879. *Lepidophyllum brevifolium* Lesquereux, Coal Flora, Atlas, p. 14, Pl. LXIX, fig. 33; text, II (1880), p. 447.
1889. *Lepidophyllum brevifolium* Lx., Lesley, Dict. Foss. Pa., I, p. 325, text fig.
1887. *Lepidophyllum* sp., Kidston, Foss. Fl. Radstock Ser., p. 395, Pl. XXVII, figs. 7*a*, 7*b*.

This, the most abundant species of this genus in the flora of McAlester, is represented by a large number of bracts which differ but little from the form described from Wilkesbarre by Lesquereux[1] in 1858 as *L. brevifolium*. As in other species of this genus there is here considerable variation in the size and form of the bracts, which are chiefly notable for the proportionately very long sporangiophore, and the broad, very short blade. As is shown in Pl. LXVIII, Fig. 17, the axis of the sporangiophore is narrow, rather thick, slightly and obtusely carinate, broadening very rapidly to the base of the blade. The wings of the sporangiophore are broad, membranaceous, slightly convex-bordered, rounded at the distal angles. The blade is rather thin, dorsally slightly convex, with a rather narrow, not very thick midrib. In the specimens before me the borders of the blade are less convex than in the examples figured by Lesquereux and Kidston,[2] while the lateral

[1] Rogers: Geol. Pa., II, 2, p. 876, Pl. XVII, fig. 6.
[2] Foss. Fl. Radstock series, p. 395, Pl. XXVII, fig. 7*a*, 7*b*.

angles are less prolonged downward. The same differences which perhaps constitute a varietal distinction for the McAlester specimens are seen in a comparison of material from the Radstock series now in the Lacoe collection of the U. S. National Museum.

An interesting fragment in the collection is a portion, apparently from near the apex, of a cone (*Lepidostrobus brevifolius*) of this species, which is shown in Pl. LXVIII, Fig. 18. The proportionate length of the sporangiophores is greater in this example on account of the probably undeveloped state of the bracts and the unusually small size of the blades.

To this species probably belong specimens of *Sporocystis* found on the same shales. These, as flattened, are nearly orbicular, a little thick, glossy, and about 5 or 6 millimeters in diameter. *Sporocystis brevifolius* is the only lepidodendroid evidence in the Cherryvale collection.

Localities.—Roof of the McAlester coal, one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6487-6492); also at Cherryvale, Indian Territory (U. S. Nat. Mus. Reg. 6615), and mine No. 11, near Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6371).

LEPIDOPHYLLUM LANCEOLATUM L. & H.

1832. *Lepidophyllum lanceolatum* Lindley and Hutton (non Brongn.), Foss. Fl. Gt. Brit., I, Pl. VII, fig. 3 (4?).

1855. *Lepidophyllum lanceolatum* L. & H., Geinitz, Verst. Steink. Sachsen, p. 34, Pl. II, fig. 8.

1858. *Lepidophyllum lanceolatum* L. & H., Lesquereux, in Rogers: Geol. Pa., II, 2, p. 875, Pl. XVII, fig. 1.

1860. *Lepidophyllum lanceolatum* L. & H., Lesquereux, Rept. Geol. Surv. Ky., III, p. 556, Pl. VII, fig. 7.

1869. *Lepidophyllum lanceolatum* L. & H., Von Roehl, Foss. Fl. Steink. Westphalens, p. 141, Pl. XXVIII, figs. 10a-b.

1879. *Lepidophyllum lanceolatum* L. & H., Lesquereux, Coal Flora, Atlas, p. 14, Pl. LXIX, fig. 38.

1886. *Lepidophyllum lanceolatum* L. & H., Zeiller, Fl. foss. houill. Valenciennes, Atlas, Pl. LXXVII, figs. 7, 8a-b; text (1888), p. 505.

1889. *Lepidophyllum lanceolatum* L. & H., Lesley, Dict. Foss. Pa., I, p. 325, text fig.

1855. *Lepidostrobus lepidophyllaceus* Gutb., Geinitz, Verst. Steink. Sachsen, p. 35, Pl. II, figs. 6, 7.

1855. *Sagenaria dichotoma* Stb., Geinitz, Verst. Steink. Sachsen, p. 39 (pars, excl. syn.), Pl. II, fig. 6 (non Pl. III, fig. 1-12).

1870. *Lepidostrobus lanceolatus* (L. & H.) Lesquereux [non (Brongn.) Gutb.] Rept. Geol. Surv. Ill., IV, p. 470.

1880. *Lepidostrobus lanceolatus* (L. & H.) Lesquereux, Coal Flora, II, p. 436, Pl. LXIX, fig. 38.

A number of the specimens present show blades having the size and form illustrated by Lindley and Hutton,[1] or in the earlier publications by Professor Lesquereux.[2] The sporangiophore is not, however, shown in any of the fragments and the identification remains therefore slightly

[1] Foss. Fl. Great Brit., I, 1832, Pl. VII, fig. 3.
[2] Geol. Pa., II, 2, p. 875, Pl. XVII, fig. 1.

uncertain, although the considerable number of blades and their uniform agreement with the species render the identity highly probable.

Some confusion appears to exist as to the authority for the above-named species. The name *Lepidophyllum lanceolatum* was first published by Brongniart in 1828[1] as a nomen nudum. But in the publication of a species under the same name, with description and figure, by Lindley and Hutton, in 1832, there is nothing to show that the British authors verified or claimed an identity of their Jarrow species with the type of Brongniart from Montrelais. On the contrary, the prima facie evidence points to an independent use of the same name. On this account, as well as by reason of the fact that Brongniart's name was merely a nomen nudum, the species described and figured by Lindley and Hutton should be credited to them, although the publication of the same binomial at an earlier date would, in this case, preoccupy its use and make it desirable, unless the types from Montrelais and the Jarrow colliery represent the same species, to rename the British type.

Lepidophyllum lanceolatum is most closely related to *L. oblongifolium* Lx., and it is often very difficult to distinguish the two species in an assemblage of material from many localities. In general, however, the former is more slender toward the tip and acute, while the blade is, on the whole, rather longer.

Localities.—Roof of the McAlester coal at (1) mine one-half mile west of McAlester, Indian Territory (U. S. Nat. Mus. Reg. 6496); (2) mine No. 11, at Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6397); (3) Savanna, Indian Territory (U. S. Nat. Mus. Reg. 6569).

The species appears to be present in the two beds at a horizon about 2,000 feet above the McAlester coal, in the Missouri, Kansas & Texas Railway Cut, one-half mile south of South McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6668, and 6630.

LEPIDOPHYLLUM cf. MANSFIELDI Lx.

1879. *Lepidophyllum mansfieldi* Lesquereux, Coal Flora, Atlas, p. 14, Pl. LXIX, fig. 34; text, II (1880), p. 449.

The tentative reference given above will serve as a record of the occurrence in the McAlester flora of a large *Lepidophyllum*. Unfortunately only the blades are present. The latter are large, extremely broad at the base of the upper third, contracting rapidly to an acute apex. The midrib is not so conspicuous, nor is the blade so strongly dorsally convex as in the Cannelton species, which owes its characteristic transverse wrinkling to this convexity. The fragments in hand are possibly to be referred to an unpublished species from the Lower Coal Measures of Missouri. They differ from *L. majus* Brongn. by the much greater width, especially in the upper part.

Locality.—Roof of the McAlester coal, one-half mile west of McAlester, Indian Territory. U. S. Nat. Mus. Reg. 6499.

[1] Prodrome, p. 87.

LEPIDOPHYLLUM TRUNCATUM Lx.

1879. *Lepidophyllum truncatum* Lesquereux, Coal Flora, Atlas, p. 13, Pl. LXIX, figs. 9, 10; text, II (1880), p. 458; III (1884), p. 911.

1884. *Lepidostrobus macrocystis truncatus* Lesquereux, Coal Flora, III, p. 784, Pl. CVIII, fig. 1.

The fragments here included are apparently of exactly the same form and character as those from Cannelton, Pennsylvania, figured in the Atlas to the Coal Flora under the above name. The Cannelton types were, however, later correlated by Professor Lesquereux with a segment of a large axis, with sporocysts still adherent, from the same locality. The examination of the types under both names convinces the writer of the correctness of Professor Lesquereux's conclusion, though the earlier generic reference is perhaps preferable to the other. The originals of *Lepidophyllum truncatum*, like the examples from Indian Territory, seem to represent merely vacant detached spore cases (*Lepidocystis*) through which a portion of the axis of the sporangiophore is expressed in the fossil, or on which the impression of attachment is still preserved. As such detached *Lepidocystis* the correlation of these fragments with the cone, *Lepidostrobus truncatus*, is quite natural, the sporangia of the latter being full and in place. Furthermore, the circumstantial evidence is strong to show, in the opinion of the writer, not only that the *Lepidocystis vescicularis* Lx. from Cannelton is but a differently preserved vacant sporangium of the same cone, but also that *Lepidophyllum mansfieldi* is possibly the scale of the same cone, which may have belonged to *Lepidophloios*.

The portion of cone from Cannelton described by Lesquereux as *Lepidostrobus truncatus* is totally different in kind from the minute cone, with small narrow bracts, earlier described by him[1] from Illinois under the same name.

Locality.—Roof of Grady coal, 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6730.

LEPIDOCYSTIS Lesquereux, 1880.

Coal Flora, II, p. 454.

LEPIDOCYSTIS VESICULARIS Lx.

1870. *Carpolithes vesicularis* Lesquereux, Rept. Geol. Surv. Ill., Vol. IV, p. 462, Pl. XXXI, figs. 19-21.

1879. *Lepidocystis vesicularis* Lesquereux, Coal Flora, Atlas, p. 13, Pl. LXIX, figs, 18-20; text II (1880), p. 457.

The sporangia described under the above name probably belong to the cones with large scales of the type of *Lepidophyllum mansfieldi*, *L. majus*, etc. The descriptive treatment of *Lepidocystis* is not yet sufficiently complete to differentiate the spore cases to the degree that

[1] Rept. Geol. Surv. Ill., Vol. IV, 1870, p. 442, Pl. XXXI, fig. 5.

has been reached in the systematic elaboration of the bracts, nor is it probable that such detailed discrimination is practicable without recourse to minute study or the use of the microscope. Accordingly, it is highly probable that the vacant spore cases of several species of the large-bracted Lepidostrobi are included in the *Lepidocystis vesicularis* Lx., and the *L. fraxiniformis* (Stb.) Lx. The chief distinction between these two species appears to be the proportionate narrowness and greater rectangularity of the latter.

The Cannelton examples of *L. vesicularis* are believed by the writer to be referable to *Lepidophyllum mansfieldi*,[1] found associated therewith.

The remains described in 1884 from Cannelton as *Lepidostrobus macrocystis truncatus* Lx., may be only portions of cones of this species from which the bracts are broken away, though this correlation is suggested as merely hypothetical.

Locality.—Roof of Grady coal, 2 miles east of Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6697.

A similar sporangium case, perhaps specifically inseparable, was found in the roof of the Grady coal, at mine No. 11, near Krebs, Indian Territory. U. S. Nat. Mus. Reg. 6380.

LEPIDOPHLOIOS Sternberg, 1825.

Flora d. Vorwelt, I, Tent., p. XIII.

LEPIDOPHLOIOS sp.

Among the plants from the Atoka quadrangle are three short segments of a flattened branch of *Lepidophloios*, about 3 centimeters in diameter. The form of the bolsters and the leaf scars is similar to *L. laricinus*, but the details of the leaf scars are too obscure to warrant an identification of the species.

Locality.—Mine "Six and one-half," sec. 2, T. 1 S., R. 10 E, Atoka quadrangle, Indian Territory. U. S. Nat. Mus. Reg. 6678.

GYMNOSPERMS.

CORDAITINEÆ.

CORDAITEAE.

CORDAITES Unger, 1850.

1822. *Flabellaria* Sternberg, Versuch, I, 1, p. 32 (pars).
1849. *Pychnophyllum* Brongniart (non Rémy), Tableau d. gen., p. 65.
1850. *Cordaites* Unger, Gen. Spec. Pl. Foss., p. 277.

CORDAITES COMMUNIS Lx.

1878. *Cordaites communis* Lesquereux, Proc. Am. Phil. Soc., XVII, p. 320.
1880. *Cordaites communis* Lesquereux, Coal Flora, II, p. 534.
1893. *Cordaites communis* Lx., D. White, Bull. U. S. Geol. Survey No. 98, p. 105.

[1] Coal Flora, III, p. 784, Pl. CVIII, fig. 1

Owing to the difficulty in procuring fragments sufficiently large for a proper comparison, the identifications of this species in the present collections are to be considered as only provisional.

The American material recorded as *C. communis*, *C. borassifolius*, and *C. lingulatus* deserves a critical comparison with the similar forms from the Old World Carboniferous.

Localities.—Missouri, Kansas and Texas Railway cut, one-half mile south of South McAlester, Indian Territory; stage about 2,000 feet above the McAlester coal (U. S. Nat. Mus Reg. 6440); roof of McAlester coal at mine No. 11, near Krebs, Indian Territory (U. S. Nat. Mus. Reg. 6381); at Cherryvale, Indian Territory (U. S. Nat. Mus. Reg. 6613), and at west mine near Alderson, Indian Territory (U. S. Nat. Mus. Reg. 6694).

CARDIOCARPON Brongniart, 1828.

Prodrome, p. 87 (pars).

CARDIOCARPON BRANNERI Fairch. & D. W. MSS.

This species, described by Prof. H. L. Fairchild and myself in an unpublished report on the flora of the Coal Measures of Arkansas, is apparently closely related to *C. fluitans* Dn. The originals are from the Upper Coal Measures at Van Buren, Arkansas.

Locality.—Cherryvale, Indian Territory, westernmost mine; roof of McAlester coal. U. S. Nat. Mus. Reg. 6616.

RHABDOCARPOS Goeppert & Berger, 1848.

De Fruct. et Semin. Form. Lithanthr., p. 20.

RHABDOCARPOS MULTISTRIATUS (Presl) Lx.

1838. *Carpolites multistriatus* Presl, in Sternberg: Versuch, II, p. 208, Pl. XXXIX, figs. 1, 2.

1880. *Rhabdocarpus multistriatus* (Presl) Lesquereux, Coal Flora, II, p. 578 (pars).

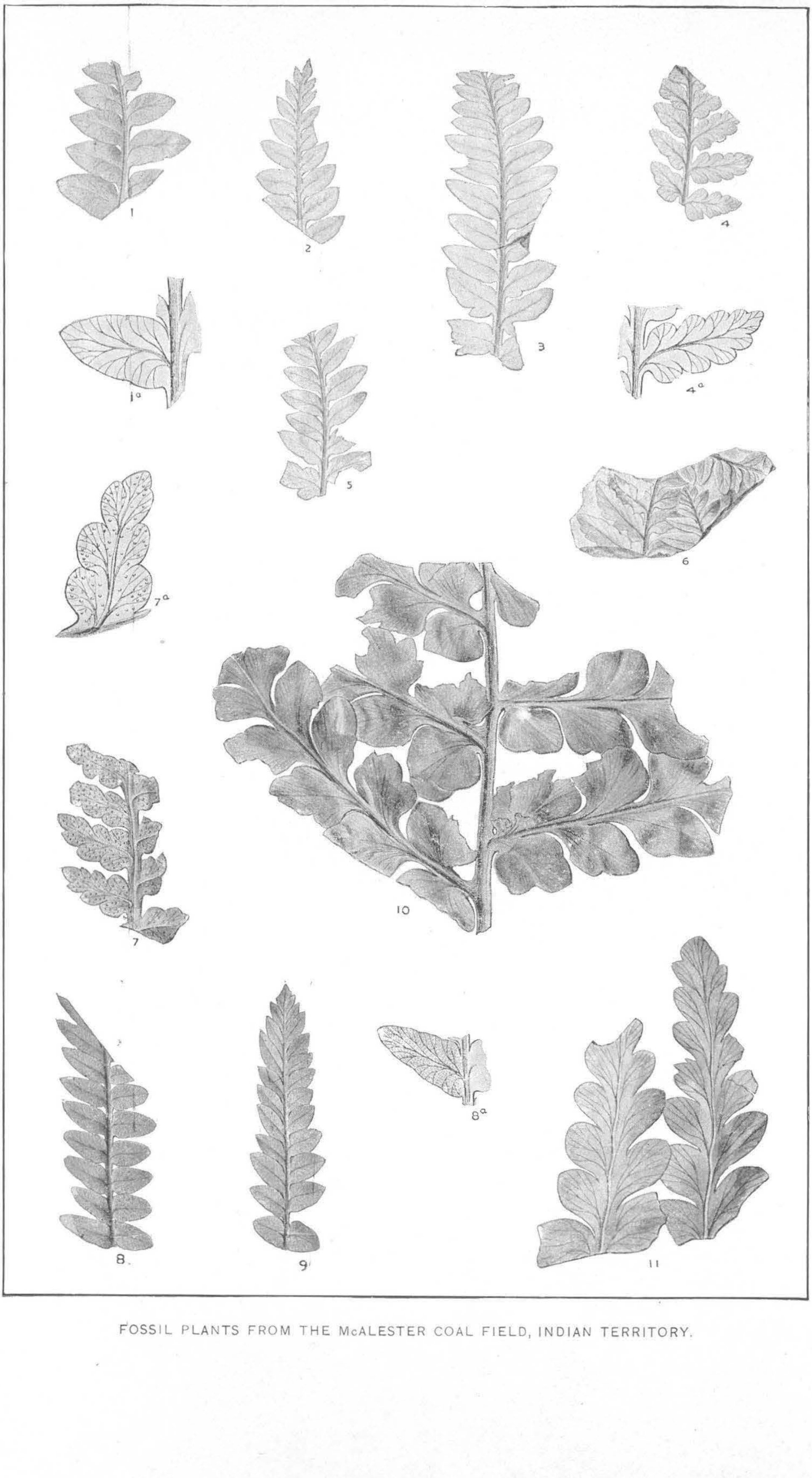
The material from our Coal Measures recorded under the above name includes, perhaps, examples of one or more other species, such as *Trigonocarpon schultzianum* Goepp. & Fiedl., or *T. acuminatum* of Newberry. It is in need of revision. The fruits in hand, though not well preserved, appear to agree with the form generally labeled under this name in the American collections.

Localities.—One-half mile east of McAlester, Indian Territory; roof of the McAlester coal (U. S. Nat. Mus. Reg. 6506), Hartshorne, Indian Territory; roof of the Grady coal (U. S. Nat. Mus. Reg. 6572).

PLATE LXVII.

PLATE LXVII.

	Page.
FIGS. 1–6. *Mariopteris occidentalis* n. sp	
FIGS. 1*a*, 4*a*. Portions of figs. 1 and 4 ($\frac{2}{1}$)	
FIG. 7. *Sphenopteris taffii* n. sp	
FIG. 7*a*. *Sphenopteris taffii* enlarged detail ($\frac{2}{1}$)	
FIGS. 8, 9. *Mariopteris occidentalis villosa* n. sp., n. var	
FIG. 8*a*. *Mariopteris occidentalis* enlarged detail ($\frac{2}{1}$)	
FIGS. 10, 11. *Pseudopecopteris macilenta* (L. & H.) Lx	



FOSSIL PLANTS FROM THE McALESTER COAL FIELD, INDIAN TERRITORY.

PLATE LXVIII.

PLATE LXVIII.

Pago.

FIGS. 1, 19. *Sphenopteris taffii* ? n. sp ....

FIGS. 2–4. *Pecopteris richardsoni* n. sp ....

FIGS. 3*a*, 4*a*. *Pecopteris richardsoni* enlarged details ($\frac{2}{1}$) ....

FIGS. 5–7, 9. *Neuropteris harrisi* n. sp ....

FIG. 8. *Neuropteris harrisi* ($\frac{2}{1}$) ....

FIG. 10. *Annularia stellata* (Schloth.) Wood ? sporangium ....

FIGS. 11, 12. *Sphenophyllum suspectum* n. sp ....

FIG. 13. *Sphenophyllum suspectum* restoration, enlarged........................

FIG. 14. *Lepidodendron choctavense* n. sp ....

FIG. 14*a*. *Lepidodendron choctavense*, bolster enlarged ....

FIGS. 15–17. *Lepidophyllum brevifolium* Lx..

FIG. 18. *Lepidostrobus brevifolius* (Lx.), fragment of upper portion of cone containing *Lepidophyllum brevifolium* Lx..

FOSSIL PLANTS FROM THE McALESTER COAL FIELD, INDIAN TERRITORY.

PRELIMINARY REPORT ON PALEOZOIC INVERTEBRATE FOSSILS FROM THE REGION OF THE M'ALESTER COAL FIELD, INDIAN TERRITORY.

By GEORGE H. GIRTY.

INTRODUCTION.

In the fall of 1897 there was referred to me a considerable collection of invertebrate fossils made by Mr. J. A. Taff and party during field work of the previous season. This collection, which furnished much of the material for the following report, was made at various points in Indian Territory, and consisted chiefly of Coal Measure fossils.

Two small lots, however, collected on a brief reconnoissance trip, proved to be of unusual interest as establishing the presence in this region of a characteristic and well-differentiated Lower Helderberg fauna. When this fact was definitely recognized Mr. François E. Matthes, of the United States Geological Survey, who was working in that Territory at the time, was requested to prepare a profile of these beds and make collections through them. The profile will be found reproduced upon Pl. LXIX with the strata numbered so as to fix the collections made from them. The profile was run from a point just west of the Choctaw-Chickasaw boundary, and close to the center of T. 1 S., R. 8 E. It was extended over 4½ miles, approximately in a straight line, bearing about 15° south of west. The collections from this section indicate an extensive and interesting series. The beds from No. 1 to No. 8, inclusive, are of Lower Helderberg age. No. 10 is referred with some uncertainty to the age of the Niagara group, No. 12 probably to the Hudson River period, while Nos. 13 to 25, inclusive, have been referred to the age of the Trenton limestone of New York.

Some other smaller collections were made by Mr. Matthes several miles farther to the east from a ridge of limestone in the western tier of sections of T. 1 S., R. 9 E., which I referred to the Lower Carboniferous era. Subsequent collections, however, have thrown considerable doubt upon this reference. The strata are said to have a uniformly strong dip to the east. Five of the collections were made in consecutive beds numbered A to E, inclusive, bed A being stratigraphically lowest in the section.

The bulk of the collections made by Mr. Taff and party belongs to the Upper Coal Measures, as I have just said, but the Ordovician and Silurian are also indicated. Except for some fossils of somewhat doubtful age from the limestone ridges of the McAlester and Atoka quadrangles, the Lower Coal Measures make no appearance in the collection, but may be represented stratigraphically by several thousand feet of unfossiliferous shales underlying the Upper Coal Measures. From the available data it seems that in this region we have a very extensive series of strata, beginning at least as early as the Trenton and continuing on, with some paleontologic breaks, well up into the Upper Coal Measures.[1]

It gives me pleasure to express a portion of my obligation toward Mr. Taff, Mr. Richardson, Mr. Matthes, and others, for the ample collections which I have had the opportunity to examine. Acknowledgments are also due to Mr. Charles Schuchert, of the United States National Museum, for many courtesies facilitating the preparation of this report. His suggestions also have often proved of value and I have had frequent recourse in doubtful cases to his intimate knowledge of North American Brachiopoda.

Some explanation may not be out of place for an apparent neglect to cite the bibliographies of species in this report. We have now, in the way of bibliographies of Paleozoic invertebrate paleontology, S. A. Miller's North American Geology and Paleontology, Charles Schuchert's Bibliography and Index of North American Brachiopoda,[2] Stuart Weller's Bibliographic Index of North American Carboniferous Invertebrates,[3] and others.[4]

These works are practically accessible to every one and it seems unnecessary in a contribution of this kind, which is not of a monographic nature, to consume time and space simply in copying bibliographic lists. Accordingly, where no bibliography is cited it will be understood that I accept those of Schuchert and Weller, and only where I desire to add or subtract from these has more than the place of original description been cited.

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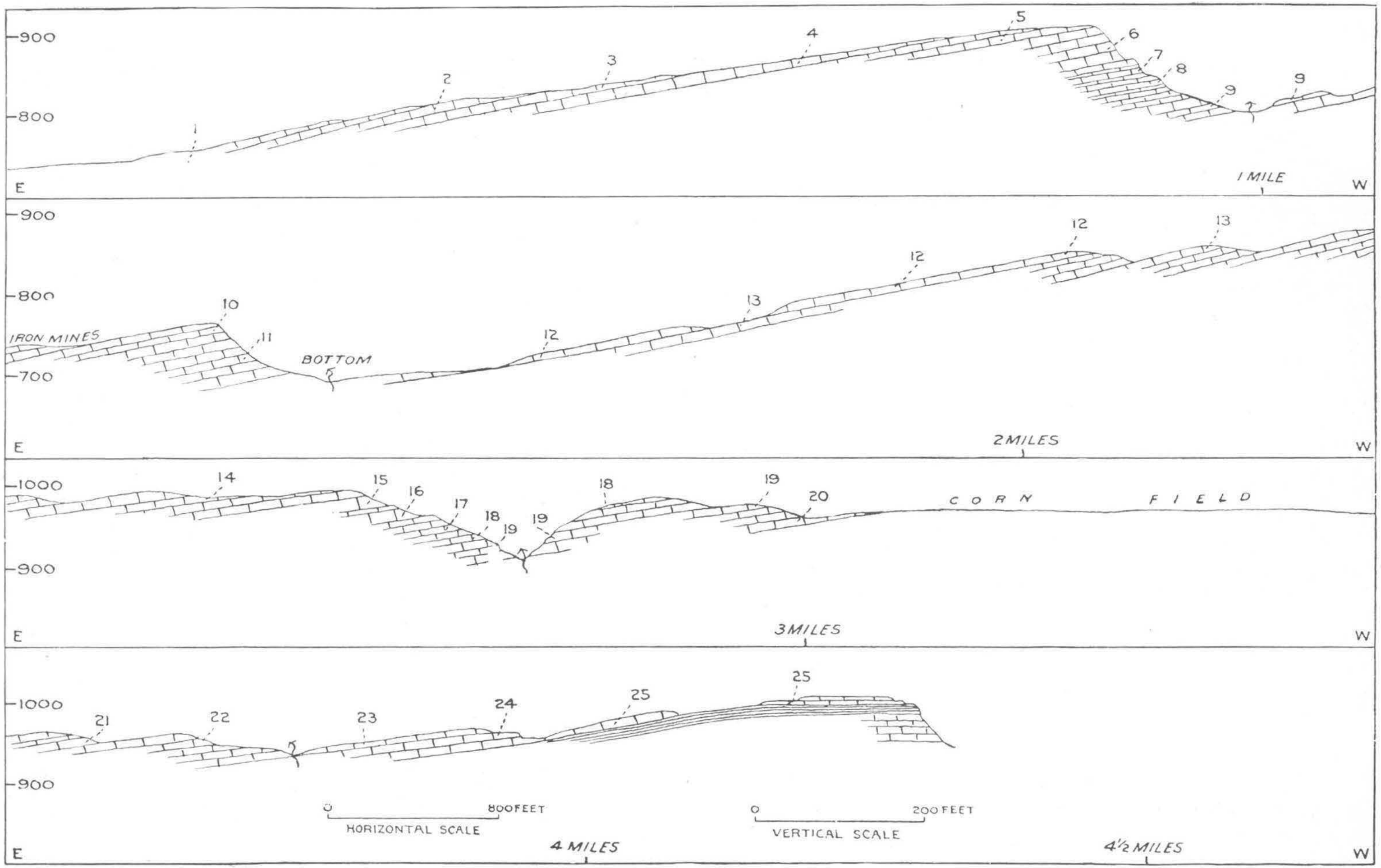
[1] Since the first collections from Indian Territory were made and the present report was prepared I have had the privilege, during the fall of 1898, of spending a number of weeks with Mr. Taff and party, and of making collections in the region under discussion. Much material had already been gathered, so that large additions have been made to the collections upon which this report is based. The most interesting results of these later collections are a black shale fauna, new to the region, and a large accession to the collections from the limestone ridges which traverse the McAlester quadrangle from northeast to southwest, and which may prove to be a continuation of the early portion of the Mississippian series. The fauna is an interesting and in some respects a peculiar one.

It has not been possible to incorporate the results of the recent collections in the present report, but from time to time as continued additions of material reveal new facts in connection with the paleontology of this interesting region, I hope to make such notice of them as their importance warrants.

[2] Bull. U. S. Geol. Survey No. 87.

[3] Bull. U. S. Geol. Survey No. 153.

[4] The bibliographies mentioned are only those to which I have had most frequent recourse in my own work.



PROFILE OF A LINE NEAR THE CENTER OF TOWNSHIP 1 SOUTH, RANGE 8 EAST, INDIAN TERRITORY.

UPPER COAL MEASURES.

Collections from sixteen localities have been referred to the age of the Upper Coal Measures. These can be assembled, as much through lithologic and stratigraphic considerations as by reason of faunal peculiarities, into several closely similar subfaunas. One of these occurs in a bed of highly ferruginous shale some 50 feet below the McAlester coal. Collections were made at two points with the following results:

McAlester quadrangle. Cherryvale, Indian Territory, railroad cut midway between the two mines, 50 feet below the McAlester coal.

Derbya crassa ?	Spiriferina kentuckyensis.
Productus nebraskaensis.	Retzia sp. (small).
Chonetes mesolobus.	Aviculopecten? whitei.
Reticularia perplexa.	

McAlester quadrangle. North side of Krebs, Indian Territory, about 50 feet below the McAlester coal.

Derbya crassa.	Retzia sp. (small).
Productus nebraskaensis.	Aviculopecten occidentalis.
Productus muricatus.	Aviculopecten carboniferus.
Chonetes mesolobus.	Entolium aviculatum.
Spirifer rockymontanus.	Schizodus sp.
Reticularia perplexa.	Nucula ventricosa.
Spiriferina kentuckyensis.	Euphemus carbonarius
Seminula sp.	

Among the undetermined forms are a Bellerophon, an Allorisma, and several gastropods.

From the roof of the McAlester coal[1] itself I identify *Aviculopecten? whitei;* from the roof shale of the Grady or Hartshorne coal mine at Hartshorne, Indian Territory (McAlester quadrangle), *Lingula mytiloides?*, and from a horizon about the same as the last, in a shale associated with coal in the Atoka quadrangle (center east side of sec. 10, T. 2 S., R. 10 E.) I find *Stearoceras gibbosum.*

The roof of the Lehigh coal furnishes an abundance of fossils, and collections have been made at several points.

Atoka quadrangle. North side of sec. 36, T. 1 S., R. 10 E.

Myalina perattenuata.	Pleurophorus taffi.
Aviculopecten occidentalis.	Solenomya sp.
Schizodus meekanus.	Bucanopsis sp.
Schizodus affinis.	Spirorbis sp.

Atoka quadrangle. Sec. 2, T. 1 S., R. 10 E., mine No. 6½.

Lophophyllum proliferum.	Bellerophon percarinatus.
Chonetes mesolobus.	Trepospira sphærulata.
Productus muricatus.	Orthoceras sp.
Patellostium montfortianum.	Nucula ventricosa.
Euphemus carbonarius.	Nucula sp.

[1] At McAlester, Indian Territory, in the McAlester quadrangle.

Atoka quadrangle. Lehigh, Indian Territory, Mine No. 5.

Edmondia? reflexa.	Solenomya or Pleurophorus.
Schizodus meekanus?	Bucanopsis perlata.

Atoka quadrangle. Sec. 11, T. 1 S., R. 10 E.

Fish plates.	Schizodus affinis.
Schizodus meekanus.	

Fossils occurring in these shales are both macerated and crushed. When weathered they seem to break up into fragments, and even on blocks it is difficult to uncover a specimen without having it break into pieces. The preservation is better in the unweathered shale and in concretionary masses, which sometimes are found. It proved impossible to make determinations with exactness, owing to the poor condition of much of this material.

Some fossils, apparently weathered out of shale or limy beds, are entire and perfectly preserved. They furnish the following fauna which is somewhat higher stratigraphically than that of the Lehigh coal:

McAlester quadrangle. One-fourth mile or less west of Krebs Station, on Choctaw Railway.

Spirifer cameratus.	Eupachycrinus tuberculatus?
Chonetes mesolobus.	Crinoid stems.
Productus prattenianus.	

The lower portion of the Savanna sandstone has furnished the following faunas, the fossils being preserved in the shape of internal and external casts:

McAlester quadrangle. Sec. 19, T. 2 N., R. 13 E.

Synocladia or Fenestella.	Pleurophorus taffi.
Productus nebraskaensis.	Allorisma subcuneatum.
Productus prattenianus.	Allorisma sp.
Chonetes mesolobus.	Schizodus wheeleri.
Derbya crassa.	Astartella vera.
Spirifer rockymontanus.	Nuculana arata.
Aviculopecten occidentalis.	Euomphalus subrugosus?
Pinna peracuta.	Lophospira sp.
Edmondia? reflexa.	

Atoka quadrangle. Southwest corner of sec. 4, T. 2 S., R. 11 E.

Productus nebraskaensis.	Pleurophorus taffi.
Productus prattenianus.	Allorisma subcuneatum.
Chonetes mesolobus.	Schizodus sp.
Derbya crassa.	Astartella vera.
Spirifer rockymontanus.	Nuculana arata.
Aviculopecten occidentalis.	Euphemus carbonarius.
Streblopteria tenuilineata.	Bellerophon percarinatus.
Placunopsis recticardinalis.	Patellostium nodocostatum.
Pinna peracuta.	Bulimorpha inornata.
Edmondia? reflexa.	Macrocheilus sp.
Edmondia subtruncata ?	

Atoka quadrangle. Southwest ¼ of SW. ¼ sec. 4, T. 2 S., R. 11 E.

Productus nebraskaensis.	Schizodus sp.
Productus prattenianus.	Astartella vera.
Chonetes mesolobus.	Nuculana arata.
Derbya crassa.	Nucula sp. (small, rare).
Spirifer rockymontanus.	Euphemus carbonarius.
Aviculopecten occidentalis.	Bellerophon percarinatus.
Streblopteria tenuilineata.	Patellostium nodocostatum.
Pinna peracuta.	Lophospira sp.
Edmondia ? reflexa.	Euconospira turbiniformis.
Edmondia subtruncata ?.	Loxonema cf. cerithiformis.
Pleurophorus taffi.	Pleurotomaria sp.
Allorisma subcuneatum.	Macrocheilus sp.

Three localities in different portions of the Boggy shale have furnished the following faunas:

Coalgate quadrangle. Southeast ¼ of NE. ¼ sec. 11, T. 2 N., R. 12 E.

Productus prattenianus.	Aviculopecten occidentalis.
Derbya crassa.	Bellerophon crassus.
Myalina swallowi.	

McAlester quadrangle. Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 12 E.

Schizodus wheeleri.	Schizodus pandatus.
Schizodus meekanus.	Solenomya sp.
Schizodus telliniformis.	Bellerophon sp.

McAlester quadrangle. On line between secs. 24 and 25, T. 5 N., R. 12 E.

Pleurophorus taffi.	Schizodus affinis.
Schizodus subcircularis.	

The localities whose faunal lists have just been given can all be referred to the horizon of the Upper Coal Measures of the Mississippi Basin. A comparison of the lowest fauna represented[1]—from the ferruginous concretionary shale 50 feet below the McAlester coal—with that of the sandstones far above shows them to be essentially the same. The chief difference observable is that the fauna of the upper sandy beds has a more littoral character, marked by the predominance of lamellibranch types, while in the finer sediments, shales, and limestones the proportion of brachiopods is greater. The differences which can be pointed out are slight, and do not warrant a subdivision of these beds upon paleontologic evidence.

LOWER COAL MEASURES.

In a recent publication dealing with this region[2] Drake cites three fossiliferous localities as belonging to the Lower Coal Measures. One

[1] Two species have been identified from the horizon of the Hartshorne coal, which is lower than any in the Coal Measures of this region from which collections have been made. These have been mentioned above under the name of *Lingula mytiloides?* and *Stearoceras gibbosum*, but they hardly constitute a fauna with which to compare that of the higher beds.

[2] A geological reconnaissance of the coal fields of the Indian Territory: Leland Stanford Junior University Publications, Cont. to Biol., from Hopkins Seaside Lab. No. 14, 1898; reprinted from Proc. Am. Phil. Soc., Vol. XXXVI, No. 156, pp. 392-393.

of these, the limestone ridge 2½ miles south of Ponola and Wilburton, is a locality of which mention has already been made (ante, p. 542). These consist of a series of parallel cherty and limestone ridges of varying elevation, which lie to the south of the McAlester coal field. The physical character of the rocks and the faunas which they contain make it probable that the several ridges are merely repetitions by faulting of the same set of beds.

The first collections from these ridges were rather scanty; but along with several types whose exact identification from a few imperfect examples was difficult and whose stratigraphic significance was slight, appeared a small productoid of the type of *Productella subaculeata*, a species of Favosites or Michelinia and several species of Productus closely simulating Burlington types. On the strength of these forms, and in default of any strong evidence to the contrary, I referred these limestones with little hesitation to the age of the lower portion of the Mississippian series. Later collections, while furnishing *Productella subaculeata* in abundance and also more specimens of Michelinia, show associated with them species of Rhynchopora, Retzia or Hustedia, Astartella, Nuculana, Pleurophorus, etc., which closely resemble, if they are not identical with, representatives of the same genera common in the Upper Coal Measures. A careful comparative study of this fauna, which is rather extensive, will require more time than I have yet been able to devote in order to determine whether the evidence corroborates Drake's references of these beds to the Lower Coal Measures or my own early determination of them as of Mississippian age.

At present I am strongly inclined to regard Drake's determination as the correct one, but desire to reserve a definite opinion until further study. I do not know whether the horizons of the two other localities cited by Drake from the Lower Coal Measures are represented in our collections or not. Aside from the list from limestone ridge, fourteen species are mentioned as belonging to this horizon. Of the ten forms which have been identified specifically, only three names do not occur in his lists from higher beds. These are *Productus longispinus*, *Discina convexa*, and *Septopora biserialis*, all of which are common in the Upper Coal Measures.

The following is an annotated list of the faunas referred to this horizon:

McAlester quadrangle. Sec. 31, T. 4 N., R. 16 E., limestone ridge where crossed by the creek.

Spirifer sp.

A single imperfect ventral valve with all the characters of *Sp. centronatus*, lacking, however, the concentric lamellose striæ of that species. Spirifers of this type, with only the fine radiating striæ (referring to the surface ornamentation, not to the conspicuous radiating ribs), occur in Lower Carboniferous strata.

McAlester quadrangle. Limestone ridge on the west bank of Blue Creek.

Favosites sp.

An aggregation of polygonal and closely tabulate corallites, probably belonging to this genus or to Michelinia. The diameter of the largest corallite is under 4 millimeters, rather small for Michelinia, and the tabulation is more that of Favosites.

McAlester quadrangle. Limestone ridge at the Missouri, Kansas and Texas Railway crushing plant.

Spiriferina spinosa.	Cleiothyris sp.
Eumetria verneuilana?	Astartella ? sp.

McAlester quadrangle. North side of sec. 1, T. 3 N., R. 15 E. From limestone ridge at Natural Arch.

Zaphrentis sp.	Proetus sp.
Spirifer striatus?	

The following are from a ridge of limestone which runs for several miles through the western tier of sections in T. 1 S., R. 9 E. (Atoka quadrangle), Indian Territory.

Productus flemingi, var. burlingtonensis?	Productus semireticulatus?

The four localities indicated by the symbols A, B, D, and E in the following faunal lists belong to a series of five consecutive strata having a strong eastward dip which form the ridge of limestone just referred to. Stratigraphically, the lowest of these strata is the one numbered A, and the others are superposed in alphabetic order. The horizon C seems to be missing from our collections. Possibly the fauna of *P. flemingi ?* var. *burlingtonensis ?* and *P. semireticulatus ?* came from that bed.

Locality A.

Campophyllum sp.	Eupachycrinus sp.
Bryozoan fragments.	Crinoid stems.
Seminula sp.	

Locality B.

Spirifer centronatus.	Productella concentrica.

The single fragmentary spirifer from this locality might almost as well be any one of a large number of spirifers from Mississippian and Coal Measure strata. Not so with the shells identified as *Productella concentrica.* While the preservation is not all that might be wished, it is nevertheless not very bad, and an actual comparison reveals no characters by which this shell may be distinguished from the form described as *P. concentrica.* That species is common in both Missouri and Ohio, and seems to hold a pretty definite horizon near the base of the Lower Carboniferous, and I can recall no species in the Coal Measures with which it would be likely to be confused.

Locality D.

Productus lævicosta.
Productus semireticulatus?
Productus sp.
Productella cf. P. arcuata.
Productella concentrica.
Dielasma sp.

Locality E.

Productus scitulus?
Spirifer Keokuk?

The small, finely striated Productus, which is here provisionally referred to Meek and Worthen's species, is very abundant, but crushed, broken, and otherwise poorly preserved. With it I find a single Spirifer of small size of the same character as *Sp. Keokuk.*

LOWER HELDERBERG PERIOD.

The discovery in Indian Territory of a well-developed expression of what has usually been considered a rather restricted fauna, that of the Lower Helderberg of New York, so far distant even from its nearest known appearance, in Tennessee, is of general interest. It was made by Prof. H. S. Williams and recorded in a paper by Mr. R. T. Hill.[1] *Delthyris perlamellosa*, *Leptæna rhomboidalis*, *Uncinulus nucleolatus* and *Lingula? rectilatera* were identified, and the conclusion drawn, "It is safe to say the horizon is Upper Silurian, and probably equivalent to the Lower Helderberg of New York." It is my privilege to confirm Professor Williams's correlation and to record an extensive and characteristic Lower Helderberg fauna from this region.

Referring to the profile[2] of the beds from which collections were made by Mr. François E. Matthes, the fauna as presented seem to show that all the beds from Nos. 1 to 9, inclusive, were deposited during Lower Helderberg time.

From No. 1 the following characteristic Lower Helderberg fossils were obtained:

Favosites conicus.
Dalmanella subcarinata.
Rhipidomella oblata var. emarginata.
Platyceras sp.
Dalmanites pleuroptyx.

No. 2 furnished the following fauna:

Fenestella sp.
Streptelasma waynense.
Strophonella cf. planulata.
Rhynchonella sp.
Pholidops sp.
Meristella arcuata.
Renssellaeria sp.
Euomphalus sp.

The matrix of No. 1 is a dark-colored, more or less porous, chert containing scanty and almost inaccessible organic remains. That of No. 2 is a white, soft, highly crystalline limestone, with poorly preserved fossils. For various reasons the faunal lists from these stations are not satisfactory. This white limestone (No. 2) is dissimilar to everything

[1] Notes on a reconnaissance of the Ouachita Mountain System in Indian Territory: Am. Jour. Sci., 3d series, Vol. XLII, 1891, p. 121.

[2] The profile (Pl. LXIX), which will be found facing p. 540 was kindly prepared by Mr. Matthes.

else in the section, and the fauna, while containing several species common to the other beds, shows much individuality. The chert (No. 1) is closely associated with the white limestone and supposed to overlie it, but Mr. Matthes informs me that it is a thin bed which was observed at only one locality and its relations are somewhat doubtful. Its fauna is more closely related to that of the mass of the Lower Helderberg below than to that of the white limestone which it is believed to immediately overlie.

The succeeding beds, Nos. 3, 4, 5, 6, 7, and 8, together with the two localities collected by Mr. Taff, show a varied, prolific, and characteristic Lower Helderberg fauna, which is listed in the following table:

Lower Helderberg fauna from beds in Indian Territory.

	*3	*4	*5	*6	*7	*8	†a	‡b	§c
Hindia sphæroidalis	×	×	....	×	....	....	....	....	×
Streptelasma waynense	....	....	....	×	×	....	....	×	....
Favosites conicus	....	×	×	×	×	....	×	×	....
Cladopora sp	....	×	....	....	....	....	....	....	....
Crinoid	....	....	×	....	....	....	....	....	....
Crinoid	....	....	....	....	....	....	....	×	....
Callopora perelegans	....	....	....	....	....	....	....	×	....
Fistulipora parasitica	....	....	×	....	×	....	....	....	....
Fistulipora cf. maculosa	....	....	....	×	....	×	....	×	....
Fistulipora sp	....	....	....	×	....	....	....	....	....
Orthostrophia strophomenoides	×	....	×	×	×	×	....	×	×
Dalmanella subcarinata	....	×	....	×	×	....	....	×	×
Rhipidomella oblata	....	×	×	....	×	×	....	×	×
Rhipidomella oblata var. emarginata	....	×	×	×	×	×	....	×	×
Bilobites varicus	....	....	....	....	....	×	....	....	....
Leptæna rhomboidalis	×	×	×	×	×	×	....	×	×
Strophonella punctulifera	....	×	×	×	×	....	....	....	....
Strophodonta varistriata	....	....	....	×	×	....	....	....	....
Uncinulus nucleolatus	....	....	....	×	×	×	....	×	....
Uncinulus ? acutiplicatus	×	×	....	....	....	×	....	....	×
Uncinulus pyramidatus	....	×	×	×	×	×	....	×	....
Uncinulus campbellanus	....	×	....	....	....	....	×	....	....
Delthyris perlamellosus	....	×	×	....	....	×	....	×	×
Spirifer cyclopterus	....	×	....	....	....	....	....	....	×
Atrypa reticularis	....	....	....	×	×	....	....	....	....
Anastrophia verneuili	....	....	....	×	....	×	....	×	....
Gypidula galeata	....	....	....	×	....	....	....	....	....
Rensselaeria æquiradiata	....	....	....	×	....	....	....	....	....

* Referring to beds in Mr. Matthes profile (see Pl. LXIX, p. 540).
† From beds in Mr. Matthes section, but exact location no longer known.
‡ Atoka quadrangle. Southwest corner sec. 16, T. 1 S., R. 8 E.
§ Atoka quadrangle. Northwest corner sec. 21, T. 1 S., R. 8 E.

Lower Helderberg fauna from beds in Indian Territory—Continued.

	*3	*4	*5	*6	*7	*8	†a	†b	§c
Rhynchospira formosa	....	....	....	....	....	×	....	....	....
Trematospira hippolyte	....	×	....	....	....	....	....	....	....
Meristella arcuata	×	×	....	....	....	....	....	....	×
Meristella arcuata var. atoka	....	×	×	×	×	×	×	×	....
Platyceras sp	....	×	....	....	....	....	....	....	....
Platyceras gebhardi	....	....	....	....	×	×	....	×	....
Platyceras tenuiliratum	....	....	....	....	×	....	....	×	....
Plethospira? sp. nov	....	....	....	....	....	....	....	....	×
Loxonema attenuatum?	....	....	....	....	×	....	....	....	....
Euomphalus n. sp	....	....	....	....	....	×	....	....	....
Aviculopecten securiformis	....	....	×	....	....	....	....	....	....
Megambonia lata	....	....	....	....	....	....	....	×	....
Megambonia lata var	....	....	×	....	....	....	....	×	....
Orthoceras rude	....	....	×	×	×	×	....	....	....
Orthoceras pauciseptum	....	....	....	×	×	....	....	....	....
Dalmanites pleuroptyx	....	....	×	×	×	×	×	×	×
Phacops logani	....	....	×	....	....	×	×	×	....
Phacops hudsonicus	....	....	×	×	×	×	×	×	....
Proetus protuberans	....	....	....	×	....	....	....	....	....

* Referring to beds in Mr. Matthes profile. See Pl. LXIX.
† From beds in Mr. Matthes section, but exact location no longer known.
‡ Atoka quadrangle. Southwest corner sec. 16, T. 1 S., R. 8 E.
§ Atoka quadrangle. Northwest corner sec. 21, T. 1 S., R. 8 E.

It will be seen from this table that the collections made at different stations show little if any local or stratigraphic peculiarities, but are essentially the same throughout. Taken as a whole, this fauna is characteristic, and presents fewer points of individuality than might have been expected from its remoteness from the typical exposures of the Lower Helderberg. Generally speaking, it may be said that the fauna from Indian Territory is more similar to that from Tennessee than that from New York. A few new species have been recognized and extensive collections would undoubtedly discover others, but I have proposed no specific names, because the new forms have been almost invariably represented by solitary individuals. They have, however, been described and in some instances figured.

In the typical Lower Helderberg the predominant types are the Molluscoidea, not only in number of described species, but also and more especially in the number of individuals obtainable. This, the collections from Indian Territory seem to show, is not so true of that region. I judge that other groups are proportionately better represented, both in species and individuals, than in New York.

The Bryozoa are rather conspicuously absent, and it may be worth mentioning that the collections show only one Fenestellid (a large frond from No. 2) and not a single branching type outside of the Monticuliporoids.

Although larger collections may considerably modify these conclusions, it seems that the Brachiopoda show somewhat less differentiation in respect of species, less abundance of individuals, and often less robustness of size. The following peculiarities would probably be suggested by a perusal of the table annexed, but they may be briefly set down here.

Among the Orthis types it is interesting to find *Orthostrophia strophomenoides* among the most abundant and persistent, while, on the other hand, *Bilobites varicus*,[1] which occurs in myriads in certain layers of the Helderberg Mountains, is represented by only two rather small specimens. As against the large number of Orthids from this period described by Hall, I have been able to distinguish only three in the collections from Indian Territory. These are mostly of small individuals, and it is noteworthy that one of them is *R. oblata* var. *emarginata* of the Tennessee Lower Helderberg.

Of the Strophomenidæ we find only *Leptæna rhomboidalis*, *Strophonella punctulifera*, and *Strophodonta varistriata*, the last two being rare.

The rhynchonellas are plentiful, although they are rather small, and fewer species are represented in our collections, and it is again noticeable that none of the large New York forms are among them.

Of the spirifers, while *Sp. cyclopterus* and the highly characteristic *Delthyris perlamellosa* are present and fairly abundant, the total absence of *Sp. macropleura* is noteworthy.

Atrypa reticularis, *Anastrophia verneuili*, and *Gypidula galeata*, which are so common in New York, are here among the rare forms.

Of the Meristidæ I find only *Meristella arcuata* and an abundant though somewhat individual type which I have distinguished as a variety of the same. None of the large New York species are present, and all the specimens which I have seen are rather small.

Similar conditions might be pointed out as existing in other groups, but enough has been said to show that certain peculiarities give a somewhat distinctive facies to the Lower Helderberg of Indian Territory. These peculiarities are in the main shared by the Lower Helderberg of Tennessee, and are manifested (1) by the absence of familiar and the presence of new forms, (2) by the rarity of abundant and abundance of rare forms, and (3) frequently by a lack of specific diversity which often takes the shape of omitting large and strongly characterized species, those present being often small types, sometimes undersized and seldom exhibiting a marked degree of specific differentiation.

I can not refrain, however, from calling attention to the trilobites which, though usually rare in New York, form one of the common groups. The simple, not greatly differentiated *Dalmanites pleuroptyx*, is the only

[1] Later collections show this species to be much more abundant than was at first supposed.

species of that genus which I have been able to distinguish, but it is a common fossil. It is more especially interesting, however, to note the abundance of Phacops, of which *P. logani* and *P. hudsonicus* are both present. Indeed, the latter, of which, at the time the third volume of Paleontology of New York was in preparation, but a single fragmentary specimen had come to hand, is more abundant than the former, and many entire specimens have been collected.

The Lower Helderberg fauna of Indian Territory, like that of Tennessee, probably represents little more than the Delthyris shaly limestone of New York. In pursuing the study and making the comparisons incidental to this report, I have been impressed with its somewhat primitive or undifferentiated character. This is doubtless partly, though I doubt if entirely, due to the conditions under which collections were made in New York and in Indian Territory and the extent of the collections. Whether this peculiarity of facies is due to the repressive influence of some uncongenial environmental condition, or is the expression of the primitive character of a migrating fauna which attained a fuller differentiation in its progress through Tennessee into New York, it is impossible to say.

NIAGARA PERIOD.

The Niagara period was doubtfully identified by Prof. H. S. Williams in the same publication in which the determination of the Lower Helderberg period was recorded. No fauna is cited in support of this conclusion, but the beds so identified are represented as underlying the Lower Helderberg.

In the section given on Pl. LXIX, beds 1 to 8, inclusive, are regarded as representing the Lower Helderberg period. Bed No. 9 consists of a limestone of quite different character from the Lower Helderberg limestones, but it contains no fossils. Bed No. 10 is still different lithologically, being a siliceous pisolite (the limestone of No. 9 also seems to be more or less oolitic), with a few almost inaccessible fossils, among which three species have been recognized—*Atrypa reticularis*, a small, coarsely plicate variety of a kind common in the Niagara limestone of Waldron, Indiana, but not found in the Lower Helderberg fauna; *Orthothetes subplanus*, a type of shell which can be exactly mated among *O. subplanus* of the Niagara group, and which ranges up into the Lower Helderberg period; and *Strophostylus cyclonema ?*, a gasteropod with fine revolving and lamellose transverse ornamentation which, though very similar to the species just cited, is possibly distinct. This fauna finds no relation to the facies of the Lower Helderberg fauna presented by the beds above, and seems to show closer affinities with the fauna of the Niagara period, to which I have provisionally referred it.

ORDOVICIAN.

Horizon No. 11 has furnished a few crinoid stems, but nothing determinable.

From the next horizon (No. 12) the only species yet known is *Rhynchotrema capax*. This species, taken in conjunction with the stratigraphic position of the bed, leads to the conclusion that the horizon is probably that of the Hudson River of the Ordovician.

Horizon No. 13 has furnished *Bellerophon bilobatus ?*, *Rafinesquina deltoidea*, and *Ormoceras tenuifilum*, a single specimen of each.

Horizon No. 14 gives us *Amplexopora* sp., and No. 15 only a fragment of a sponge(?), indeterminable.

From horizon No. 16 have been obtained *Rafinesquina alternata*, *R. minnesotaensis*, and imperfect Bellerophons.

From Nos. 17 and 18 nothing has been identified, the organic remains being fragmental.

No. 19 has furnished the following fauna: *Gonioceras anceps ?* (perhaps a new species), *Orthoceras* sp., *Monotrypa* sp., *Monotrypa ?* sp.; No. 20, *Helicotoma* cf. *verticalis;* and No. 21, nothing determinable. From No. 22 have been obtained two or three specimens of *Monotrypa* and *Orthoceras bilineatum ?* From No. 23 fragments are found of a large undetermined Orthoceras.

Horizon No. 24 has furnished *Zittelella typicalis ?*, *Monotrypa* sp., *Maclurea* cf. *bigsbyi*. There are several specimens of Zittelella in the small collection, and it is interesting to find characteristic specimens of this genus in such comparative abundance so remote from the original, and indeed the only, locality where they are known to occur.

Locality 25 is the last and lowest locality from which collections were made. While fossils all through this section seem to have been fairly plenty, at this point they are especially so, and a few small blocks of limestone have furnished a large number of silicified fossils, chiefly gasteropods, of which the following list represents the most abundant and best preserved, but does not include a number of small and fragmentary specimens:

Rafinesquina alternata?
Orthoceras sp.
Orthoceras bilineatum.
Maclurea bigsbyi.
Raphistomina cf. R. modesta (probably new).
Holopea rotunda.
Holopea similis?
Trochonema fragile?
Liospira n. sp. (like L. rugata).
Eotomaria labiosa?
Eotomaria n. sp.
Lophospira elevata.
Lophospira centralis.
Hormotoma n. sp. (between H. subangulata and H. trentonensis).

The foregoing faunal lists, imperfect as I know them to be in many respects, afford adequate evidence to determine the geological equivalence of the several strata with some certainty. I conclude that the lowest stratum included in Mr. Matthes's section is no older than the Trenton limestone of New York, with which horizon, indeed, the major portion of the Ordovician section can be correlated, although the upward range probably reaches the Hudson River period. For this latter conclusion the presence of *Rhynchotrema capax* in bed No. 12 is good, though indecisive, evidence. To the Trenton also may be referred the horizon represented by Mr. Taff's collection from the Atoka quadrangle, SE. ¼ sec. 6, T. 3 S., R. 9 E. This locality furnishes *Orthis tricenaria* and *Rafinesquina minnesotaensis*. This fauna is of interest as occurring within 20 feet of the underlying granite.

LOWER HELDERBERG FOSSILS.

HINDIA SPHÆROIDALIS Duncan.

Calamopora fibrosa Roemer, 1860. Fauna des Westl. Tenn., p. 20 (non *C. fibrosa* Goldfuss).

Astylospongia inornata Hall, 1863. Sixteenth Rept. New York State Cab. Nat. Hist., p. 70.

Sphærolites nicholsoni Hinde, 1875. Abstract, Proc. Geol. Soc. London, p. lxxxviii, in Quart. Jour. Geol. Soc. London, vol. 31.

Hindia sphæroidalis Duncan, 1879. Ann. Mag. Nat. Hist. (5), Vol. IV, p. 84.

Hindia fibrosa Miller, 1889. North Amer. Geol. and Pal., p. 160.

Hindia sphæroidalis Ulrich, 1890. Geol. Surv. Illinois, Vol. VIII, p. 226 et seq.

Hindia fibrosa Girty, 1897. Fourteenth Ann. Rept. New York State Geologist for 1894, p. 259.

In discussing the structure and zoological relationship of this sponge in 1894 I used the name *Hindia fibrosa*, the specific appellation being derived from a singularly erroneous identification by Roemer of this sponge with Goldfuss's *Calamopora fibrosa*. The position that this name should be retained I believe now to be ill taken, and agree with Ulrich (loc. cit.) in the proper synonymy to be employed. Ulrich discusses this subject in detail in the publication above referred to, and adduces adequate reason for rejecting *Sphærolites* Hinde for *Hindia* Duncan or *Microspongia* Miller & Dyer, and for employing the specific term *sphæroidalis* suggested by Duncan instead of *fibrosa* (Roemer), *inornata* (Hall) or *nicholsoni* (Hinde).

The specimens from Indian Territory are perfectly typical in every way. They appear as siliceous masses from 13 millimeters to 26 millimeters in diameter, the spicular framework being replaced by calcite or else, in the more cherty layers, weathered out with a rusty residue.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

DUNCANELLA FANNINGANA (Safford).

Petraia fanningana Safford, 1869. Geology of Tennessee, p. 320, Pl. H., figs, 3*a*, 3*e*, 3*f*(?), 3*g*(?).

This species, like *Streptelasma waynense*, has never to my knowledge been described. Unfortunately it seems to be a form of some rarity, being represented in our collection from Tennessee by only one good and one doubtful example, and the data which it is permitted to add here are less extensive than was the case in the species just mentioned.

The specimen in question has a length of 19 millimeters, and a diameter of 4.5 millimeters, being, apparently, from Safford's figures, a rather small specimen. The shape is cylindrical, slightly tapering and more or less tortuously bent. The theca is marked by pretty strong and, for the size, coarse external rays. The regularity of shape is interrupted by constrictions and swellings of some prominence, and toward the front there is a well-marked invagination of renewed growth. Fortunately the apex is excellently preserved, showing the theca to be missing and the septa, thirteen in number, strongly exsert.

There seem to be sixteen septa in the maturer part of the shell, which are straight, very heavy, and unite in the center with what appears to be a solid, columella-like rod. The septa expand strongly toward the theca, becoming in fact really bifid, so that it is possible there are secondary septa present adnate to the primary ones. The septa are distinctly spinose, some of them, but I have seen no evidence of interseptal tissue.

D. fanningana has not as yet been found in Indian Territory, and the above description is based upon what may be called typical material from Tennessee.

Although this species was referred by its author to Petraia, and is recorded by Miller (North American Geology and Paleontology) under the genus Streptelasma, the structural peculiarities above enumerated leave no doubt that it should be more correctly referred to Duncanella. The question then presents itself as to whether *D. rudis* Girty described from the Lower Helderberg group of New York may not be a synonym for this species. This I at first believed to be the case, but a more careful comparison convinces me that they are distinct, a point which will receive discussion later. Both species occur together in Tennessee, though *D. fanningana* is not known from New York.

Formation and locality.—Lower Helderberg period. Tennessee.

DUNCANELLA RUDIS Girty.

Duncanella rudis Girty, 1897. Fourteenth Ann. Rept. New York State Geologist for 1894, p. 299, Pl. II, figs. 7, 8.

Corallum simple, straight, turbinate, moderately expanded. External rays rather sharply expressed and crossed by fine lines of growth and faint annular constrictions and irregularities. Calyce deep, theca and septa strong. The latter, which are about twenty in number (18 to 22), thicken near the outer wall and appear to be made up of two plates, proximate for the most part, but occasionally spreading near their circumferential extremities so as to leave a cavity between them. Internally the septa unite with an axial tube or sort of inner wall, in which they also terminate. Interseptal tissue, none.

D. rudis shows great variation in size and rapidity of expansion. One typical example has a length of 14 millimeters and a diameter of 6 millimeters. Another, with about the same length, has a diameter of 9 millimeters. Another, 13 millimeters long, has a diameter of perhaps 11 millimeters. Owing to the depth of the calyce, whose thin walls are slightly or not at all reinforced by the nascent septa, the distal end is usually more or less broken or else compressed.

In the Lower Helderberg strata of Tennessee this species is associated with *D. fanningana* and *Streptelasma waynense*, and often there is difficulty in distinguishing the three species on external characters. Probably Safford himself experienced the same difficulty, for his figure *2b* (Geol. of Tenn., 1869, Pl. H), which is smaller than *2c* and without secondary septa, may represent an example of *Duncanella rudis*, while *3f*, with its numerous septa, can scarcely belong to *Duncanella fanningana*, to which it is referred, for the latter has not nearly so many of these structures, as his other figures show; two specimens before me have each sixteen.

D. rudis approaches more nearly to *Streptelasma waynense* than to *D. fanningana*, and the study which has been devoted to these species has almost convinced me of their identity, and that Duncanella is really a condition of Streptelasma. This question will be more fully discussed under the caption *Streptelasma waynense*. In the Tennessee material I employed two sets of data to distinguish these species. If a specimen showed the theca incomplete and the septa exsert it was referred in general to *D. rudis*. If, however, this character was from one reason or another indeterminable, resort was had to a cross section, when, if there were only primary septa united centrally in an axial tube, the specimen was placed with *D. rudis*, and if there were secondary septa and the axial tube or pseudocolumella was wanting it was referred to *S. waynense*. But these internal characters were found to intergrade in a measure and to be in part at least an expression of the age of the corallite and its rapidity of expansion. Furthermore, the corals from Indian Territory proved so ambiguous in character that, although provisionally referring them to *S. waynense*, I am still unable to assert with confidence whether the characters which they present are typical of Streptelasma or Duncanella.

Especially slender specimens of *D. rudis* might readily pass for young examples of *D. fanningana*, if reference was not had to internal characters; but the elongate, cylindrical, curved form of mature and typical *D. fanningana* serves to distinguish it readily, and it is my impression that the naked end of the corallum is larger and the septa more strongly exsert. The septa are also less numerous.

In his Manual of Paleontology, 1889, Vol. I, p. 267, Nicholson describes the septa in *D. borealis* as meeting centrally, so as to form a sort of pseudocolumella, a feature in regard to which his original description expresses uncertainty. Hall shows the same species with the septa united centrally with an axial tube instead of a columella (Indiana, Geol. and Nat. Hist., Eleventh Ann. Rept., 1881, Pl. I, fig. 9), and the same condition appears to prevail in *D. rudis*. My own observations tend to show that in very slender examples the axis is of a columellar character, and tubular in more expanded ones, the inner wall sometimes having a considerable inside diameter. Similarly the tendency is for tubular axes to contract into solid ones toward the apex of the fossil, and for columellar axes to develop into tubular ones as growth progresses.

Although neither *D. rudis* nor *D. fanningana* has as yet been discovered in the Helderberg strata of Indian Territory, it is hoped that a discussion of them is sufficiently apposite and that the facts presented are of sufficient interest to warrant its insertion here.

Formation and locality.—Lower Helderberg period. New York and Tennessee.

STREPTELASMA WAYNENSE (Safford).

Petraia waynense Safford, 1869. Geology of Tennessee, pp. 314, 320, Pl. H, figs. 2*a*, 2*h*.

Corallum small, nearly straight, conical, usually gradually tapering; marked externally by very distinct longitudinal rays, which are crossed by fine lines of growth and sometimes irregularities and constrictions, which, however, are never very strong.

Calyce deep, with thin walls which for some distance are not marked by septa. There are about 20 (18 to 20) primary septa usually united into groups of 2, 3, 4, or 5 by the coalescence of their ends near the center, two or more of the groups being united across the center by productions from the united septa. Alternating with the primary septa are an equal number of much smaller secondary septa. Dissepimental tissue very scantily developed, if at all, and confined to the apex of the corallum below the deep cup.

One large specimen has a length of 34 millimeters, with a diameter of about 16 millimeters. As this species has never to my knowledge had the advantage of a description, the notes just given, based on typical material from Tennessee, will not be without value.

In general appearance this species so closely resembles *Streptelasma strictum* Hall of the same geologic age from New York that it would be hard, indeed, from external characters to say wherein they differed. *S. waynense* never, so far as my experience goes, attains the size of the largest specimen figured by Hall (Pal. New York, Vol. VI, Pl. I, fig. 4), though the largest specimen from Tennessee which I have examined is as large as the average of *S. strictum*, or perhaps a trifle larger; but, with the exception of size, I would say that *S. waynense* is exactly the same as *S. strictum* externally, and has the same range of variation. The chief differential character is in the number of septa. *S. strictum* has usually 28 primary septa (26 to 30), while *S. waynense* has on an average 18 or 20. In both species this number is fairly constant in the same individual at different periods of its growth within reasonable limits. A section through a specimen of *S. strictum* taken at a point where the corallum had a diameter of 8 millimeters shows 24 primary septa, while a similar section in *S. waynense* at a diameter of 11 millimeters shows 20 primary septa. I am inclned to think that in addition to being more closely septate than *S. waynense*, *S. strictum* has a considerably more extensive development of dissepimental tissue. In some specimens of both species the septa are distinctly spinose (as seen in transverse sections).

An examination of a considerable number of individuals of *Duncanella rudis* and *Streptelasma waynense* has led me not only to doubt the value of the former as a distinct species, but also to question the integrity of Duncanella as distinct from Streptelasma, of which indeed Hall once placed it as a subgenus (Dept. Geol. and Nat. Hist., Indiana, Eleventh Ann. Rept., 1881, p. 227). In *Duncanella borealis* the corallum consists of a conical cup from which proceed septa meeting centrally with what Nicholson calls a pseudocolumella (see Nicholson, Manual of Pal., 1889, p. 267). There is no interseptal tissue, and no secondary septa. The most unique feature of the genus, as is well known, consists in the fact that the septa are exsert at the base. In the previous discussion of *D. rudis* and *S. waynense* it will be noticed that both species have the same number of septa and are practically identical in all external characters, the essential difference being that *D. rudis* has exsert septa, a pseudocolumella, and lacks secondary septa. Regarding the latter point, however, observations upon a number of specimens shed some light. Specimens which, on account of their slender shape and exsert septa, I have referred to *D. rudis*, often have the septa forked at their bases where they join the theca, a condition which is sometimes indicated, if not sometimes actually present, in *D. borealis*. This is not seen in every septum of the specimen, but some show it and others do not. Other specimens, the conditions of whose bases render it improbable that the septa were exsert, and which for this and other reasons have been referred to *S. waynense*, have the septa bifurcated for over half their length without any secondary septa showing, and representing, I believe, the secondary septa adnate by their extremities to the primary ones, a condition which Hall mentions as sometimes occurring in *S. strictum*. Other specimes have the secondary septa distinct from the primary ones; the secondary are much shorter than the primary with which they alternate. Indeed I am convinced that the secondary septa originate in this species by bifurcation, for in grinding down a specimen, beginning from its apex, I have seen the bifurcation become more and more pronounced until the shorter septa became entirely separated from the older ones. At this stage the secondary septa were seen to be situated near but directed away from the septa which threw them off, afterwards apparently assuming a median position and a more radial direction. Similarly I have seen the pseudocolumella as apparently a solid rod, a tube of varying internal diameter and integrity of containing wall, and as more or less grouped septal extremities. I believe these appearances to be simply a matter of degree, dependent partly upon the stage of development of the individual at which the section was taken, and partly upon individual peculiarities, such as rapidity of expansion. At all events, the long, slender individuals appear to have rod-like axes; more rapidly expanding ones have tubular axes which sometimes have a large internal diameter, while older examples seem to show no axes at all, but have the septa joined by their extremities into groups of 2, 3, 4, or 5. In brief, I believe that *D. rudis* and *S. waynense* are one and the same form, and that the differences, both specific and generic, by which I have distinguished them in the above discussion, are those of degree only. Regarding the exsert septa of Duncanella, it might be suggested that where, at the end of the free swimming stage, the larvæ settled down upon some solid object, as a coral or a brachiopod, to which they could attach themselves, the theca was completely formed and shows marks of cementation, but where they rested upon the mud some organic expansion was improvised for their support and the theca was basally incomplete and the septa exsert. Such a hypothesis would explain the small size and often slender shape of Duncanella as representing individuals dwarfed by unnatural and unwholesome environment. Some confirmatory evidence for such a theory, for at present it can be called little more, may be found in the fact that Duncanella always, so far as known, accompanies Streptelasma. Thus we have *D. borealis* and *S. radicans* in the Niagara, *D. rudis* and *S. strictum* in the Lower Helderberg of New York, *D. rudis* and *S. waynense* in the Lower Helderberg of Tennessee. In the latter case the two forms merge into each other and have the same number of septa, but in the case of *D. borealis* and *S. radicans* it must be confessed that the primary septa of the Streptelasmoid form are much more numerous—just twice as many (see Hall, who gives 10 for *D. borealis* and 20 for *S. strictum*).[1] If the above conjecture, which appears to be not without foundation, proves true, one of two contingencies must inevitably follow. Either the definition of Duncanella must be altered so as to include *S. waynense*, or else the genus must be set down as a synonym for Streptelasma. There is little doubt that typical *D. rudis* is congeneric with *D. borealis* and there is equally little doubt that *S. waynense* is of a type commonly referred to Streptelasma, whatever the real generic characters of Streptelasma may prove to be.

The following data, taken from different individuals of *D. rudis* and *S. waynense*, have a distinct bearing upon the question involved.

Corallum broken at the base, moderately expanding. At a diameter of 6.5 millimeters a transverse section shows 20 septa, thickened and sometimes forked at the end, joined centrally to a tubular axis of unusually large size.

Corallum slender and with exsert septa. At a diameter of 4 milli-

[1] It is noteworthy that in this instance also *D. borealis* and *S. radicans* would have the same number of septa if the bifurcated septa of the former be interpreted as secondary septa adnate to the primary ones.

meters a section shows 20 (or 21) septa crowded together, many with forked ends, joining a rod-like (?) central axis.

Corallum slender and with exsert septa. At a diameter of 4 millimeters and also some distance further along, where the corallum has a diameter of about 5 millimeters, the appearance is the same, 18 (?) crowded septa, many of them slightly bifurcate, meeting centrally a tubular axis with comparatively thin walls and small bore.

A large specimen 25 millimeters long, moderately expanding, septa probably exsert. At a distance 10 millimeters up, where the diameter is 6 millimeters, there are 20 septa, many strongly bifurcated, meeting at the center a tubular axis of thick walls and large bore.

Specimen rather large, 29 millimeters long, moderately expanding. Apex broken, probably attached. Two sections at 7.5 millimeters and 11.5 millimeters from broken end, where the diameter is 6 millimeters and 7 millimeters respectively. Both sections show a very large axial tube with about 20 primary septa. Some of the latter are not forked at their peripheral ends, others slightly forked, and others more strongly, while there are two or three separate secondary septa. These last are intermediate in position, but point toward the primary septa, from which they have apparently just been separated.

Specimen 14 millimeters long, moderately expanding. Section taken about 8 millimeters from apex, which is incomplete and may have been either attached or open with exsert septa. Axial tube very large, septa 19 or 20, which are more or less grouped, so that it is difficult to say whether a group represents a deeply forked primary septum or several of them cognate. Forking varies from not at all to strong.

Another specimen, referred to the same species, because below it shows the tubular axis with forked primary septa, when cut through the calyce shows 36 short septa, which in part of the cup are plainly alternate but in the rest of it appear to be equal. Another individual, smaller and younger in itself but cut at relatively the same point, shows the tip of the central axis, which at this point appears to be solid. The primary septa, which do not reach the axis, are more or less grouped by being cognate. One of them is deeply forked. Between the primary septa may be seen secondary septa, though very slightly developed (perhaps not really septa). The apex of this specimen is complete and flattened as if from attachment. A section 6 millimeters up has a small axial tube with thick walls and 16 primary septa, forked slightly or not at all.

An individual referred to *Streptelasma waynense* is rapidly expanding, being 17.5 millimeters long with a diameter of 13 millimeters. Section taken near the base, 6.5 millimeters up, where the diameter is about 6.5 millimeters, shows 20 primary septa, which are grouped and united in the center, though anything in the nature of a columella is very indefinite. Secondary septa also are shown which are short, a few being intermediate and radially directed; others, however, are still smaller, situated on or near the expanded base of the primary septa, and directed away from it.

Specimen slender, 19 millimeters long. Section taken 9 millimeters from the end, with a diameter of 6 millimeters, shows 20 grouped primary septa, between which are smaller secondary septa, though not an equal number.

Specimen slender, 14.5 millimeters long. Section 6.5 millimeters from end, diameter 3.5 millimeters, shows 16 grouped primary septa, with alternate secondary septa.

About the same characters are maintained through quite a series of specimens, and the following differences may be pointed out as distinguishing *D. rudis* and *S. waynense* in our Tennessee material. The septa are 20 in number in either species. In *D. rudis* they are powerful and usually bifurcated, meeting in the middle with a tubular axis. In *S. waynense* the septa are more slender, spinose, grouped, not united with an axial tube, and with well-developed secondary septa.

Specimens from Indian Territory, however, present characters so intermediate between the two forms which I have been able to distinguish in Tennessee, that I am unable to determine with which they should properly be joined.

Thus, an individual which has a length of 24 millimeters, and moderately tapering, almost certainly lacks the exsert septa of Duncanella. At a diameter of 3.5 millimeters there are 19 septa, some of which I am in doubt whether to call cognate septa or bifurcated septa. Many of them show a slight forking at their ends. The septa are thick and do not exactly meet in a tubular axis, but rather by their tangent ends leave a hollow center. The same appearance is more pronounced 4.5 millimeters farther on, where the diameter is about 6.5 millimeters. There we see 20 heavy septa slightly forked at their outer ends and leaving an irregular hollow space in the center of the corallum. A trifle farther along the septa are grouped as in *S. waynense*, but are not united in any way into a common structure, the groups being entirely disconnected.

Another slender almost cylindrical individual shows at a diameter of 6 millimeters 20 septa which have the slender spinose nature of *S. waynense*, but are united centrally into a strong solid columella, in which, however, the individual septa appear to retain their identity. Most of them are in addition so strongly forked that the point of bifurcation is nearer the columella than the theca.

Another individual seems to have more distinctively the characters of *S. waynense* as described above.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

FAVOSITES CONICUS Hall.

Favosites conica Hall, 1874. Twenty-sixth Rept. New York State Mus. Nat. Hist., p. 112.

In pointing out the resemblant features of *F. conicus* and *F. helderbergiæ*, I was led upon a former occasion[1] to suggest that the two forms represented only different stages of growth in the same type of corallum. This may indeed be true; yet, giving due weight to the characters of difference pointed out by Hall, noting also that the one form (*F. conicus*) is quite abundant in Indian Territory, where the other so far as known does not occur at all, and partly also for convenience, it seems expedient to retain both names.

This appears from our collections to be one of the common species in the Lower Helderberg strata of the Southwest The largest specimen has a diameter of 48 millimeters, but the average is about 25 millimeters. These coralla show great variation in shape, but usually they are subcircular in outline and of a generally conical shape. Sometimes it is depressed conical, sometimes more lofty, often also hemispherical. The constituent cells vary in size and many of them are distinctly larger than those of a large explanate specimen of *F. helderbergiæ* from typical strata of the Lower Helderberg group with which comparison was made. Many of them have a diameter of 3 millimeters, or a trifle less, and agree in point of size with a characteristic specimen of *F. conicus* now before me. The coralla, however, never, so far as I have seen, assume quite the elongate conical shapes characteristic of the species. Tabulæ very close together, characters of mural pores and septal spines or nodes not ascertained.

I regard this identification, while not beyond question, as in all probability correct. At all events, precisely the same form apparently occurs in the Lower Helderberg rocks of Tennessee, although it seems to be much less abundant.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

CLADOPORA sp.

A species of Cladopora which is probably new, but the material not adequate to describe as such. I have a single fragment, coarsely silicified, about 16 millimeters long. The branch is not circular in outline, but elliptical (perhaps compressed) with a major axis of 12.5 millimeters and a minor axis of 12 millimeters. The circular cells measure 2 millimeters in diameter, sometimes a trifle less, and are separated slightly less than that distance from each other. The closest species to this of the same geological horizon is undoubtedly *C. halli* Girty, which also lacks raised lips underneath the zooidal openings. The

[1] Fourteenth Ann. Rept. New York State Geologist for 1894, 1897, p. 302.

latter appears to be, however, a smaller species, with much smaller and less frequent zooidal openings.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

ORTHOSTROPHIA STROPHOMENOIDES Hall.

Orthis strophomenoides Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 46.

Though showing considerable variation in shape, etc., but more especially in the striæ and other surface characters, the Southwestern representatives of this species are typical in every way, and it is interesting to note that this species, which, in New York and also in Tennessee, is, I believe, one of the rarer Helderberg forms, is abundant in Indian Territory. Nearly every locality has furnished some specimen of it and sometimes a large number, so that it may be reckoned as among the most plentiful species from that region.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

DALMANELLA SUBCARINATA Hall.

Pl. LXX, figs. 1*a*–1*g*.

Orthis subcarinata Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 43.

This is one of the common species in the collections examined. All the specimens are undersized, and, if the material is representative, it would seem that *D. subcarinata* seldom attained more than three-fourths the size of specimens found in New York. The specimens figured are characteristic. Other than in size the specimens from Indian Territory are typical and internal characters confirm the identification. Some slight variation from Hall's figures is seen, but not sufficient to be of specific value. Externally the shell is shield-shaped; the ventral valve is rather convex and more or less angulated, tending toward a dihedral angle in curvature. Dorsal valve subplane, with an angular sinus. The depth of the sinus and angulation of the ventral valve rather variable. There are about 34 striæ in the space of 10 millimeters around the margin of a mature shell, the striæ being often of unequal size alternate ones, or often every third, fourth, or fifth striæ, being stronger than those intermediate. This, however, is never a pronounced character. Often in size and other external characters some of the specimens approach *D. planiconvexa*, but the internal features, where observed, are those of *D. subcarinata.*

Formation and locality.—Lower Helderberg period. Atoka quadrangle. T. 1 S., R. 8 E., Indian Territory.

RHIPIDOMELLA OBLATA Hall.

Pl. LXX, fig. 3*a*.

Orthis oblata Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 41, figs. 1-5.

This species, as I have identified it from Indian Territory, attains a larger size than *Dalmanella subcarinata*, though, so far as our collections show, never quite so large as New York specimens. It can readily be distinguished from the above-named species by its subequal valves, more regularly oval shape, lack of well-expressed fold and sinus, and coarser striation. The internal markings are also quite different, and where seen are those of characteristic *Rh. oblata* (see Pl. LXX, fig. 3 *a*). Around the anterior margin of a large specimen about 25 striæ occur in the space of 10 millimeters. These are bifurcated, separated by about their own diameter (or a little less), and many of them are distinctly seen to be tubular or to have been extended into short tubular spines whose broken ends are seen distributed over the surface with some regularity, especially along the somewhat lamellose lines of renewal of shell growth. This character, though not mentioned by Hall, can be seen also on characteristic specimens of the species from New York and is common throughout the genus. It would seem to ally this species to *Rh. tubulistria*, which is of the same general shape and possesses this character to a marked degree, but which is said to be distinguished by its prominent fasciculate striæ.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

RHIPIDOMELLA OBLATA var. EMARGINATA Hall.

Pl. LXX, figs. 2*a*.-2*j*.

Orthis oblata var. *emarginata* Hall, 1859. Pal. New York, Vol. III, p. 164, Pl. XA, figs. 4-6.

It is interesting to find this species, which before has been known only from Cumberland, Maryland, occurring abundantly in the Lower Helderberg strata of Indian Territory. It is also common from the same strata in Tennessee, and it is with these specimens, whose identification I believe to be unassailable, that comparison has been made. There can be no doubt that the Tennessee form and that from the Territory are the same. The latter is, however, often smaller, and frequently has the distinguishing characters not quite so strongly marked. While there can be little doubt of the practical identity of the interiors illustrated by Hall with others seen in my material, both from Tennessee and Indian Territory, there are some points in which his figures appear to be incorrect, or, if not, to show an interesting variation. Therefore this species has been illustrated with some detail. In some other respects, and no less in the character of its internal markings, does *Rh. oblata* var. *emarginata* resemble Hall's *Orthis quadrans*, if his drawings are to be relied on, but the latter has been referred by Hall and Clarke to Dalmanella, and the angulated ventral valve would serve to distinguish the two forms. Another somewhat similar form is Hall's *Orthis concinna*, but *Rh. oblata* var. *emarginata* seldom assumes the subquadrate shape which distinguishes both these species. In Tennessee a length of 23 millimeters is a size which very few specimens exceed, but in Indian Territory the average is considerably smaller, while some individuals, whose maturity or rather senility is indicated by a thickening of the edges of the shell and of all the internal characters, are no more than 8 millimeters in length.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

LEPTÆNA RHOMBOIDALIS (Wilkens).

Conchita rhomboidalis Wilkens, 1769. Nachricht von seltenen Versteinerungen, p. 77, Pl. VIII, figs. 43, 44.

This species is represented in the collection from nearly every locality. Frequently specimens of *L. rhomboidalis* are quite small, geniculation occurring only 10 millimeters from the apex, but other individuals are found which reached a diameter of an inch before geniculation.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

UNCINULUS? ACUTIPLICATUS (Hall).

Rhynchonella acutiplicata Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 73, fig. 7.

After carefully considering the relations of my specimens from Indian Territory to *Uncinulus ? acutiplicatus*, *U. vellicatus*, and *Rhynchotrema formosum*, it seems that an identification with the species first mentioned possesses the greater probability of accuracy.

Briefly described, the form before me is as follows: Shape, subcircular to transversely subelliptical; lateral angles strongly rounded; fold high, sometimes narrow, marked by 5, sometimes 6, angular plications; sides with about 7 (5 to 8) angular plications.

In shape all the species above named present points of strong superficial resemblance. A number of individuals of *Rh. formosum* examined were in agreement in having 9 to 10 plications on the sides and 4 somewhat larger ones on the fold. The material from Indian Territory thus differs in having fewer plications on the sides (7 instead of 9) and more on the fold (5 instead of 4), besides which the plications are uniformly distinctly coarser. While it agrees rather with *U. vellicatus* in having more than 4 plications on the fold, the latter has finer plications than *Rh. formosum* and more of them on the sides. Thus in several essential particulars the type from Indian Territory differs from *Rh. formosum* and *U. vellicatus* and approaches *Uncinulus acutiplicatus*, the identification with which I believe to be probably, though not certainly, correct.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

UNCINULUS PYRAMIDATUS Hall?

Rhynchonella pyramidata Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 70.

The form which I have doubtfully referred to *U. pyramidatus* is perhaps more common than any of the rhynchonelloids from Indian Territory.

It is small, about the size of *U. nucleolatus*, and much smaller than full-grown *U. pyramidatus*. The outline is subtriangular. There are 5 (4 to 6) plications on the fold and 5 to 7 on the sides. This shell often becomes quite gibbous, the upward bend of the ventral sinus and the downward bend of the sides of the dorsal valve being decisive and angular.

In shape and other characters this form is very similar to *U. pyramidatus*, though, as before stated, it is much smaller. It can without difficulty be distinguished from *U. nucleolatus*, with which it occurs, by its more triangular instead of circular outline and the abruptness with which the sinus and dorsal sides are flexed.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

UNCINULUS NUCLEOLATUS Hall.

Rhynchonella nucleolata Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 68.

I have little doubt of the correctness of this identification, and most of the variations which my material is seen to possess can be duplicated in typical specimens from New York. From these subspherical shells I have distinguished a more triangular variety, provisionally referred to *U. pyramidatus*.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

UNCINULUS CAMPBELLANUS (Hall) ?

Rhynchonella campbellana Hall, 1857. Tenth Rept. New York State Cab. Nat. Hist., p. 79.

Only two specimens have been referred to this species, and those doubtfully. They resemble the form which I have identified as *U. pyramidatus*, except for being more elongate and a trifle larger. They are much smaller than mature *U. campbellanus*, but certainly are of that general type.

Formation and locality.—Lower Helderberg period. Atoka quadangle, T. 1 S., R. 8 E., Indian Territory.

DELTHYRIS PERLAMELLOSUS (Hall).

Spirifer perlamellosa Hall, 1857. Tenth Rep. New York State Cab. Nat. Hist., p. 57, figs. 1–5 on p. 58.

This highly characteristic species is moderately abundant in Indian Territory and differs unappreciably, if at all, from the species as it is found in Tennessee and New York.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

SPIRIFER CYCLOPTERUS Hall.

Spirifer cycloptera Hall, 1857. Tenth Rep. New York State Cab. Nat. Hist., p. 58.

Rare. Only five specimens from two localities in the collection.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

ATRYPA RETICULARIS (Linnæus).

Anomia reticularis Linnæus, 1767. Systema Naturæ, ed. 12, Vol. I, p. 1132.

Comparatively rare. Five specimens from two localities; small, about 25 millimeters long.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

ANASTROPHIA VERNEUILI (Hall).

Pentamerus verneuili Hall, 1857. Tenth Rep. New York State Cab. Nat. Hist., p. 104, figs. 1, 2.

Fairly abundant and wholly characteristic. This species is, however, much more abundant in Tennessee.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T 1 S., R. 8 E., Indian Territory.

GYPIDULA GALEATA (Dalman).

Atrypa galeata Dalman, 1828. Kongl. Svenska. Vet.-Akad. Handl. for 1827, p. 46, Pl. V, fig. 4.

Of this species, which is so plentiful in certain strata of the Lower Helderberg of New York, only a single specimen has come to hand. It is, however, quite characteristic.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

RENSSELAERIA ÆQUIRADIATA (Conrad).

Atrypa æquiradiata Conrad, 1842. Jour. Acad. Nat. Sci., Philadelphia, p. 266, Pl. XVI, fig. 17.

A single specimen, but apparently quite normal to this species.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

RHYNCHOSPIRA FORMOSA (Hall).

Waldheimia formosa Hall, 1857. Tenth Rep. New York State Cab. Nat. Hist., p. 88.

But one specimen has been found belonging to this species. It is a small, subpentagonal individual, with a length of about 8 millimeters and a width of 6.5 millimeters. The ventral valve has a pronounced sinus, produced by two fine depressed median plications. The dorsal valve has a fainter sinus, occasioned by a somewhat stronger median groove, with the two adjacent plications slightly depressed. On each side of the sinuses there are 5 or 6 moderately fine, strong plications. This is, of course, smaller, and with fewer plications than mature *Rh. formosa*, but finds its counterpart in a small or immature form referred to this species from Perry and Decatur counties, Tennessee. It resembles *R. electra* in many particulars, but is much smaller, and when grown to the same size would probably be found to have more numerous plications.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

TREMATOSPIRA HIPPOLYTE (Billings)?

Pl. LXXI, fig. 3*a*.

Retzia hippolyte Billings, 1863. Proc. Portland Soc. Nat. Hist., p. 112, Pl. XIII, fig. 6.

A single specimen, which may be described as follows: Shell small, transverse, subcircular, marked by 13 high thin plications, which have between them grooves about equal to their own size. Beak small, erect. Fold and sinus present, but not distinct.

This little shell might almost be an Atrypina or Anoplotheca, but is biconvex, with sharper plications and without the imbricating growth lines of those genera. Nor, on the other hand, has it the double sinus formed by partly undeveloped bifurcating median plications of Rhynchospira. It appears to belong to the short hinge-lined type of Trematospira, most nearly resembling *T. hippolyte* Billings and *T. tennesseensis* Hall and Clarke. It is, however, smaller than the latter, with more numerous plications. It is also much smaller than *T. hippolyte*, and apparently with more angular plications and more erect beak. If this is a young specimen, as the erect beak suggests, it might grow to nearly the size of *T. hippolyte* without adding materially to the number of plications, and in that case would readily pass for a representative of Billings species. It can scarcely be a young individual of *T. multistriata*, as specimens of that size have fewer, more numerous, and bifurcating striæ, while in this specimen the striæ are all simple. Length, 8 millimeters; width, 9.5 millimeters.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

MERISTELLA ARCUATA var. ATOKA n. var.

Pl. LXXI, figs. 1*a*–1*f*.

Meristellas are very plentiful in the Lower Helderberg rocks of Indian Territory. They show considerable range of variation, but may be characterized as being small, with a high, angular fold. The following description applies to well-marked individuals of the type which I designate as *M. arcuata* var. *atoka.*

Shell rather small, subtriangular; width slightly greater than the length.

Umbo of the ventral valve full; beak small and strongly incurved; sinus strongly marked, beginning above the middle of the shell as a depressed line, deepening and broadening as growth advances, but never losing its angular character, the upturning of the sinus toward the front and the angularity so pronounced as often to make a distinct emargination in the anterior outline, which would otherwise be well rounded. Young examples are subcircular, but usually with a faint angular sinuation, noticeable in the two valves as seen from the front.

From this type, by gradations, considerable variations are found. The fold varies both in strength and shape, and specimens occur in which this feature is high and rounded as well as high and angular, and others in which it is low and rounded and low and angular. But generally it is both angular and well marked. Similarly the shape varies from being wider than long to being longer than wide, the beak of the ventral valve in that case being higher and more projecting. Perhaps several specific names might be employed for the extremes of variation, but I do not believe that these distinctions would be justified. A few specimens with rounded fold and sinus I have identified with *M. arcuata* Hall (see Pl. LXXI, figs. 2*a*–2*c*), but I much suspect that they are really variations from the other, which is the dominant type, and may be a distinct species instead of only a variety of *M. arcuata.* It is rare in the Helderberg of New York, if it is found there at all, and it is not common in Tennessee.

In its small size and the emargination of the anterior outline *M. arcuata* var. *atoka* resembles *M. bella* Hall, but in that species the latter peculiarity is effected by a sinus occurring in both valves, which is not the case with *M. arcuata* var. *atoka.*

I suspect that this form may yet prove to be identical with *M. meeki*, although I am without characteristic specimens of the latter for comparison. Certainly the two possess some striking points of similarity, but aside from being much smaller I have never seen the high and peculiarly flattened beak represented in Hall's illustrations (Pal. New York, vol. 3, pl. 44, figs. 6*b*, 6*c*).

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

PLETHOSPIRA ? n. sp.

Pl. LXX, fig. 4*a*.

A description of this species will add but little to the figure of it given on Pl. LXX, fig. 4*a*. The shell is of medium size, rather gradually expanding; spire moderately high, consisting of four whorls. The single specimen obtained, which is incomplete at the base, has a height of 20 millimeters and a greatest diameter of about the same. The band, which is rather narrow, is situated peripherally, or just below that position, and the whorls appear to be ornamented only with lines of growth. The characters, so far as observed, seem to belong to the genus Plethospira, and this form has been provisionally placed with that genus. While undoubtedly a new species, or, at all events, new to this horizon (*Pleurotomaria labrosa* being an unrelated species), I do not feel justified in proposing for it a new name under the circumstance of rather insufficient data. It is evidently closely related to, and may be identical with, *Pleurotomaria rugulata* Hall of the Marcellus period.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

LOXONEMA ATTENUATUM Hall?

Loxonema attenuata Hall, 1859. Pal. New York, Vol. III, p. 296, Pl. LIV, fig. 8; Pl. LVII, fig. 3.

A single poorly preserved and otherwise imperfect gasteropod of the Loxonema type appears to belong to Hall's *L. attenuatum*. The specimen in question has a length of 54 millimeters and consists of 4 whorls. The specimen in general taper and size of the constituent whorls seems to agree closely with the upper Pentamerus species figured by Hall on pl. 67 (fig. 3) of Paleontology of New York, Vol. III.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

EUOMPHALUS n. sp.

As in the case of Plethospira sp., this form also is probably new, at least to the horizon; but I do not feel warranted to propose a new name for the imperfect specimen at hand. This has a diameter of 15.5 millimeters and consists of 4 very slightly expanding volutions, the outer one having a diameter of only about 4.5 millimeters. The upper surface of the specimen is plane, the spire being slightly elevated, or not at all, and the under side is slightly concave. Constituent whorls circular in section. This form presents many points of similarity to *Eu. sinuatus* Hall, but appears to be smaller and with the whorls more gradually expanding.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

MEGAMBONIA LATA Hall.

Pl. LXX, figs. 5*a*, 5*b*.

Megambonia lata Hall, 1859. Pal. New York, vol. 3, p. 277, pl. 50, fig. 4.

The essential characters of this species are shown by figs. 5*a*–5*b* of Pl. LXX. The specimen figured is seen to agree very closely in shape with Hall's figure of *M. lata* (Pal. New York, Vol. III, pl. 50, fig. 4), with which it has been provisionally identified. It is evidently very much smaller than the New York form, however. With it is associated a somewhat related type which may be designated *Megambonia lata* var.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

MEGAMBONIA LATA var.

This variety is distinguished by its regularly curved outline, which is somewhat transverse. The shape is in fact subcircular, slightly transverse; beak small, nearly central, slightly projecting; axis little if at all inclined to the hinge line. The outline is rather characteristic of Paracyclas than of Megambonia, but the primary generic features are undetermined.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

ORTHOCERAS RUDE Hall.

Orthoceras rudis Hall, 1859. Pal. New York, vol. 3, p. 346, pl. 72, figs. 4*a*, 4*b*.

Hall states that the septa in this species "are more distant and less convex than in *O. longicameratum*, and the shell more robust."[1] Specimens of both these species from the Helderberg region now before me show that this is a mistake, for *O. longicameratum* attains a size fully equal to that of *O. rude* and the septa appear to be no more convex. The essential difference I believe to lie in the length of the septa, which in *O. rude* are distinctly longer than in *O. longicameratum*. Specimens from Indian Territory appear to agree with typical individuals in this particular, affording the following measurements: Diameter, 26 millimeters; height of septa, 11 millimeters. Diameter, 19 millimeters; height of septa, 6 millimeters. These measurements, taken from different and imperfect specimens, show a certain range of variation, but all are proportionally greater than in *O. longicameratum*.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

DALMANITES PLEUROPTYX (Green).

Asaphus pleuroptyx Green, 1832. Mon. Trilobites of North America, p. 55, cast No. 18.

Dalmanites pleuroptyx and *D. micrurus* were described by Green in the same volume (Mon. Trilobites of North America, 1832, pp. 55, 56). The type of the former came from the Lower Helderberg group in the

[1] Pal. New York, vol. 3, p. 346.

Helderberg Mountains, New York; that of the latter was said to come from the limestone of Trenton Falls, but Hall has shown that it, too, is of Lower Helderberg age (Pal. New York, 1859, Vol. III, p. 357). Green did not compare the two species, but Hall redescribed and refigured them from much more abundant material and sought to distinguish them by certain differential characters, which he summarized as follows:

Until recently I had regarded the numerous specimens of the pygidium occurring in the pentamerus and shaly limestones of the Helderberg group as belonging to one species, presenting some variety in the number of annulations; but a comparison with the original specimen of *D. micrurus*, described by Dr. Green, shows that it has a more rigid aspect, is less curved outward, and is proportionately narrower on the posterior half of the pygidium, and the axis is proportionately longer and more rigid, while in specimens which have not suffered pressure the sides are more abruptly bent downward to the margins. These forms, whether large or small, have shown usually twenty articulations of the axis and fourteen or fifteen ribs in the lateral lobes, without any evidence of gradation in number which would unite the preceding species. (Hall, Pal. New York, 1859, Vol. III, p. 360.)

The following tables, based upon specimens from New York, Tennessee, and Indian Territory, will serve to indicate some of the variations which occur in the number of annulations borne by the axis and the pleura of various pygidia belonging to these species:

Variations in Dalmanites pleuroptyx and D. micrurus.

Size.	Locality.	Annulations on axis.	Annulations on pleura.
Medium	Tennessee	17	14
Large, broken	Tennessee	19	16
Large	Tennessee	18	15
Large	New York	*a* 18–19	16
Small	Indian Territory	15–16	13
Small	Indian Territory	16	11
Medium	Indian Territory	19	13
Medium	Indian Territory	20	17
Very small	Indian Territory	13	10
Very small	Indian Territory	15	9
Medium	Indian Territory	18	14
Medium	Indian Territory	16	12
Large	Indian Territory	20	15
Small	Indian Territory	16	11
Small	New York	19	14
Small	New York	18	14
Small	New York	*b* 18	14
Medium	New York	19	13
Small	New York	18	14
Rather small	New York	18	12

a Type of *D. micrurus*. *b* Type of *D. pleuroptyx*.

A careful study of all the available material of Green's two species of Dalmanites from the Lower Helderberg group has all but convinced me that both names were proposed for the same form.

The differential characters mentioned by Hall have already been quoted. These are not very striking in themselves, and become still less so when a series of specimens is compared. The surface ornamentation of all of the individuals examined is, so far as I can distinguish, exactly the same. The table just given shows the range of variation seen in the number of ribs present on the axis and pleura of the pygidium. This organ also shows variation in shape, some specimens being slenderer and more strongly arched, others proportionately broader and also flatter; but all the differences observed are not very great, even in extreme individuals, and they are connected by intermediate forms by insensible gradations.

It can not be urged that one of the species is, in fact, unrepresented among the collection studied, for it includes casts of both Green's types. Specimens from Indian Territory clearly indicate that the pointed end of the pygidium was really prolonged into a short spine, and the same character is indicated by the broken end of several Helderberg specimens, by Green's type of *D. micrurus*, and by several of Hall's figures. This caudal spine, while much less pronounced a feature than in *D. nasutus*, is at the same time stronger than I have ever seen the species credited with. The same structure occurs both in the long narrow type of pygidium and in the broader, flatter type.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

PHACOPS LOGANI Hall.

Phacops logani Hall, 1859. Pal. New York, vol. 3, p. 353, pl. 73, figs. 15–25.

This species is fairly well represented in our collections from Indian Territory, though it is less plentiful than *P. hudsonicus*. Both forms appear to be slightly undersized and do not reach quite the dimensions of some individuals from Tennessee and New York.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

PHACOPS HUDSONICUS Hall.

Pl. LXXI, figs. 4*a*–4*d*.

Phacops hudsonicus Hall, 1859. Pal. New York, Vol. III, p. 355, pl. 73, figs. 26–28.

It is interesting to note that this species, which in the collections of the New York State Survey was represented by a single head at the time the description was written, is quite plentiful in Indian Territory, being more largely represented than the accompanying form, *P. logani.*

In Tennessee *P. hudsonicus* is abundant, but slightly less so than *P. logani.* The quantity of material examined makes it possible to add some details to Hall's description which may be emended as follows:

Head semielliptical, varying somewhat in proportions but always transverse, the posterior angles extended and abruptly rounded. Cheeks triangular and produced behind.

Glabella subpentagonal; transverse, usually having the width $1\frac{1}{2}$ times as great as the length; tumid, produced, and covered with pustulose tubercles. The upper and middle furrows are faint, but the basal furrow is strong and deep. The basal lobe of the glabella strongly outlined by the basal furrow above, the occipital furrow below, and by the rapidly converging axial furrows. It is short, with a detached node at each extremity.

The occipital ring is strongly elevated, usually rising to a pointed node in the center and with two less distinct nodes at the sides.

The cheeks are triangular, more or less produced and rather abruptly rounded behind.

Eyes small, extending backward to the line of the basal furrow and with an elevation of four ranges of lenses.

The axis of the thorax is prominent and narrower than the lateral lobes, the annulations being furnished with a node at each extremity. The lateral lobes are nearly plane and horizontal toward the axis, but are abruptly bent downward a little less than half their length from the axis. Each pleura is grooved, the groove extending beyond the point of curvature.

The surface of the pygidium and thoracic segments is finely granulose, as is that of the cheeks of the cephalic shield, but the portions of the latter adjacent to the glabella, as well as the glabella itself, are raised into granulose pustules of several sizes.

This species is extremely close to *P. logani*, with which it is associated, and the only character which, to my knowledge, can be relied upon to distinguish them is the comparative size and number of facets in their eyes. As pointed out by Hall, the eyes of *P. hudsonicus* are smaller and possess fewer lenses than *P. logani.* The occipital ring of the latter species has usually a pointed pustule in the center. This character is never found in *P. logani*, so far as my experience goes, but, on the other hand, it is variable in *P. hudsonicus*, and I believe sometimes inconspicuous. Otherwise the two species seem to be in perfect agreement. The character of the eyes is scarcely one in which we would expect to see a sexual difference manifested, but possibly the existing difference is of that character. However, apparent facts of distribution would seem to oppose such an interpretation.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

Proetus protuberans Hall.

Proetus protuberans Hall, 1859. Pal. New York, Vol. III, p. 351, Pl. LXXIII, figs. 5–8.

A single fragment of limestone less than an inch in any diameter contains portions of three or four individuals of this species. All specimens are small, the heads being less than 8 millimeters in diameter and the other parts in proportion. Although so small, I believe this to be the form which Hall described under the above name, for all the points which I have been able to ascertain accord with his figures and description, to which I have nothing to add save evidence confirmatory of the hypothesis that the genal angles were prolonged into spines in entire specimens. Although not actually observed in my material, the character of the break and shape of the fractured surface leaves no doubt that this was the case.

Formation and locality.—Lower Helderberg period. Atoka quadrangle, T. 1 S., R. 8 E., Indian Territory.

LOWER COAL MEASURE (?) FOSSILS.

Campophyllum sp.

A single specimen represents this species. It has a diameter of about 16 millimeters, and is known only in cross section. There are in the neighborhood of 30 primary, and the same number of secondary, septa. The length of the primary septa is about half the radius of the section. The outer zone of vesicular tissue is about one-fourth of a radius thick. At about this point all the way around the interseptal tissue becomes denser and more regularly adjusted, so as to form a well-defined, dense, whitish ring. Through this the primary septa protrude and the secondary ones also for a short distance, both sets, like the ring, distinguished by being dense and opaquely white. The outer zone is finely vesicular, the median zone from the ring to the ends of the primary septa more loosely so, and the whole aseptate center filled with broad, tabulose vesicles. I am not quite sure that this is properly a Campophyllum, yet it approaches that genus.

Campophyllum torquium, like this form, has a fairly well-defined inner ring of sclerose tissue, and the interior is tabulate. The latter is, at all events, quite distinct specifically from the species mentioned.

Formation and locality.—Lower Coal Measures (?). Atoka quadrangle, western tier of sections in T. 1 S., R. 9 E. In bed A of Mr. Matthes's section (see Pl. LXIX).

Eupachycrinus sp.

A single specimen from bed A in the limestone ridge in the western tier of sections of T. 1 S., R. 9 E., seems to belong to the tuberculated group of Eupachycrinus which comprises *Eu. bassetti*, *Eu. tuberculatus*, *Eu. verrucosus*, *Eu. magister*, and *Eu. sphæralis*, all of the Upper Coal Measures. The specimen in question is much smaller than any of these species, and differs especially in the character of its surface ornamentation. The shape of the plates is exactly that of *Eu. verrucosus* White and St. John, as figured by Meek (Final Rep. U. S. Geol. Surv. Nebraska etc., 1871, p. 150, fig. 3). Only two of the anal plates are retained, but these also correspond in shape and position. The surface consists of suddenly elevated, high, and rather angular tubercles, which tend to be flattened and prolonged into angular ridges. This is especially true near the sutures, where the ridged character is pronounced. The ridges are directed at right angles to the suture line, and ridges of adjacent plates incline to correspond as if continuations; the sutures themselves are distinctly depressed, although not with a pronounced bevel.

Diameter, 18 millimeters; height, 8 millimeters.

Formation and locality.—Lower Coal Measures (?). Atoka quadangle, western tier of sections in T. 1 S., R. 9 E. In bed A of Mr. Matthes's section (see Pl. LXIX).

PRODUCTUS BURLINGTONENSIS Hall ?.

Productus flemingi var. *burlingtonensis* Hall, 1858. Geol. Surv. Iowa, Vol. I, pt. 2, p. 598, Pl. XII, figs. 3*a*, 3*g*.

There is but a single specimen of this species, which, however, shows a very close agreement, almost an exact identity, with typical *P. burlingtonensis.* The striæ are perhaps a trifle finer and the transverse wrinkles on the posterior portion slightly stronger, but I can not regard the two forms as more than varietally distinct, unless a more extensive series of better-preserved specimens reveals other dissimilar characteristics. Another very similar form which it also resembles is Meek's *P. multistriatus*, but the sinus is not so strongly expressed, and the cardinal angles, although broken and covered by closely adhering matrix, seem not to be auriculate, as in that species.

Formation and locality.—Lower Coal Measures (?). Atoka quadrangle, western tier of sections in T. 1 S., R. 9 E (See Pl. LXIX).

PRODUCTUS SEMIRETICULATUS (Martin) ?.

Anomites semireticulatus Martin, 1807. Petref. Derb., p. 7, Pl. XXXII, figs. 1, 2; Pl. XXXIII, fig. 4.

I have seen what appears to be exactly this form of Productus from the Osage group at Boonville, Missouri. It is a large shell, not high nor strongly arched, especially toward the anterior region, where it is nearly plane. The beak is small and projecting and the mode of growth attenuate. The longitudinal striæ are uneven and nodulose, as if by the bases of the numerous small spines, a condition which almost certainly obtained over the anterior portion. The transverse rugosities are fine and not restricted to the posterior region. Both sets of ornamentation are more or less irregular and weak, especially the transverse.

Formation and locality.—Lower Coal Measures (?). Atoka quadrangle, western tier of sections in T 1 S., R. 11 E (See Pl. LXIX).

UPPER COAL MEASURE FOSSILS.

EUPACHYCRINUS TUBERCULATUS Meek and Worthen?

Erisocrinus tuberculatus Meek and Worthen, 1865. Proc. Acad. Nat. Sci., Philadelphia, p. 150.

The single specimen which is provisionally referred to this species I have little doubt belongs to the group of tuberculated forms of Eupachycrinus which includes *Eu. bassetti*, *Eu. tuberculatus*, *Eu. verrucosus*, *Eu. magister*, and *Eu. sphæralis*, although if my specimen is normal and undistorted it probably can not be identified with any of the species just mentioned. Its salient characters are small size, shallowness of the calyx, strongly concave under surface, and character of its anal plate.

The diameter of the calyx is about 23 millimeters and its altitude about 7 millimeters. The column is small (about 2.5 millimeters) and the inferior side of the calyx so deeply and suddenly depressed to receive it that the under basals seem to have been almost upright. They are therefore almost out of sight when the calyx is viewed directly downward upon its under side.

The shape of these plates has not been made out. The basals are pentagonal, except one, which is hexagonal. Apparently only one anal plate was present, or, at all events, only one preserved. It is rectangular in form and placed vertically upon the horizontally truncated end of the hexagonal basal and between the lateral faces of two of the radials which abut upon it.

The surface is not well preserved, but seems to be covered with tubercles and to have had the sutures somewhat, though not strongly, beveled.

Although smaller than *Eupachycrinus tuberculatus*, and differing also in the more depressed under basals and the shape and position of the anal plate, it seems to resemble it in the disk-like shape of the calyx and in the character of the surface ornamentation.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, one-fourth mile or less west of Krebs Station, Indian Territory, on the Choctaw Railway.

LINGULA MYTILOIDES Sowerby ?

Lingula mytiloides Sowerby, 1813. Min. Conch., Vol. I, p. 55, Pl. XIX, figs. 1, 2.

I have little doubt that the form from Indian Territory is the common one figured by Meek and Worthen as *L. mytiloides* Sow. (Geol. Surv. Illinois, Vol. V, 1873, p. 572, pl. 25, figs. 2*a*, 2*c*). The material at hand is not very abundant nor well preserved, being frequently wrinkled and distorted through pressure. In size it is distinctly smaller than *L. mytiloides* of Meek and Worthen, though not very much so, and the proportions are the same. The largest specimen is 9 millimeters long. The shape likewise is similar to that illustrated by Meek and Worthen, the sides being more or less straight and parallel, the anterior end varying between subtruncate and more acutely rounded, while the posterior end in the dorsal valve is very blunt (as in Pl. XXV, figs. *2a*, *2b*), but more pointed in the ventral (fig. *2c*).

Meek suggests a comparison of this form with *L. umbonata* Cox, but if Cox's figure is at all correct, his is a very different form.

Formation and locality.—Upper Coal Measures. Atoka quadrangle, Hartshorne, Indian Territory, in the roof shale of the Grady or Hartshorne coal.

CHONETES MESOLOBUS Norwood and Pratten.

Chonetes mesoloba Norwood and Pratten, 1854. Jour. Acad. Nat. Sci., Philadelphia, Vol. III, p. 27, Pl. II, fig. 7.

This species is rather constantly present in the collections examined, both in the yellow sandstones, in the ferruginous concretionary shale where specimens are represented by casts, and in the other shales associated more or less closely with the coals, from which processes of weathering release free and almost perfect specimens. From the locality mine No. 6½, north of Lehigh, a large collection of this species was made. The average specimen has a width of 13 mm. and is strongly lobed. In the collection from near Krebs and elsewhere, especially in the sandy beds of the McAlester quadrangle, along with the strongly lobed, typical variety occurs one often somewhat larger, in which the lobation is less pronounced, often scarcely perceptible. In the case of the Krebs material, this is occasioned in some degree, at least, by a slight crushing which has caused the shell to split at the beak, and in some instances has thrust the high dorsal septum up through the shell of the ventral valve.

In the sandy beds the shell is represented by internal and external casts, and the valves are mostly detached. External casts, except in rare instances, appear to the eye quite smooth, the delicate surface characters not being retained by the somewhat coarse substance of the mold. Internal casts show the strongly pustulose character of the inner surface, which sometimes gives them an appearance as if striated. They also show, in the case of the ventral valve, the small septum in the rostral portion dividing the beak of the cast, and in the dorsal valve the thin and high, though short, median septum, developed chiefly anterior to the median point of the shell.

These larger shells, whose appearance in form of casts has just received comment, can not with certainty be referred to *Ch. mesolobus*, though they are associated with the typical form and seem to grade into it. The more or less complete obsolescence of lobation gives them a certain ambiguity of expression. Their obscured surface ornamentation and general shape suggest a comparison with *Ch. glaber*, but I believe that *Ch. glaber* has not the prominent dorsal septum of *Ch. mesolobus*, and of these specimens, while *Ch. granulifer* has a characteristic alate shape, although provided with the same arrangement of septa.

On the whole it seems that these shells can best be referred to *Ch. mesolobus*, while noting the variation from the normal type.

Formation and locality.—Upper Coal Measures. Atoka quadrangle, southwest corner sec. 4, T. 2 S., R. 11 E.; Atoka quadrangle, southwest lot of SW. ¼ sec. 4, T. 2 S., R. 11 E.; Cherryvale, Indian Territory, railway cut between the two mines, 50 feet below the McAlester coal; McAlester quadrangle, north side of Krebs, Indian Territory, about 50 feet below the McAlester coal; McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.; McAlester quadrangle, one-fourth mile or less west of Krebs, on the Choctaw Railway; mine No. 6½, north of Lehigh, Indian Territory.

RETICULARIA PERPLEXA (McChesney).

Pl. LXXII, fig. 1*a*.

Spirifer perplexus McChesney, 1860. Desc. New Pal. Foss., p. 43.

Some casts of the exterior of this shell in very fine ferruginous shale concretions show the surface ornamentation with great perfection. This consists of rather regular concentric rows of spines, the distance between the rows being of course progressively greater as the shell grows larger, except toward the front, where they are crowded together. Between these spiniferous rows are rounded concentric striæ, about 5 to 10 in each group, which are distinct only on the anterior half of the shell. The spines are of two sorts. The larger are hollow and double-barreled and distributed with considerable regularity in radiating and concentric rows. The smaller are exceedingly small, solid, supported by faint ridges entending forward from their bases and are situated in concentric rows just in front of the large double-barreled ones. There are usually three of these between two of the large spines, the central one being slightly posterior to the others, so that there might be said to be a double row of smaller spines. There is also often a spine of this sort intermediate between the groups of three just mentioned, corresponding in position to the alternate posterior one of each group, thus regularly completing the double series. In the condition of preservation observed the larger spines are represented by circles, or, better, by ovals longitudinally bisected, the smaller spines by simple perforations; and there is often seen a perforation of the same character, either at the anterior intersection of the axis and the circle, or even in the infilling of the spine itself. It is these perforations which I have interpreted as the missing alternate minor spines.

When studied with a high power there sometimes appear cavities, representing ridges, at all four axes of the tubular spines, but I am not convinced that these are not imperfections in the matrix which the higher power employed brings to the fore. Certainly the one at the anterior end of the median partition is much larger and more constantly present.

There is also a system of faint, rounded, radiating striæ which connects the bases of the large spines.

Formation and locality.—Upper Coal Measures. At a horizon 50 feet below the McAlester coal, in the McAlester quadrangle at Cherryvale, Indian Territory (railway cut between the two mines), and on the north side of Krebs, Indian Territory.

SPIRIFER ROCKYMONTANUS Marcou.

Spirifer rockymontani Marcou, 1858. Geology of North America, p. 50, Pl. VII, fig. 4.

A specimen from near Krebs, Indian Territory, shows the surface characters of this species very perfectly. This is seen to consist of fine concentric and radiating striæ superimposed upon the more obvious radiating ribs, and forming a beautifully regular sculpturing. The concentric striæ are lamellose and, if anything, slightly stronger than the radiating elements. The same scheme of ornamentation is seen in *Sp. striatiformis* of the Waverly group, where, however, it is more coarsely done.

This is quite different from the ornamentation of *Sp. cameratus*, where the surface is nearly smooth, the fine radiating striæ being almost absent and the concentric ones not so regular and lamellose, being altogether inconspicuous and partaking more of the nature of growth lines than of sculpturing strictly so called.

In the sandy layers this species attains a considerable size and presents a marked resemblance to *Sp. increbescens*, which has like superficial characters.

Formation and locality.—Upper Coal Measures. McAlester quadrangle. sec. 19, T. 2 N., R. 13 E.; Atoka quadrangle, southwest $\frac{1}{4}$ of SW. $\frac{1}{4}$ sec. 4, T. 2 S., R. 11 E.; McAlester quadrangle, north side of Krebs, Indian Territory, about 50 feet below the McAlester coal.

AVICULOPECTEN OCCIDENTALIS (Shumard).

Pecten occidentalis Shumard, 1855. Geol. Rept. Missouri, p. 207, Pl. C, fig. 16.

This species occurs in several of the localities represented in our collections and is usually abundant. It exhibits considerable variety in form from rather broad to narrow individuals, while retaining essential characters unchanged.

The form from Indian Territory is identical with one occurring in Saline County, Illinois, identified by Worthen as *A. clevelandicus*, a species which Meek regards as a synonym for *A. occidentalis*. Though of the same shape, this form shows distinctly finer ribbing than one from near Atchison, Kansas, with which comparison has been made.

Meek states that this species is not oblique,[1] and certainly his figures

[1] Final Rep. U. S. Geol. Surv. Nebraska, etc., 1872, p. 191.

are consistent with this observation. Upon this point Shumard is noncommittal in both description and figures.

The fossils under discussion are distinctly, though not strongly, oblique.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E. (small and not very plentiful); McAlester quadrangle, southeast ¼ of NE. ¼ sec. 11, T. 2 N., R. 12 E.; Atoka quadrangle, southwest ¼ of SW. ¼ sec. 4, T. 2 S., R. 11 E.; McAlester quadrangle, north side of Krebs, Indian Territory, about 50 feet below the McAlester coal; Atoka quadrangle, north side sec. 36, T. 1 S., R. 10 E.

AVICULOPECTEN? WHITEI Meek.

Aviculopecten whitei Meek, 1872. Final Rept. U. S. Geol. Surv. Nebraska, etc., p. 195, Pl. IV, figs. 11*a*, 11*c*.

Two specimens, each from a different locality, though somewhat crushed, can with some certainty be referred to this species.

Formation and locality.—Upper Coal Measures. Cherryvale, Indian Territory, railway cut midway between the two mines and at horizon 50 feet below the McAlester coal; McAlester, Indian Territory, roof of McAlester coal.

PINNA PERACUTA Shumard.

Pinna peracuta Shumard, 1858. Trans. St. Louis Acad. Sci., Vol. I, p. 214.

Placed at a disadvantage by the poor state of preservation of the pinnalike form which is found with some frequency in this collection, and misled by the small size of most of the individuals, I was at first disposed to place the fossils under discussion with Meek's *Aviculopinna americana.* Though distinctly larger than *A. americana*, as it is represented in Nebraska (Meek notes 1.35 inches as the length of his specimens—Final Rept. U. S. Geol. Surv. Nebraska etc., 1872, p. 197), specimens from Ohio attain a size of 2.03 inches. In addition, the hinge characters of my specimens are certainly the same as those of *A. americana.* This feature Meek describes as a "well-defined ridge along the dorsal margin" (op. cit., p. 197). As seen on internal casts, the hinge structure, which appears to be the same in both valves, consists of a pair of parallel grooves very close together, the outer one constituting in effect the outline of the shell. Meek evidently had in mind the inner groove, which in the shell itself would of course be represented by a ridge. What I believe to be the actual condition is a groove with somewhat raised edges, the outer one being the edge of the shell. The inner groove (in the cast) is not persistent, but vanishes short of the posterior end.

I have not been able to discover the minute anterior lobe of Aviculopinna, although this might easily be referred to the unfavorable preservation in a somewhat sandy matrix, and the surface, instead of being traversed by the regular lamellose striæ of *A. americana*, shows much fainter markings, like those of *Pinna peracuta*, with which also the divergence of the basal and cardinal margins is in accord.

As *Pinna peracuta* is known to occur in these same beds (collected by Mr. Vaughn in 1897), it seems more probable that these are young or dwarfed examples of that species.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.; Atoka quadrangle, southwest $\frac{1}{4}$, SW. $\frac{1}{4}$ sec. 4, T. 2 S., R. 11 E.

EDMONDIA SUBTRUNCATA Meek?

Edmondia subtruncata Meek, 1872. Final Rep. U. S. Geol. Surv. Nebraska etc., p. 215, Pl. II, fig. 7.

This species is known from the yellow sandstones near Lehigh, Indian Territory, having been collected there by Mr. Vaughn in 1896.

From the Atoka quadrangle, southwest corner sec. 4, T. 2 S., R. 11 E., and from southwest $\frac{1}{4}$ of SW. $\frac{1}{4}$ sec. 4, T. 2 S., R. 11 E., a few small Edmondias have been sent in, which are probably immature specimens of the same species.

At first I was inclined to consider the smaller specimens (no large individuals occur in the more recent collections) as representing *Edmondia geinitzi* Meek,[1] but certainly young examples of *E. subtruncata* would be indistinguishable from them. Indeed, I am not certain but that *E. geinitzi* itself, of which the specimen illustrated is not wholly characteristic and the drawing not quite true to the specimen, is founded upon young specimens of *E. subtruncata*.

In the existing states of preservation a comparison between these small specimens of *E. subtruncata* and typical *E. geinitzi* is difficult. The former, represented by internal casts, seems to be covered by heavy, almost imbricating, concentric corrugations which are regular and equal, and those upon the outside (as seen by casts of the exterior) are represented by heavy, lamellose, concentric ridges. Meek's figure of *E. geinitzi* shows well the character of the surface, which seems to consist of sharp, thin, equidistant, concentric ridges. The preservation of these fossils which occur in the fine clay shales of Division C, Nebraska City, is of the sort where the original shell substance is reduced by maceration to a mere plane of cleavage, and the external and internal casts, brought thus into contact, have taken on a somewhat common character. I would judge that the surface of these small specimens of *E. subtruncata* was different from that of *E. geinitzi*.

Formation and locality.—Upper Coal Measures. Atoka quadrangle, southwest $\frac{1}{4}$, SW. $\frac{1}{4}$ sec. 4, T. 2 S., R. 11 E.

[1] Final Rept. U. S. Geol. Surv. Nebraska, etc., 1872, p. 215, Pl. X, fig. 8a. Proposed in reversion for a small shell provisionally identified as *Edmondia? nebraskaensis* Geinitz.

NUCULANA ARATA (Hall).

Nucula arata Hall, 1852. Stansbury's Exped. Gt. Salt Lake, Utah, p. 413, Pl. II, figs. 5*a*, 5*b*.

The species found in Indian Territory differs from *Nuculana bellistriata* in several important particulars. It is somewhat more attenuate, with the umbones usually more central. The posterior lunette is depressed, with its surface consequently more nearly horizontal, and it is bounded laterally by a sharp angulation. The surface is marked by numerous rigid, angular striae, about 3 in the space of 1 mm., separated by shallow, rounded grooves, wider than the ridges between which they stand. These characters, ascertained from better preserved material recently collected, make it probable that this form belongs with *N. arata* rather than with *N. bellistriata* var. *attenuata* to which, on account of its more slender shape, I originally referred it.

It might be added that this species also seems to have a larger number of teeth than the *N. bellistriata*, which Stevens describes as having "about 25 teeth, 5 of which are smaller than the others and clustered under the beaks."

In specimens from Indian Territory I have counted 14 or 15 in front of the beak and 18 or 19 behind it, and just under the beak, where the teeth become more crowded, there must be 5 to 10 not included in these counts, which are obtained from specimens measuring about 17.5 millimeters in length.

I should feel no surprise if White's *N. obesa* should prove to be a synonym of *N. arata* Hall.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.; Atoka quadrangle, southwest corner sec. 4, T. 2 S., R. 11 E.; Atoka quadrangle, southwest ¼ of SW. ¼ sec. 4, T. 2 S., R. 11 E.

SCHIZODUS King.

This genus is on the whole plentifully represented in the collections under discussion and presents a perplexing series of forms. I have distinguished five different species among them, two of which are referred to species already known, but the others, perhaps unwisely, have been described as new. Two of these are represented by single specimens of quite unique shapes; the other is more plentifully represented, though still rare. It is comparatively easy to recognize these five forms among the specimens studied, as they are fairly constant and seem not to intergrade to any extent. The specimens from the shales (chiefly the roofing shales of coals) have proved more difficult to handle and are unsatisfactory, because they are all either crushed or imperfect, so that it is a delicate matter to estimate their original shape. Although I have identified them with species found elsewhere in the collection, it is not impossible that they should go to some of the other known forms.

SCHIZODUS SUBCIRCULARIS Herrick.

Pl. LXXII, fig. 8*a*.

Schizodus subcircularis Herrick, 1887. Bull. Sci. Lab. Denison Univ., Vol. II, p. 41, Pl. IV, fig. 24.

Two or three specimens from the McAlester quadrangle agree almost exactly with Herrick's figure of this species. They are associated with *Sch. affinis* Herrick, of which I can regard it as no more than a distinct variety, if so much. Nevertheless, until the examination of more extensive material shall afford conclusive evidence upon this point, I use Herrick's name.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, line between secs. 24 and 25, T. 5 N, R. 12 E.

SCHIZODUS AFFINIS Herrick.

Pl. LXXII, figs. 4*a*–4*f*.

Schizodus affinis Herrick, 1887. Bull. Sci. Lab. Denison Univ., Vol. II, p. 41, Pl. IV, figs. 22, 22*a*.

As far as can be told from the figures given by the two authors, *Schizodus affinis* of Herrick is founded upon the same form which Meek identified in 1873 (Geol. Surv, Illinois, Vol. V, Pl. XXVI, figs. 17*a*–17*e* and fig. 18) as *Schizodus rossicus* de Verneuil. The resemblance is most striking between his figure 18 and Herrick's figures.

In our collections this species is represented most abundantly from the McAlester quadrangle (line between secs. 24 and 25, T. 5 N., R. 12 E.), where it is quite common and constant in all its characters. It is there associated with *Sch. subcircularis* Herrick which seems to be a mere variety of the above.

It occurs at several other localities also, but more sparingly and sometimes becomes more transversely elongate, so tending to pass over into *Schizodus meekanus*. It is associated with the latter species at these localities, but never attains quite the same proportions, although as both forms are rather rare a more complete collection may show that they intergrade.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, line between secs. 24 and 25, T. 5 N., R. 12 E; Atoka quadrangle, southwest corner sec. 4, T. 2 S. 11 E. (rare). McAlester quadrangle, sec. 19, T. 2 N., R. 13 E. (small and rare). Near Lehigh, Choctaw Nation, Indian Territory, about ½ mile south of Coal Creek, east of railroad (rather abundant). Atoka quadrangle, in the roof of the Lehigh coal at north side sec. 36, T. 1 S., R. 10 E., and in sec. 11, T. 1 S., R. 10 E.

SCHIZODUS TELLINIFORMIS n. sp.

Pl. LXXII, fig. 6*a*.

Shell of medium size, about 1½ times as wide as it is high, subtriangular; beak subcentral, sharp, prominent; inferior margin gently curved, posterior extremity acutely rounded, anterior extremity more blunt; line from the beak to the posterior angle nearly straight. The shape of this shell is quite unique for the genus, but could be easily derived from *Sch. meekanus*, of which it is perhaps only a variety, by supposing the hinge line and the truncating posterior slope so inclined toward each other as to become coincident in direction.

Formation and locality.—Upper Coal Measures. McAlester quadrangle. Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.

SCHIZODUS PANDATUS n. sp.

Pl. LXXII, fig. 5*a*.

Shell of medium size, somewhat resembling a Leda in shape; beak subcentral; inferior margin strongly curved; anterior outline nearly semicircular, posterior outline sharply rounded, straight above. The inferior outline is so strongly curved as to bring the point of greatest diameter about halfway up the shell. The characteristic truncation is thus thrown into a nearly horizontal direction and but little inclined from the hinge line.

This species much resembles the type specimen of *Sch. wheeleri* as figured by Meek, and also a form figured by him as Schizodus sp. (Final Rep. U. S. Geol. Surv. Nebraska, etc., 1872, Pl. X, fig. 1*b*, and p. 210, Pl. X, fig. 2, respectively.) It differs from both in much the same characters having the beak more central, being more transverse, less truncated, and without a diagonal angulation.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.

SCHIZODUS MEEKANUS n. sp.

Pl. LXXII, fig. 7*a*–7*c*

Schizodus wheeleri Meek, 1871 (pars). Final Rep. U. S. Geol. Surv. Nebraska etc., p. 209, Pl. X, figs. 1*e*, 1*f*.

Schizodus wheeleri Keyes, 1894 (pars). Missouri Geol. Surv., Vol. V, Paleontology of Missouri, Pt. II, p. 123, Pl. XLVI, figs. 3*a*, 3*b*.

Shell medium sized to very large, transverse; hinge line straight, scarcely less than half the width of the shell, converging with the inferior margin which is gently curved; posterior end truncated at an angle of about 60° with the basal margin; beak prominent, about one-half the distance back from the anterior margin; anterior end strongly rounded.

This form is not common in the collections studied, but seems to be well characterized. It is fairly constant in character and is probably the same species as that figured by Meek as *Sch. wheeleri*, and afterward by Keyes as above cited. Meek himself seems to have been in some doubt as to the identity of this form with *Sch. wheeleri*, and a comparison of the figures given by him and by Keyes with those of the typical specimen of *Sch. wheeleri* (Meek, 1871, op. cit., Pl. X, fig. 1*b*) shows certain marked differences. When I compare *Schizodus meekanus* from Indian Territory with that figure, I find that the former is larger and more transverse, the beaks larger and more prominent, and the inferior margin straighter. This material also differs from the figures of Meek and Keyes, who evidently drew from the same specimens (figures cited above and referred to this species), in being still more transverse with the beak perhaps a trifle more central.

Since the foregoing lines were written there has come to hand the description of *Schizodus insignis* Drake[1] from strata identified as Permian, 5 miles east of McDermott, Indian Territory. It is possible that *Sch. meekanus* will prove to be a synonym for Mr. Drake's species with which the incompleteness of the type specimen renders a decisive comparison difficult. Although its whole posterior outline is missing, some estimate of its transverse extension may be derived from the fact that the major portion of the posterior muscle scar is shown on the figure. The outline of this portion of the shell, however, still remains in doubt. From its size and probable proportions, however, I suspect that *Sch. insignis* may ultimately take precedence over *Sch. meekanus*, or at least a portion of that species, for I am not wholly satisfied that the large example figured should be included with the type.

As there is some doubt about the true shape of *P. insignis*, and as it also is supposed to belong to a somewhat later age than that to which I have referred my specimens, I retain *Sch. meekanus* until subsequent investigation.

Formation and locality.—Upper Coal Measures, near Lehigh, Indian Territory, about one-half mile south of Coal Creek, east of the railroad; Atoka quadrangle, southwest ¼, SW. ¼ sec. 4, T. 2 S., R. 11 E.; Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.; Atoka quadrangle, north side sec. 36, T. 1 S., R. 10 E. (roof of Lehigh coal); Atoka quadrangle, sec. 11, T. 1 S., R. 10 E.

PLEUROPHORUS TAFFI n. sp.

Pl. LXXII, figs. 2*a*–2*c*.

Shell rather large, transversely elongate, very inequilateral. Width about two and one-half times the greatest length, sometimes a little more, sometimes a little less. Distance of the beak from the anterior end about two-thirds the length of the shell. Hinge line straight, about two-thirds the entire width of the shell. Inferior margin straight or nearly so and parallel with the hinge line, or slightly diverging posteri-

[1] Geol. reconnaissance of the coal fields of Indian Territory: Proc. Amer. Phil. Soc., vol. 36, No. 156, p. 402, pl. 9, fig. 7.

orly. Posterior edge subrectilinear, truncating the shell at an angle of about 45° or a little more. Superior posterior junction angular; rounded below. Anterior end, lobe-like. Convexity, moderate. There is a constant, oblique ridge running from the umbones to the posterior inferior angle, and just in front of it is a shallow, undefined sinus. Anterior scar large, strongly defined, about half way up the shell and a little in front of the beak. Just above and a little posterior to this is a small accessory scar. Pallial line and posterior scar not observed.

I have not been able to make out that either valve of this species had any cardinal teeth, but in the left valve there is usually to be seen the groove of a posterior lateral tooth parallel to the hinge line. This is quite strong posteriorly, but disappears toward the beak. The tooth corresponding to this in the opposite valve I have not with certainty observed.

This form belongs to a group of shells commonly referred to Pleurophorus, but I think it more likely that some of them should be placed under Sanguinolites.

The nearly parallel upper and lower margins, strongly truncate posterior outline, and absence of radiating ridges distinguish it from most of the North American members of Pleurophorus. Perhaps the nearest is *P. angulatus* Meek and Worthern, but that species is much smaller, is less distinctly and less obliquely truncated, and has the beak more terminal. *P. tropidophorus* bears some resemblance also, but is less elongated, less obliquely truncated, and has two radiating ribs above the oblique ridge. Comparison can be likewise made with *P. subcostatus*, but that also is faintly costate, has the beak more terminal, and the posterior outline rounded, not truncate.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.; Atoka quadrangle, southwest ¼ SW. ¼ sec. 4, T. 2 S., R. 11 E.; McAlester quadrangle, line between sections 24 and 25, T. 5 N., R. 12 E.; Atoka quadrangle, north side sec. 36, T. 1 S., R. 10 E. (roof of Lehigh coal).

EDMONDIA? REFLEXA Meek.

Pl. LXXII, figs. 3*a*–3*c*.

Edmondia reflexa Meek, 1872. Final Rept. U. S. Geol. Surv. Nebraska, etc., p. 213, Pl. X, figs. 6*a*, 6*b*, Pl. IV, fig. 7?.

While not really very rare, the shell here provisionally referred to Meek's species is one of the less common types in the Coal Measure sandstones of this area. It is intermediate in size between the typical *E. reflexa* and the form which Meek doubtfully refers to that species, and figures on Pl. IV, fig. 7, of Final Rept. U. S. Geol. Surv. Nebraska, etc., 1872.

It may be described in the following terms: Shell of medium size, transverse, elliptical; beak posterior to the anterior end by about one-quarter the width of the shell; superior and inferior margins nearly rectilinear and parallel; posterior extremity symmetrically rounded; anterior extremity somewhat less so, being slightly flattened above and drawn back under the beak, which is neither large nor prominent; curvature rather strong, surface smooth except for concentric lines of growth; anterior end usually more or less reflexed.

In the left valve, beneath the beak, is a small but deep groove directed forward, which I suppose separated two cardinal teeth. The right valve also seems to have the same structure, so that there appear to have been a pair of interlocking cardinal teeth in each valve. Similarly in both valves a strong, well-developed plate was present, projecting inward from the hinge and parallel to the plane of the valves. In internal casts the groove left by this structure begins just behind the beak and the cardinal teeth with a backward slope away from the cardinal line. Then it turns so as to be parallel with the latter and becomes very deep, continuing so to about the middle of the shell, after which it is gradually evanescent. The position of these plates seems to make it impossible that they could have interlocked in any way, thus serving the function of lateral teeth; it is more probable that the cavity between them contained a powerful internal ligament.

One specimen (Pl. LXXII, fig. 3*c*) shows distinctly the scar of a large anterior adductor, and above and a little posterior to it another scar, possibly of an accessory adductor.

The description of structural characters which has just been attempted has been founded upon examinations of internal casts, so that the hinge teeth ascribed to this shell may be partially erroneous. The feature preserved in each valve is a small ridge, representing a groove in the shell itself, which begins just in front of the beak and slants forward, upon each side of which appear to be small depressions below the general level of the hinge line.

Width of mature specimen, 22 millimeters; length, about 11 millimeters.

I have little doubt that these shells really belong to *Edmondia? reflexa* Meek. Although considerably larger than the typical specimens from Nebraska City, I have noticed that much of the material from Division C appears to be more or less dwarfed. The type specimen is somewhat more attenuate in the outline of the posterior end than other specimens associated with it, which agree with the material from Indian Territory in being broadly rounded and elliptical in shape.

It is possible that this is the species described by Herrick (Bull. Denison Univ., Vol. II, 1887, p. 30, Pl. IV, fig. 9) as *Solenomya Meekana.* Herrick thinks his shell is identical with *Edmondia reflexa* ? Meek (U. S. Geol. Surv. Nebraska etc., Pl. IV, fig. 7), and distinct from the real *E. reflexa* of the same publication. I agree with him and with Meek in doubting the identity of the specimen figured on plate 4 with typical *E. reflexa*, but Herrick's shell (Pl. IV, fig. 9) is closer in resemblance to *E. reflexa*, it seems to me, than to the doubtful form, which more nearly resembles Herrick's *Solenomya anadontoides* Meek, though they may not be the same. Herrick's figure of *S. anadontoides* (loc. cit., Pl. IV, fig. 10) is very unlike Meek's figure of the type (Geol. Surv. Ohio, Paleontology, Vol. II, 1875, Pl. XIX, fig. 11), and resembles more closely *Solenomya soleniformis* Cox, with which Meek's *Edmondia reflexa* ? should also be compared. I suspect that *Solenomya anadontoides* Meek may be the same as *S. fragilis* Cox; of this, however, I have no proof, aside from the figures and descriptions of the respective authors.

Solenomya Meekana Herrick differs from *Edmondia reflexa* ? of Meek in being proportionally broader for its length, as it is over twice as broad as long, while the latter is considerably less than twice as broad as long. The beaks appear to be more terminal, though the position of the beaks is not distinctly shown in Herrick's figure, while *E. reflexa* ? has a reflexed margin, a character not shown by the latter.

From the structural characters described it will appear that this species has many points in common with *Pleurophorus taffi*, so as to suggest that the two forms may be congeneric. There can be no question of their specific independence. It will be noticed at a glance that *E. ? reflexa* lacks the distinct angulation extending from the umbo to the inferior posterior angle which seems characteristic of the type of shells to which *P. taffi* belongs. It has two anterior muscle scars, similar in character and position to those of *P. taffi*, but they are situated so high that the smaller and more posterior is almost under the umbo. The cardinal ridge posterior to the beaks in *E. ? reflexa* is nearly parallel to the plane of the valve, and probably served to sustain a long internal cartilage, while that of *P. taffi* is more nearly perpendicular to the plane of the valves, and probably served as a lateral tooth. In the former the plate was most strongly developed cardinally, while in the latter the strongest development is posterior.

The reflexed anterior margin of *E. ? reflexa* is also indicative of different affinities from *P. taffi*.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.; Atoka quadrangle, southwest ¼ SW. ¼, sec. 4, T. 2 S., R. 11 E.; Atoka quadrangle, Lehigh, Indian Territory, mine No. 5, roof of coal.

SOLENOMYA sp.

This form is possibly the one figured by Meek (Final Rep. U. S. Geol. Surv. Nebraska etc., 1872, Pl. II, figs. 12*a*, 12*b*), which it closely resembles. Plentiful in the roof shale of the Lehigh coal, north side of sec. 36, T. 1 S., R. 10 E., Atoka quadrangle, and represented by a single specimen from Boggy Creek, on the line between secs. 23 and 24, T. 2 N., R. 11 E., McAlester quadrangle.

Formation and locality.—Upper Coal Measures.

MURCHISONIA MARCOUIANA Geinitz.

Murchisonia marcouiana Geinitz, 1866. Carbonformation und Dyas in Nebraska, p. 7, Pl. I, fig. 12.

Shell small, elongate, 8 to 10 volutions, each of which is sharply angulated proximally about one-third the distance from the nearest suture line; above and below this angulation the volution presents a flat or slightly concave surface. The reentrant character of the portion below the angulation is sometimes so pronounced that it is almost quadrate, the upper surface being nearly horizontal and the lower nearly vertical. Less than half the distance below the angulation occurs a thread-like revolving ridge.

Length, about 13 millimeters; diameter of final volution, about 6 millimeters.

If this shell possesses a band at all it is situated upon the peripheral angulation, but I believe that it did not possess this structure. On this account I have left the species with Murchisonia, for while the shells commonly referred to Murchisonia are characterized by the possession of a band and aperturial slit, Ulrich has shown some reason for believing that the typical species of Murchisonia was not a member of the Pleurotomaridæ (Geol. and Nat. Hist. Surv. Minnesota, Vol. III, Pt. II, 1897, pp. 159–160). While *M. marcouiana* may belong to the genus Orthonema to which Meek has shown another of Geinitz's Murchisonias to belong, it seems best, under the new, restricted, and proper meaning of the name Murchisonia, to leave this species with the genus in which Geinitz placed it.

It is with some confidence that my material is referred to *M. marcouiana*, with which it agrees in almost every character which it has been possible to ascertain.

Comparison in the shape of the shell and the outline of the volutions is invited by *Murchisonia terebra* of White, but the ornamentation is quite different.

Formation and locality.—Upper Coal Measures. McAlester quadrangle, sec. 19, T. 2 N., R. 13 E.

STEAROCERAS GIBBOSUM Hyatt.

A single ill-preserved and imperfect specimen which, so far as its characters can be ascertained, seems to agree with *Stearoceras gibbosum* of Hyatt.

The specimen is young or imperfect, probably both, as it is considerably smaller than Hyatt's types. The greatest diameter, 83 millimeters; greatest width of the final whorl, 51 millimeters; height of same, 38 millimeters; diameter of umbilicus, 17 millimeters.

Formation and locality.—Upper Coal Measures. Atoka quadrangle, center of east side of sec. 10, T. 2 S, R. 10 E., from shale associated with coal.

BELLEROPHONTACEA.

In considering the material presented for identification it became necessary to pass in review all the known Coal Measure species, a confusing task, the results of which it seemed would not be valueless if put in permanent form. A considerable portion of the ground had already been covered by Ulrich, whose classification has been followed except in a few minor details. This consists, I believe, wholly in transferring *Bellerophon kansasensis* from Bucanopsis to Patellostium. I have, moreover, considered all the Upper Carboniferous Bellerophons, aggregating at present 23 species, referred them to what appear their proper genera, and discussed briefly their specific relationships. They can all be placed with the Bellerophontidæ and in the four genera, Bellerophon, Bucanopsis, Patellostium, and Euphemopsis.

PATELLOSTIUM.

To this genus may probably be referred *P. kansasensis* Shumard, *P. rugopleurus* Gurley, *P. nodocostatum* Gurley, *P. textiliforme* Gurley, *P. montfortianum* Norwood and Pratten, and perhaps also *P. ourayense* of Gurley. *P. rugopleurus* and *P. kansasensis* can be distinguished from the other species mentioned by having the mesial band depressed. *P. rugopleurus* (Gurley, 1884, New Carboniferous Foss., Bull. No. 2, p. 11) is marked by numerous more or less prominent transverse costæ, but is without longitudinal striæ, except for faint traces of fine ones, "which are for the most part obsolete upon the transverse costæ along the body of the shell, but are quite distinct where they cross the transverse furrows between the more prominent ridges." This species appears to be related to *P. montfortianum*, and at the same time, by reason of its obsolescent revolving ornamentation, to connect Patellostium with Bellerophon (sensu stricto). *P. kansasensis* (Shumard, 1858, Trans. St. Louis Acad. Sci., Vol. I, p. 204) has from 22 to 24 transverse ribs which are decussated by from 10 to 12 revolving lines on each side. This, together with other characters, seems to distinguish it readily from *P. rugopleurus*. In *P. rugopleurus* the transverse furrows become obsolete over the mesial band, which is not the case with *P. kansasense*.

P. montfortianum stands by itself in this group. As is well known, its surface is traversed by regularly unequal, often alternating, fine revolving striæ, and by strong transverse undulations, some 9 to 12 or more in number. The mesial band is really raised, but the transverse rugosities are elevated into a double row of inclosing nodes, which make it appear as if depressed.

P. nodocostatum and *P. textiliforme* have elevated mesial bands or carinæ which distinguish them from *P. kansasensis*, etc. *P. nodocostatum* (Gurley, 1884, New Carboniferous Foss., Bull. No. 2, p. 9) has about nine fine revolving striæ on each side (increasing by implanation), crossed by regular prominent transverse costæ, traversing the raised (?) mesial band in a thin, sharp ridge and giving the surface a cancellated appearance. *P. textiliforme* of the same author (op. cit., Bull. No. 1, 1883, p. 6) appears to be much the same type of shell as *P. nodocostatum*, but has about 15 longitudinal striæ, and the transverse striæ become obsolete over the raised mesial band.

While *P. kansasense* and *P. rugopleurus* are similar in having the mesial band depressed, and differ from *P. nodocostatum* and *P. textiliforme*, which have the mesial band elevated, *P. kansasensis* and *P. nodocostatum* are alike in having the transverse costæ continuous over the mesial band, while in *P. rugopleurus* and *P. textiliforme* these are obsolete and discontinuous. Thus a sort of decussating classification is formed. However, the description of *P. nodocostatus* is so similar to that of *P. kansasensis* as to lead to the impression that the two may be the same species, and that the elevation or the depression of the mesial band is not a constant character, and not a proper fundamentum divisionis. Indeed, Gurley does not state definitely whether the mesial band is raised or depressed in *P. nodocostatum*. A similar agreement can not be traced between *P. rugopleurus* and *P. textiliforme*.

Without specimens and without figures of *Bellerophon ourayensis* of Gurley it is very difficult to refer it correctly. It seems to agree with Patellostium in having the longitudinal and transverse factors nearly equal, but approaches Bucanopsis in having the former very fine, but a little coarser than in *B. marcouiana*. On the other hand, it presents relations with Euphemus by the sparse character of its revolving striæ and its thread-like keel, which is little more than a revolving stria. It is, however, entirely possible that I am mistaken in placing it here, and that it should be referred to Bucanopsis.

PATELLOSTIUM NODOCOSTATUM (Gurley).

Bellerophon nodocostatus Gurley, 1884. New Carboniferous Fossils, Bull. No. 2, p. 9.
Bellerophon bellus Keyes, 1894. Missouri Geol. Surv., Vol. V; Paleontology of Missouri, pt. 12, p. 148, pl. 50, fig. 7.

Among the material submitted to me for identification is a rather abundant Bellerophon which, so far it is possible to determine, is identical with some better-preserved specimens from the Mississippi Valley. The latter can, with little doubt, be correctly referred to *Bellerophon bellus* of Keyes, which, in turn, I believe to be identical with *B. nodocostatus* Gurley.

The specimens at hand show some few additional details which can be added to the description, derived from the well-preserved material from the Mississippi Valley.

As described by others, the umbilici are open, with a tendency to be veiled by the reflexed lip which is extended across the inner portion of the final volution in the form of a thick deposit concealing the surface ornamentation at this point. This feature consists of 8 to 10 strong revolving striæ on each side crossed by equally strong transverse striæ, of which there must be 25 to 30, exclusive of those concealed by the deposition above mentioned. The revolving and transverse ornamentation is regular and of similar measurement, giving the surface a cancellated surface, the points of intersection of the two series being nodose. Other very fine revolving lines, 2 to 5 in number, can be made out with a magnifier on well-preserved specimens between the more obvious lines. Similarly, fine transverse lines can be seen between the prominent transverse ribs, but still finer than the fine longitudinal lines. The keel, to which the transverse ridges give a nodose appearance, is thin and not very high. By a slight backward bend in the groove by which the keel is bounded, the nodes on the keel are often brought opposite the grooves on the sides, but the number and spacing of the mesial nodes and lateral grooves is not quite the same, so that there is no consistency on this point, even in the same specimen.

The grooves bounding the mesial ridge are rather broad and deep and not traversed by the transverse ridges. The mesial ridge itself is bounded by a delicate thread-like revolving stria on each side.

Toward the front on full-grown shells the transverse ridges lose their strength and regularity, degenerating into more or less crowded strong growth lines.

This tendency is seen much earlier on the mesial band, which becomes slightly depressed (?), marked off by stronger thread-like revolving striæ and crossed by more or less crowded unequal ridges resembling strong growth lines.

From Keyes's description and figure I have no doubt that my material belongs to his *B. bellus*, and at the same time a careful study of Gurley's description of *B. nodocostatus* leads more and more to the belief that he had the same form under investigation.

Formation and locality.—Upper Coal Measures. Atoka quadrangle, southwest ¼, SW. ¼, sec. 4, T. 2 S., R. 11 E.

BUCANOPSIS.

To this genus belong in all probability *B. elliptica* McChesney, *B. meekana* Swallow, *B. perlata* Conrad, *B. marcouiana* Geinitz, and *B. tenuilineata* Gurley.

These may be roughly grouped into *B. elliptica* and *B. meekana*, where a carina is developed only toward the aperture; *B. perlata* and *B. marcouiana*, which are persistently carinate, and *B. tenuilineata*, where the mesial band is a depressed groove.

B. meekana is described as broadly rounded on the dorsal margin, carinated near the aperture, ornamented with fine, crowded longitudinal striæ, and very minute transverse lines (Swallow, 1858, Trans. St. Louis Acad. Sci., Vol. I, p. 204). McChesney's species appears from his description to be closely related to this, though much smaller. He gives detail concerning the sculpture of the outer surface not mentioned by Swallow. It seems highly probable that fig. 2 of Pl. III (Trans. Chicago Acad. Sci., Vol. I, 1860, p. 58) represents a different species from fig. 1, which may be taken as the type.

Conrad describes *B. perlata* thus, briefly: "Globose, with fine longitudinal lines; back obtusely carinated; aperture profoundly dilated" (Jour. Acad. Nat. Sci. Philadelphia, vol. 8, p. 270). This certainly answers in every way to *B. marcouiana*, and, indeed, in a manuscript note to Meek's copy of Carbon. und Dyas in Nebraska, I find expression of a suspicion that both names refer to the same species. Geinitz compares his species to *B. meekana* Swallow, from which he distinguishes it by its persistent keel (Carbon. und Dyas in Nebraska, 1866, p. 7, Pl. I, fig. 12), but he does not seem to have been aware of the existence of *B. perlata*. His figures of *B. marcouiana* do not agree with his text, in that the former possess regular transverse furrows which cross the keel, giving it a nodose appearance, but dying out toward the umbilici. This character is not mentioned in the description, nor is it found in *B. meekana*, with which comparison is made by Geinitz; nor yet does it occur in the specimens which Meek has identified with *B. marcouiana*. If Geinitz's figure is not composite, and if it represents real structure, the specimen probably should be referred to the genus Patellostium, and I propose to restrict *B. marcouiana* to the form described by Geinitz and identified and figured as such by Meek.

B. tenuilineata is distinguished from the other forms mentioned above by possessing a depressed mesial band. Otherwise the general characters of the shell seem to be very similar.

EUPHEMUS.

To this genus can probably be referred *Eu. carbonarius* Cox, *Eu. inspeciosus* White, *Eu. subpapillosus* White, *Eu. nodocarinatus* Hall. *Eu. carbonarius* is the central form about which the other members can be grouped. *Eu. nodocarinatus* is practically *Eu. carbonarius*, in which a double row of low nodes is developed toward the front.. It is larger than *Eu. carbonarius* and with fewer revolving striæ (14 instead of 21). *Eu. subpapillosus* is *Eu. carbonarius*, in which the last portion of the final volution is papillose instead of being smooth. *Eu. inspeciosus* is essentially a large *Eu. nodocarinatus* with slightly more numerous striæ, and distinguished from it by these characters as well as by the irregular curvature of its growth. About the middle of the final volution occurs a sort of geniculation, followed by another at the next quadrant. At the former point four or more of the central striæ, alternate ones, die out suddenly. The others become coarser and toward the front also vanish, except two central ones, which develop into a pronounced double carina.

BELLEROPHON (sensu stricto).

To this genus may be referred *B. crassus* Meek and Worthen, *B. giganteus* Worthen, *B. incomptus* Gurley, *B. harrodi* Gurley, *B. percarinatus* Conrad, *B. tricarinatus*, *B. stevensianus* McChesney, and *B. globosus* Stevens.

B. crassus, *B. giganteus*, *B. incomptus*, and *B. stevensianus* can be grouped together as having a simple shell unornamented by revolving striæ or transverse ridges, and thus distinguished from the rest of those mentioned which, though without revolving striæ, have more or less heavy transverse ridges, often with rows of nodes.

B. giganteus, which is but slightly known, seems to be little more than a gigantic form of *B. crassus*, just as *B. incomptus* is a dwarfed type of *B. crassus*. *B. stevensianus* is small, sharply carinated and with regularly disposed lamellose growth lines.

Herrick's identification of *B. decussatus* Fleming (Bull. Sci. Lab. Denison Univ., Vol. II, 1887, p. 18) can with little doubt be set down in the synonomy of this species (*B. stevensianus*).

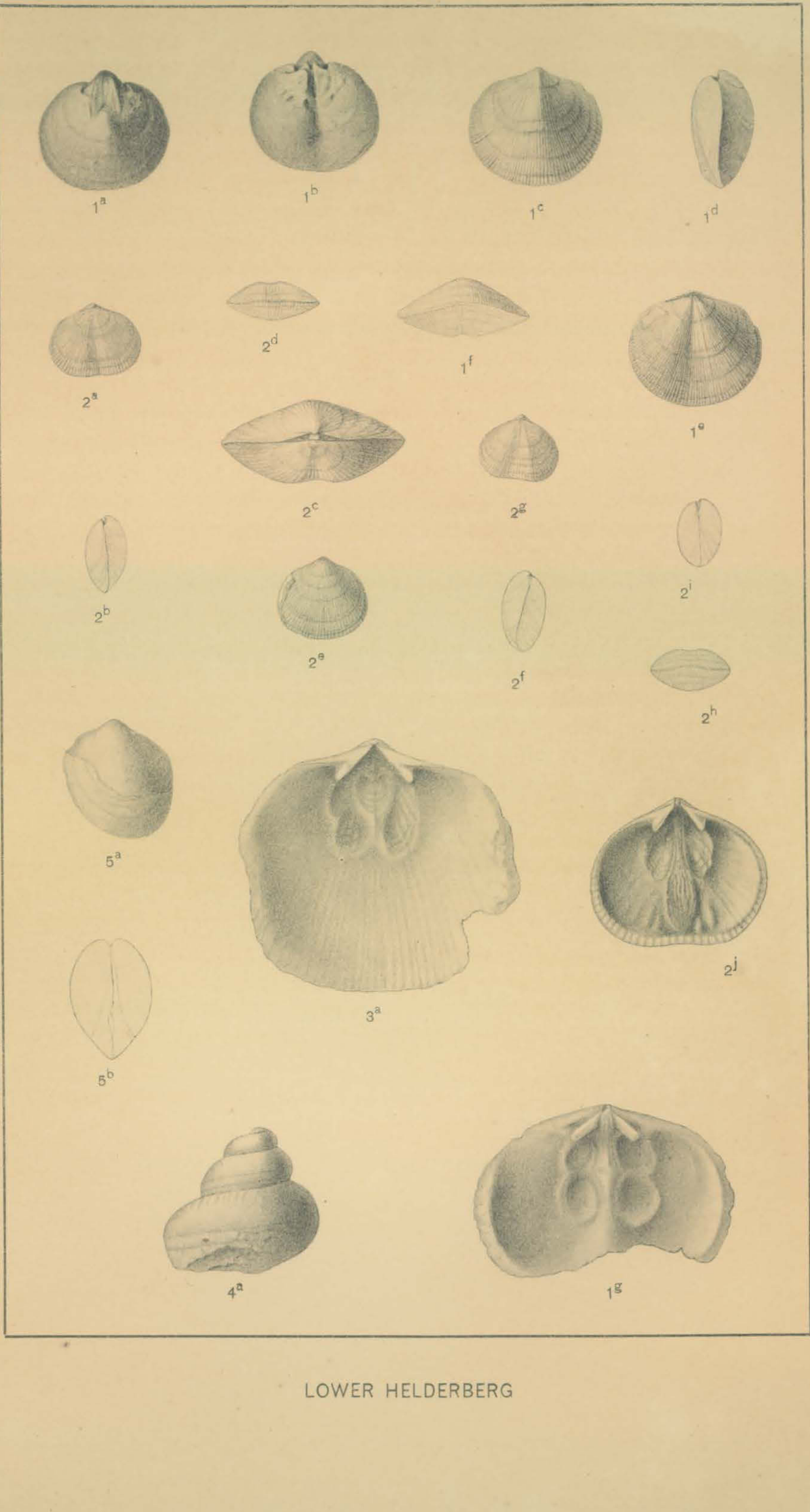
B. globosus Stevens, described in the briefest terms, seems to be an uncarinated form, ornamented only by transverse ridges. In *B. harrodi* the mesial band is elevated into a ridge which the transverse rugosities transform into a single median series of sharply elevated nodes. In *B. percarinatus* the central nodose ridge is supplemented by a more or less developed series of lateral nodes on either side. *B. tricarinatus* is a larger shell with the two lateral rows of nodes strongly developed. Whether this ascending series of forms seen in *B. globosus*, *B. harrodi*, *B. percarinatus*, and *B. tricarinatus* can be thus separated into four valid species would require a fuller suite of specimens to determine than it has yet been my privilege to examine.

To this section may possibly belong *B. subcordiformis* Herrick (Bull. Sci. Lab. Denison Univ., Vol. II, 1887, p. 18, Pl. II, figs. 7*a*, 7*c*). The original material of this species seems to have been imperfect and the description has suffered in consequence. The characters shown are so anomalous as to make the exact relations of this species a matter of doubt.

PLATE LXX.

PLATE LXX.

LOWER HELDERBERG FOSSILS.



LOWER HELDERBERG

PLATE LXXI.

PLATE LXXI.

LOWER HELDERBERG FOSSILS.

Page.

MERISTELLA ARCUATA var. ATOKA 569

FIG. 1a. The common form in Indian Territory, dorsal view.

FIG. 1b. Anterior view.

FIG. 1c. Side view.

FIG. 1d. Another somewhat larger specimen, dorsal view.

FIG. 1e. Same, anterior view.

FIG. 1f. Same, side view..

All these figures are slightly less than natural size.

Lower Helderberg period. T. 1 S., R. 8 E., Indian Territory, bed 6 (see profile, Pl. LXIX).

MERISTELLA ARCUATA 569

FIG. 2a. A large and characteristic individual of the rarer type in our collections from Indian Territory, dorsal view.

FIG. 2b. Anterior view.

FIG. 2c. Side view.

These drawings are slightly reduced from the natural size of the specimen.

Lower Helderberg period. Atoka quadrangle, northwest corner sec. 21, T. 1 S., R. 8 E.

TREMATOSPIRA HIPPOLYTE ? 568

FIG. 3a. Dorsal view of the only specimen found representing this species. ×3.

Lower Helderberg period. T. 2 S., R. 8 E., Indian Territory, bed 4 in profile (see Pl. LXIX).

PHACOPS HUDSONICUS 573

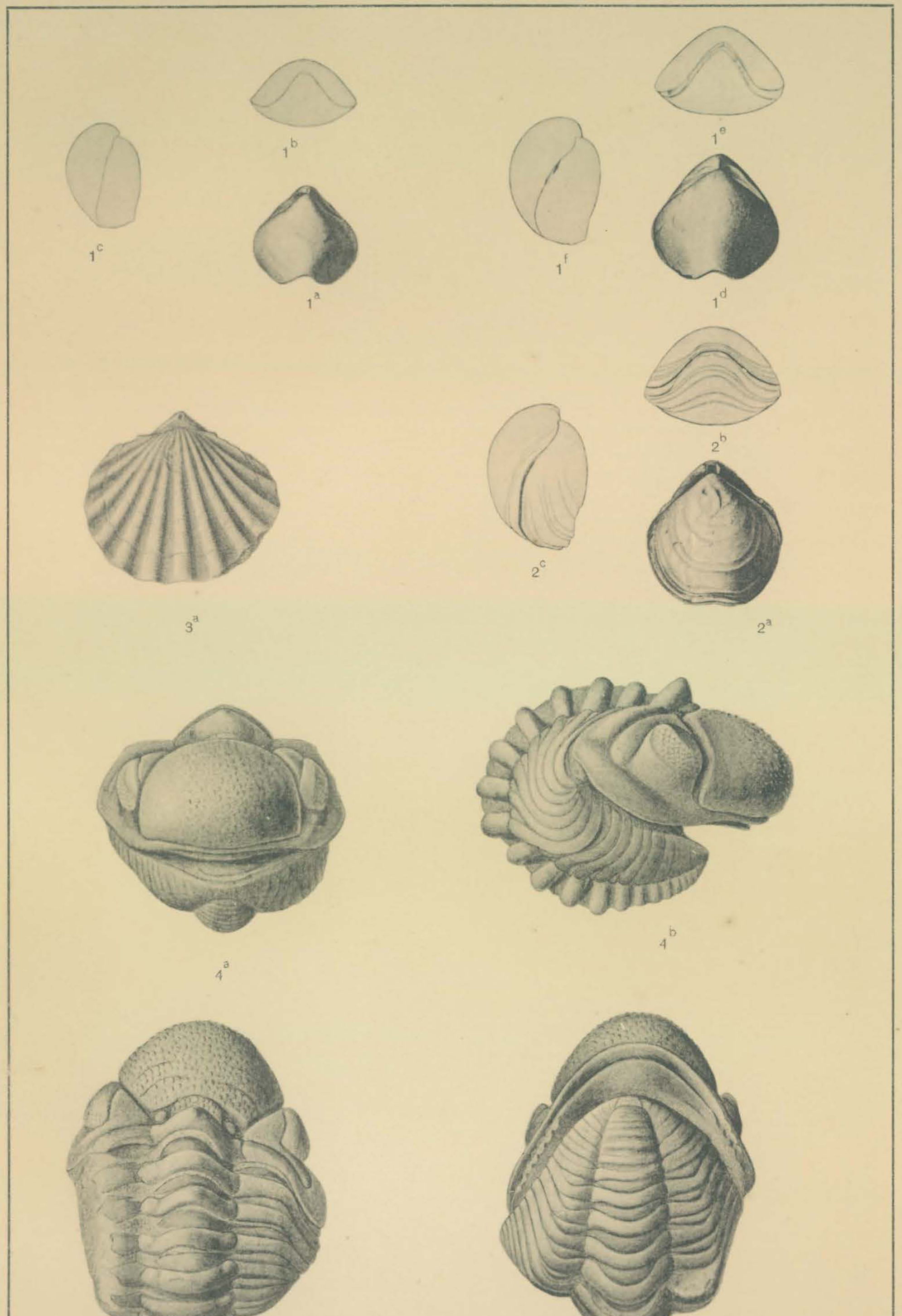
FIG. 4a. Front view of a complete individual. ×2.

FIG. 4b. Side view of same. ×2.

FIG. 4c. Same, seen from above. ×2.

FIG. 4d. Same, seen from beneath. ×2.

Lower Helderberg period. T. 2. S., R. 8 E., Indian Territory.



LOWER HELDERBERG

PLATE LXXII.

PLATE LXXII.

COAL-MEASURE FOSSILS.

Page.

RETICULARIA PERPLEXA 579

FIG. 1*a*. Cast of the exterior, showing impression left by the spinose surface, much enlarged.

Upper Coal Measures. McAlester quadrangle, north side of Krebs, Indian Territory, about 50 feet below the McAlester coal.

PLEUROPHORUS TAFFI n. sp 586

FIG. 2*a*. A large left valve of the usual type.

Upper Coal Measures. About one-half mile south of Coal Creek, near Lehigh, Indian Territory.

FIG. 2*b*. A smaller shell belonging to the same species.

Upper Coal Measures. Atoka quadrangle, T. 2 S., R. 11 E., southwest $\frac{1}{4}$ of SW. $\frac{1}{4}$ sec. 4.

FIG. 2*c*. Anterior end of a right valve. The specimen, which, like the others, is an internal cast, shows very clearly the large anterior adductor with the smaller accessory scar just above. The impression of the long posterior tooth can also be seen.

Upper Coal Measures. About one-half mile south of Coal Creek, near Lehigh, Indian Territory.

EDMONDIA? REFLEXA 587

FIG. 3*a*. A characteristic specimen of the form referred to this species.

FIG. 3*b*. A right valve of the same species.

FIG. 3*c*. Another left valve in which may be seen casts of the impressions left by a large anterior muscle, and a smaller scar just above it.

Upper Coal Measures. Atoka quadrangle, southwest $\frac{1}{4}$ of SW. $\frac{1}{4}$ sec. 4, T. 2 S., R. 11 E.

SCHIZODUS AFFINIS 584

FIG. 4*a*. A characteristic right valve.

FIG. 4*b*. Another right valve differing somewhat in shape.

FIG. 4*c*. Another right valve more similar to fig. 4*a*.

Upper Coal Measures. About one-half mile south of Coal Creek, near Lehigh, Indian Territory.

FIG. 4*d*. A left valve referred to the same species. The posterior outline of this figure is not quite angular enough.

FIG. 4*e*. Another left valve of a somewhat peculiar shape.

FIG. 4*f*. A right valve of more characteristic contour.

Upper Coal Measures. McAlester quadrangle, line between secs. 24 and 25, T. 5 N., R. 12 E.

SCHIZODUS PANDATUS n. sp 585

FIG. 5*a*. The type specimen, a left valve showing the peculiar shape of the species.

Upper Coal Measures. McAlester quadrangle, Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.

SCHIZODUS TELLINIFORMIS n. sp 585

FIG. 6*a*. View of the type specimen.

Upper Coal Measures. McAlester quadrangle, Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.

SCHIZODUS MEEKANUS n. sp 585

FIG. 7*a*. A very large left valve referred with doubt to this species.

Upper Coal Measures. McAlester quadrangle, Boggy Creek, on line between secs. 23 and 24, T. 2 N., R. 11 E.

FIG. 7*b*. Cast of a typical individual of this species.

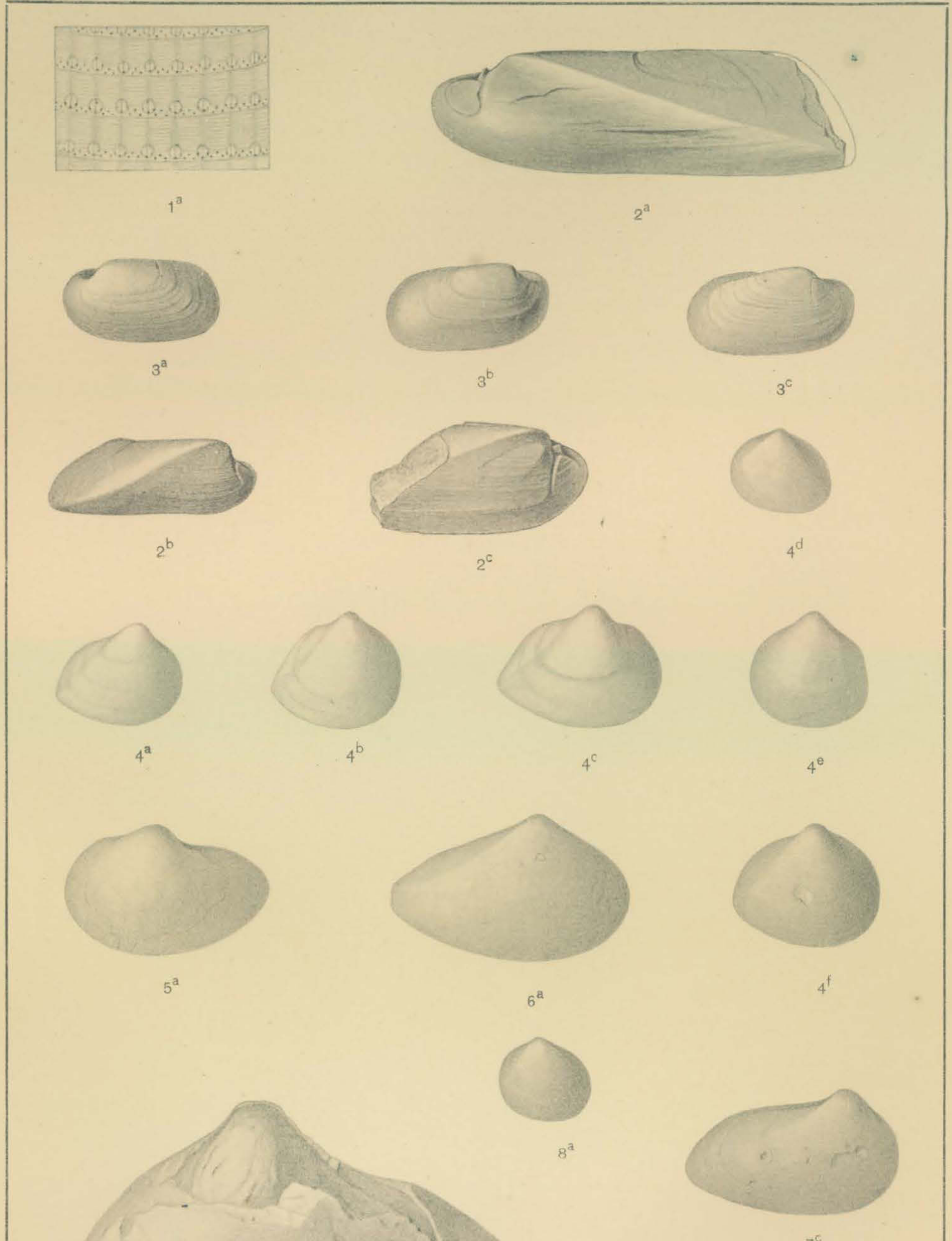
FIG. 7*b*. A left valve of the same species. The flattening of the anterior outline is probably an imperfection in the specimen.

Upper Coal Measures. Atoka quadrangle, southwest corner sec. 4, T. 2 S., R. 11 E.

SCHIZODUS SUBCIRCULARIS 584

FIG. 8*a*. A small left valve referred to this species.

Upper Coal Measures. McAlester quadrangle, line between secs. 24 and 25, T. 5 N., R. 12 E.



UPPER COAL MEASURES

GEOLOGY AND MINING INDUSTRY OF THE TINTIC DISTRICT, UTAH

BY

GEORGE WARREN TOWER, JR.

AND

GEORGE OTIS SMITH

CONTENTS.

ILLUSTRATIONS.

GEOLOGY AND MINING INDUSTRY OF THE TINTIC DISTRICT, UTAH.

By GEORGE WARREN TOWER, JR., and GEORGE OTIS SMITH.

INTRODUCTION.

The field work upon which this report is based was begun in July, 1897, and continued without interruption until December of the same year. The area studied is approximately 15 miles square and contains 234 square miles. The topographic maps, which are two in number, were prepared under the direction of Mr. R. U. Goode, Mr. S. S. Gannett doing the triangulation and Messrs. Marshall and Griswold the topography in the fall of 1896 and summer of 1897. The mapping is done on two scales; the larger area, approximately 15 miles square, is mapped on a scale of 1:62,500. This map is designed to form a part of the Geologic Atlas of the United States. The other map represents the portion of the larger area in which the majority of the mines are located. It is on a scale of 1:9,600, and covers an area of 12 square miles. The work has been greatly facilitated through the assistance rendered by the mining men of the district, among whom special thanks are due to Messrs. G. H. Robinson, W. J. Craig, W. M. Nesbit, and C. H. Blanchard. The chemical work on the ores and country rocks from the district has been done in the laboratory of the Survey by Messrs. H. N. Stokes and George Steiger, and the determination of the fossils collected is to be credited to Mr. G. H. Girty, also of the Geological Survey. In the field work the authors have cooperated constantly on every phase of the varied problems. The same is true for the office work, except that the stratigraphic and economic problems have been the especial studies of Mr. Tower, while the petrologic and remaining problems have been the special studies of Mr. Smith. In pursuance of this system of work the introduction has been written conjointly, Chapter II of Part I and all of Part II have been written by Mr. Tower, and Chapters I and III to VII of Part I by Mr. Smith.

To Mr. S. F. Emmons, under whose general supervision the work has been done, the authors can not give too much credit for his careful and able criticisms.

GEOGRAPHIC POSITION.

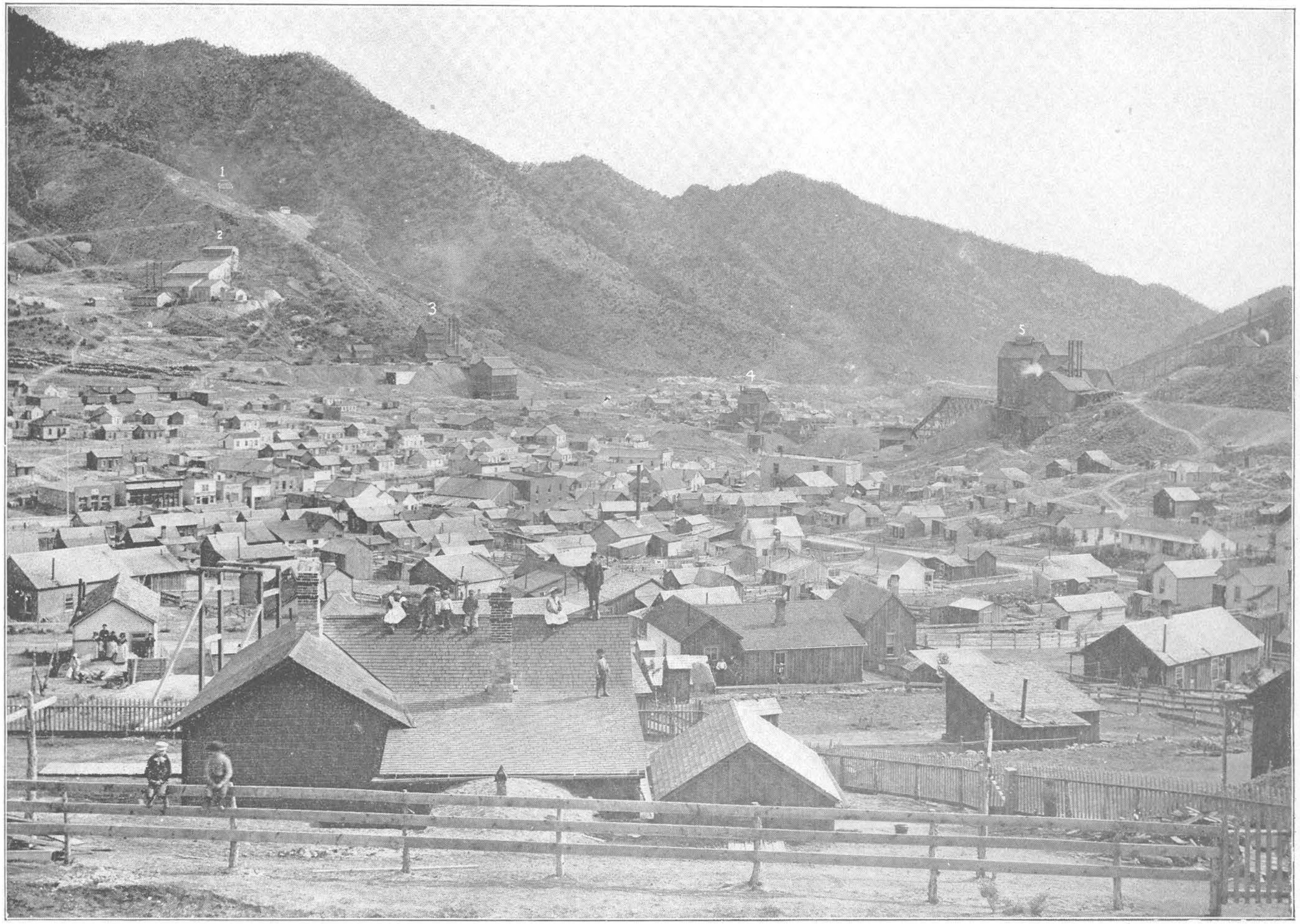
The Tintic Mountains are one of the Basin Ranges of Utah, and have the north-south trend characteristic of this type of mountains. They are crossed by the one hundred and twelfth meridian of longitude and the fortieth parallel of latitude. They are thus only 10 to 20 miles distant from the southern end of the Wasatch Mountains and form the easternmost of the Basin Ranges in this latitude. In total length the Tintic Mountains do not exceed 40 miles, but they may be considered to have their continuation to the north in the Oquirrh Mountains and to the south in the Canyon Range. Both of these lie slightly to the west of the Tintic Range, yet their common trend and their separation by only narrow passes indicate a close relationship. They are from 5 to 10 miles wide.

The Tintic mining district is located on the crest and western slope of the Tintic Mountains in the central portion of the range. It includes portions of Juab and Utah counties, the majority of the mines being situated in the former county. The district is about 65 miles south and west of Salt Lake City, with which it is connected by two lines of railroad, the Oregon Short Line and the Rio Grande Western. Eureka, Mammoth, Robinson, Silver City, and Diamond are the towns within the limits of this mining district. All of these towns are situated on the western slope. Homansville, where the first mill was erected, is just east of the divide above Eureka, while old Tintic, also important in the early days, was situated in the middle of Tintic Valley to the southwest. Goshen is in Goshen Valley, just east of the limits of the quadrangle.

TOPOGRAPHY.

In their central portion the Tintic Mountains form a well-defined topographic unit—a narrow and simple mountain ridge, with lateral valleys fluting its slopes and merging into the wide valleys to the east and west. The relief is strongly marked, the crest attaining an altitude of over 8,000 feet, while on the west Tintic Valley has an elevation of 5,600 feet and Goshen Valley, bounding the range on the east, is 4,500 feet above sea level. The abruptness of the change from the steep mountain slope to the almost level valley floor is a feature of the relief which at once impresses the observer. The crest line shows minor irregularities of direction, but the axis of the range has the general north-south course.

Outside this middle zone, however, the Tintic Mountains are less simple in their topographic development. In the southern part important transverse spurs extend eastward, almost connecting this range with the Wasatch. At the northern end of the range, also, low spurs extend to the west, forming the divide between Tintic and Rush valleys. The Tintic Mountains are thus seen to represent only the upper parts of a mountain mass, the lower slopes and foothills of which are con-



VIEW OF EUREKA, LOOKING SOUTHWEST.

1, Centennial Eureka mine; 2, Eureka Hill mill; 3, Eureka Hill mine; 4, Bullion-Beck mine; 5, Gemini mine.

cealed beneath the deposits of the surrounding valleys. The broad stretches of the valleys render the relation to the neighboring ranges less obvious.

Lateral valleys extending westward into Tintic Valley are especially characteristic of that part of the range in which the principal mines are located. These canyons, or "gulches," as they are locally termed, have been cut well back toward the crest of the Tintic Mountains.

The town of Eureka is located in the upper part of the most important of these side valleys. South of the town rises a bold spur, which extends westward from Godiva Mountain. Eureka Peak forms the highest point on this spur, and is midway between Eureka, on the north, and the town of Mammoth, on the south. The latter town and Robinson occupy Mammoth Basin, a broad, short valley, which is also tributary to Tintic Valley. On the north and east Mammoth Basin is shut in by high peaks, and presents a striking type of topography. On the south the divide between this basin and Dragon Canyon is somewhat lower. Silver City is located at the mouth of the latter canyon. Ruby Hollow and Diamond Gulch are the next valleys to the south, and from them canyons extend to the crest of the range.

The principal passes are the one between Eureka and Homansville and Silver Pass, at the head of Ruby Hollow. The former has been taken by the line of the Rio Grande Western, and is also an important route from the ranches of Goshen Valley to the mining towns on the western slope of the mountains. Silver Pass is used only for the latter purpose.

In the central portion of the Tintic Mountains the higher peaks are Packard Peak, north of Eureka; Eureka Peak and Godiva Mountain, south of Eureka; Mammoth and Sioux peaks, east of Mammoth Basin; Sunrise Peak, immediately south of Diamond, and Buckhorn Mountain and Tintic Mountain, still farther to the south. Tintic Mountain, 8,214 feet high, is the highest peak of the range.

DRAINAGE AND WATER SUPPLY.

The area of the Tintic mining district is tributary to three drainage basins: Tintic Valley, which is tributary to Sevier Basin; Goshen Valley, which drains northward by the Jordan into Salt Lake, and Cedar Valley, an independent inclosed basin. In the area included in the maps accompanying this report there is, however, only one perennial stream—Currant Creek. Even this stream is not indigenous to the Tintic Mountains, but represents the drainage of the southeast and southwest slopes of Mount Nebo, in the Wasatch Range. Currant Creek cuts through the transverse spurs of the Tintic Mountains in a bold canyon at the head of Goshen Valley and flows northward into Utah Lake, furnishing water for the irrigation of Goshen Valley. Valleys, ravines, and deep arroyos mark the channels of the occasional or seasonal streams. Thus the slopes are well sculptured.

Springs occur at a few points, being somewhat more important on the east slope in the area specially considered here. In general any overflow from these springs is soon absorbed by the alluvium of the dry channels. This distribution of underground water, as evidenced by the occurrence of springs, has an explanation in the geologic structure of this part of the range. The mines in the northern part of the district are perfectly dry, even the deepest ones not requiring pumps. To the south, however, water is found in the lower levels, one mine pumping 70 gallons per minute.

In the vicinity of Homansville, across the divide eastward from the town of Eureka, extensive sinking and drifting in the alluvium and the bed rock has developed a flow of water sufficient to supply several of the mines and mills. Four of these wells yield an average of 25 gallons each per minute throughout the year. Three other wells have an aggregate flow varying from 37 gallons per minute in February to 67 gallons in May. Throughout the summer and fall there is a steady decrease, showing the dependence of the supply upon the melting snow on the mountains and the spring rains. The larger part of the water for the district, however, is piped from Cherry Creek, a stream in the mountains west of Tintic Valley.

The open fissures so characteristic of the limestone afford channels through which the surface water can reach the lower parts of the syncline. The ground water therefore stands at a considerable depth, and, as has been noted, the springs in the limestone occur mostly on the eastern and flatter limb of the syncline. The igneous rocks, on the other hand, evidently form a more impervious mantle, so that the presence of the surface water at the higher levels may quite probably indicate that the fissures do not extend so deep in the monzonite as in the limestone. The difference in the amount of ground water is perhaps the most noticeable distinction between the two groups of mines—those in the limestone, which are dry mines, and those in the monzonite, which have considerable flow of water.

VEGETATION.

The Tintic Mountains have the scanty vegetation of an arid region. In general the landscape possesses the somber gray and brown tints of the rock masses, and only rarely does the eye find relief in the green of a tree-colored slope.

On the highest peaks and exposed rocky points occur different species of the cactus. The more common trees of the higher slopes are the pinyon (*Pinus monophylla*) and the mountain mahogany (*Cercocarpus ledifolius*). Lower, in the dry ravines, are thickets of maple bushes, especially on the eastern slope, while the aspens are found in sheltered spots, more commonly those with a northern exposure. The trees all show, in their stunted, gnarled, and twisted trunks the severity of the struggle for existence on these barren slopes. In the lower valleys the sagebrush (Artemisia) and the rabbit brush (Bigelovia) constitute almost the sole vegetation. Grasses occur in scattered tufts, but are apparently mostly dead during the dry summer months. In the past the Tintic Mountains have supported sufficient of this scanty herbage to afford range for cattle, horses, and sheep, but now the grazing is limited to a few small bands of horses.

HISTORY.

Tintic is one of the oldest mining camps in the State. Ore was discovered by a party of prospectors returning from western Utah in December, 1869, and the districts were organized the following spring. The only districts in the State discovered previous to Tintic were those of Bingham, discovered in 1863 by the soldiers of Gen. P. E. Connor; Rush Valley, or Stockton, also discovered in 1863, and Little Cottonwood, discovered in 1868. The first claim recorded in the Tintic district was called the "Sunbeam." This was located on December 13, 1869, and is in the southern part of the district. The second location, the Black Dragon, which is but a short distance north of the Sunbeam, was made on January 3, 1870. The third location was made on February 26 of the same year, on the site of the present Mammoth mine, and two days later stakes were set on the present Eureka Hill ledges.

DEVELOPMENT OF MINING INTERESTS.

For a number of years rapid development of the mines in this district was not possible, owing to poor facilities for transportation. At that time there was no railroad south of Salt Lake, and the cost of teaming to that point was $25 per ton. There was, however, a very considerable amount of ore near the surface which was rich enough to be mined in the face of almost any difficulty. These rich ores have been shipped to San Francisco, California; to Reno, Nevada; to Baltimore, Maryland, and even to Swansea, Wales. The average value of the ores was not sufficiently great to pay such heavy transportation as shipment to these places required; therefore the efforts at development of the district were turned to the erection of mills and smelters in the vicinity of the mines. The first mill erected was at Homansville, in May, 1871. The second mill in the same locality was completed in the fall of the same year. The Wyoming mill was constructed in 1873; the Miller mill in 1873; the Shoebridge mill, southwest of Diamond, in 1873; Copperopolis mill in 1873; Mammoth mill, at Tintic, in 1879; the Roseville mill, southeast of Mammoth, at about this same time, and more recently the present Mammoth mill, at Robinson, in December, 1893; the Eureka Hill and Bullion-Beck mills, at Eureka, in 1894, and the Farrell mill, at Robinson, in 1895.

The first mills erected were crude and in almost every case failed to handle the ores successfully, and the mills now working have not yet reached a perfect standard of recovery.

Owing to the poor success of the early mills and the refractory nature of much of the ore, smelting has been tried frequently. The first smelter erected in the district was built at Homansville in 1871. The second, the Tintic Milling and Smelting Company's works at Diamond, was also built in 1871. The third smelter was the Copperopolis, built in 1872. Others were the Crismon-Mammoth, built at Tintic in 1884; the Latham furnace, built at Goshen in 1874, and the Clarkson, at Homansville. Like the earlier milling processes, these smelters were also unsuccessful.

The process of leaching the ores has been tried on two occasions—once at Goshen, in 1876, and again on the site of the old Miller mill, in 1879. This method of winning values was even less successful than milling and smelting.

One of the reasons for the poor success of the mills and smelters was the scanty supply of water in the district. This want has been overcome in late years through the sinking of wells at Homansville, and the construction of a pipe line by means of which water is pumped from Cherry Creek to Mammoth, a distance of 18 miles, for the Mammoth and Farrell mills; the water from this line is also used at Eureka to make up the deficiency in the water supply of Homansville.

The development of the mines was greatly accelerated upon the advent of the railroads, the Oregon Short Line from the west in 1883 and the Rio Grande Western from the east in 1891.

The recent discovery of valuable ore bodies below the water level in the monzonite area has greatly stimulated the development of the district, and the energetic exploration of the veins now going on in this area will have a beneficial effect upon mining interests.

In the future great advance in production is likely to come through the reduction of the expense of mining by the use of electrical power. This will tend to reduce the cost of mining, and thereby increase the amount of ore for the market. Further, it is to be hoped that in the future there will be found a process for winning a greater proportion of the values from the ores than is obtained by the mill methods now in vogue.

PRODUCTION.

In the first few years after the discovery of precious-metal deposits in these mountains the production was about equally divided between the deposits in the sedimentary and those in the igneous rocks, or between the northern and the southern districts. Upon the exhaustion of the oxidized ores in the igneous rocks the output of the southern portion of the district became practically nothing, and the majority of the mines were abandoned. A few, however, worked along in a desultory sort of a way and, with the surplus derived from an occasional pocket of rich oxidized ore, pushed their shafts to greater depths, until, finally, after a lapse of nearly twenty years, rich sulphide ores were found in several of the mines, notably the Swansea and the South

Swansea. Since then these mines have produced constantly, and the renewed interest in the veins of the igneous rocks that their developments have created has already accelerated development in other mines and added greatly to the production of the district.

There has been no break in the continuity of the production from the deposits in the sedimentary rocks, though a slight falling off in the output occurred in 1893 because of the sudden drop in the value of silver. From the earliest times these mines have been productive, and the development has kept so far ahead of the actual breaking down of the ore in the stopes that the production has been one of constantly increasing proportions.

The following table, compiled from the reports of the Director of the United States Mint, affords the best data on production obtainable. The individual reports of production from the various mines have been used, so far as possible, as a check on this table, but, as it has been impossible to get reports on all the mines, and as many of the reports are incomplete, the production of the earlier years has received no check whatever.

Production of the Tintic mining district.

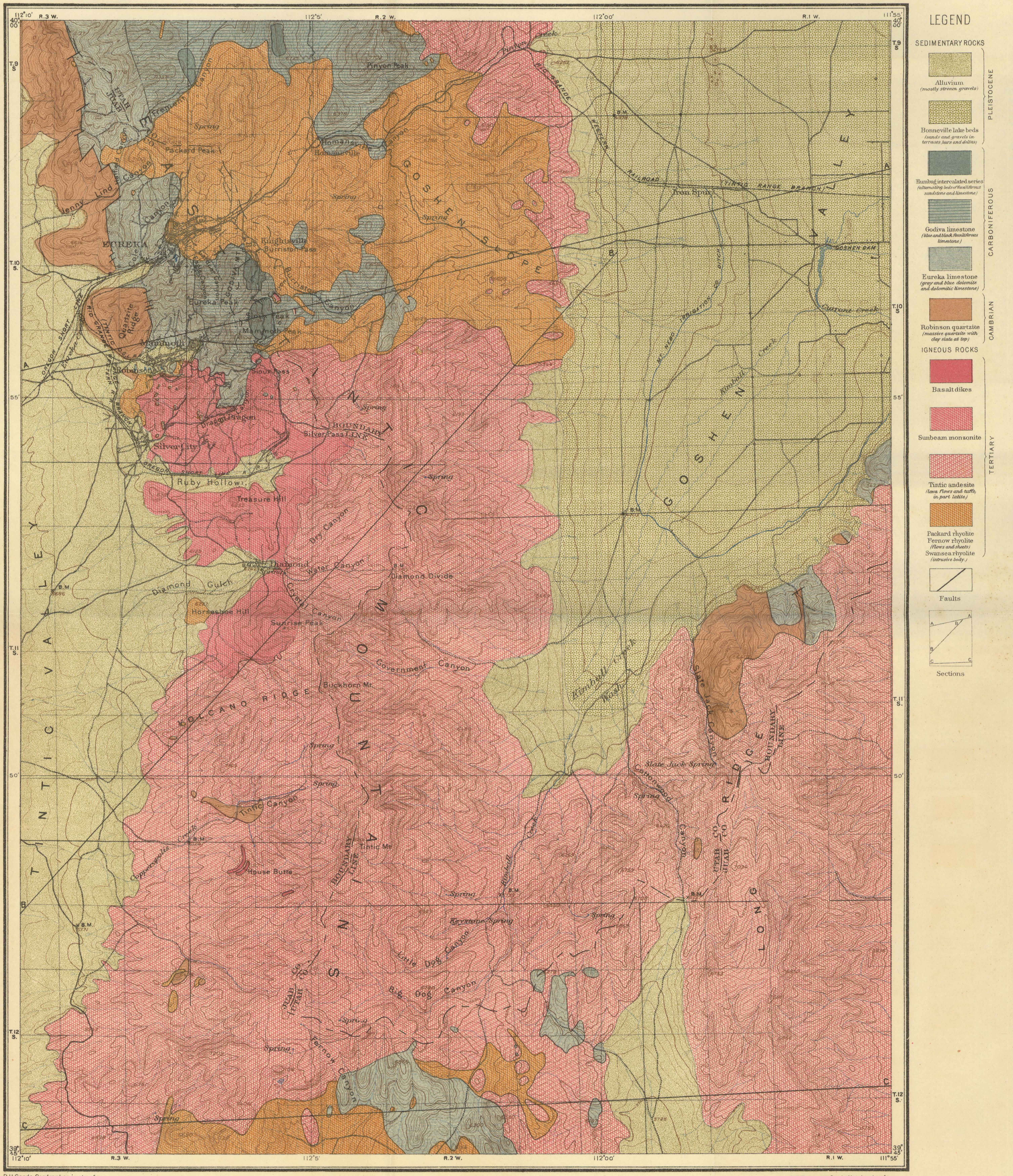
Year.	Gold.	Silver.	Year.	Gold.	Silver.
	Ounces.	*Ounces.*		*Ounces.*	*Ounces.*
1880......	3,012	8,682	1889......	14,940	2,055,700
1881......	2,332	105,354	1890......	24,633	3,801,700
1882......	3,000	232,558	1891......	19,444	2,901,730
1883......	2,000	224,800	1892......	16,470	2,011,642
1884......	1,500	612,016	1893......	15,097	1,990,860
1885......	868	868,925	1894......	18,066	2,582,033
1886......	2,300	825,000	1895......	27,525	3,517,166
1887......	3,200	1,412,463	1896......	40,470	3,955,843
1888......	7,110	1,201,620		201,967	28,308,092

It is thought the production of silver and gold previous to 1880 did not exceed $2,000,000 in value.

From 1880 to 1896, inclusive, the production in gold has been 201,967 ounces, and in silver 28,308,092 ounces.

In addition to the silver and gold, Tintic has produced a large amount of lead and copper.

The only method of calculation of the lead and copper is by finding the ratio of copper to either gold or silver. As silver is more uniformly distributed in the ores than gold, this metal has been chosen as the basis of calculation. The average content of copper and lead in 240,000 tons of ores was 0.6 per cent and 13.5 per cent, respectively. The ores which have furnished the basis of this calculation are the reported output of about two-thirds of the mines of the district. The content of silver of these same ores averages 52.50 ounces per ton. On this basis there are 20 pounds of copper to every 87.5 ounces of silver, and 20 pounds of lead to every 3.8 ounces of silver. Applying these ratios to the total production of the camp it is shown that there should have been produced 6,470,000 pounds of copper and 74,495 tons of lead for the years from 1880 to 1896, inclusive, thus roughly estimated. These calculations, however, judged from other standpoints, seem to be somewhat low for copper and high for lead.



GEOLOGICAL MAP OF THE TINTIC DISTRICT, UTAH AND VICINITY

Scale

1 ½ 0 1 2 3 4 Miles

Contour interval 50 feet

R. U. Goode, Geographer in charge
Triangulation by S. S. Gannett
Topography by R. B. Marshall

S. F. Emmons, Geologist in charge
Geology by G. W. Tower Jr. and G. O. Smith
Surveyed in 1897

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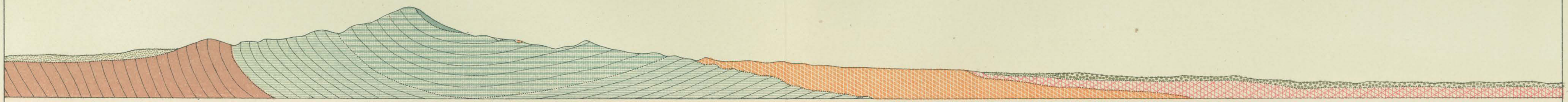
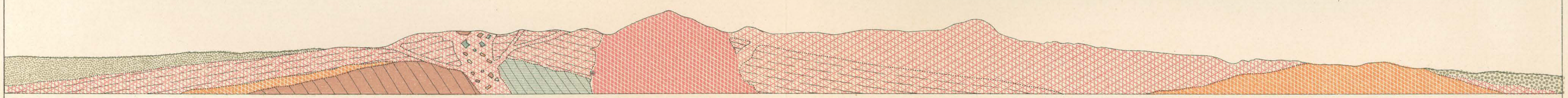
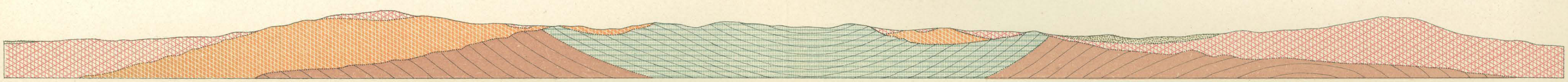


SECTION A



SECTION B



SECTION C

LEGEND

SEDIMENTARY ROCKS

PLEISTOCENE

- Alluvium (*mostly stream gravels*)
- Bonneville lake beds (*sands and gravels in terraces bars and deltas*)

CARBONIFEROUS

- Humbug intercalated series (*alternating beds of fossiliferous sandstone and limestone*)
- Godiva limestone (*blue and black fossiliferous limestone*)
- Eureka limestone (*gray and blue dolomite and dolomite limestone*)

CAMBRIAN

- Robinson quartzite (*massive quartzite with clay slates at top*)

IGNEOUS ROCKS

TERTIARY

- Sunbeam monzonite
- Tintic andesite (*lava flows and tuffs; latite in part*)
- Packard rhyolite, Fernow rhyolite (*flows and sheets*), Swansea rhyolite (*intrusive body*)

Scale

1 0 1 2 3 4 Miles

SECTIONS SHOWING STRUCTURE ON LINES A, B, AND C, PLATE LXXIV

JULIUS BIEN & CO. LITH. N.Y.

PART I.—GEOLOGY.

CHAPTER I.

GENERAL GEOLOGY.

GENERAL FEATURES.

The Tintic Range is a composite mountain range. It is built up of diverse kinds of rocks, which record several epochs in its history. Separated as these mountains are from the neighboring ranges, their geology can be correlated only in a general way with that of other portions of the Great Basin. Like the Basin Ranges to the west and the Wasatch to the east, this mountain mass consists primarily of Paleozoic strata. Intrusions of igneous rocks with volcanic outflows have in part buried this nucleus of sedimentary rocks, but sufficient remains exposed to show the geologic structure of the range.

As already noted, the Tintic Mountains are in line with the Oquirrh Range to the north and the Canyon Range to the south. Geologically, as well as topographically, the relation of these ranges seems close. All three ranges constitute one general line of uplift and exhibit structures involving a considerable amount of horizontal compression of the Paleozoic strata. In the Oquirrh Mountains two great anticlines, with an included synclinal fold, make up the range.[1] In the section of the Canyon Mountains exposed along Sevier River, the Paleozoic strata are seen to be folded into an anticline and a syncline. As will be described later in this chapter, the structure of the Tintic Range is synclinal and close plication is characteristic. Faulting is of subordinate importance in determining the structure of the range, both from the rare occurrence of the faults and from their direction, being transverse to the axis of the range. In these important features the Tintic Mountains differ from the type Basin Range of Gilbert, the faulted monoclinal,[2] and correspond rather to the type defined by the geologists of the Fortieth Parallel as an uplift due to plication.

Goshen Valley and Tintic Valley, which bound the Tintic Range on the east and the west, may be considered valleys of erosion, rather than residual troughs between lines of uplift by faulting. The alluvial and lacustrine deposits which have filled the valleys to a great depth, however, cause an apparent difference between these and the usual type of intermontane valleys. On the mountain slopes extensive accumulations of talus often conceal the geologic relations and impede the work of exact mapping.

[1] S. F. Emmons, Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 360.

[2] G. K. Gilbert, U. S. Geog. Surv. W. One hundredth Mer., Vol. III, Geology, 1874, p. 40.

The rocks occurring in the Tintic mining district are naturally grouped under two general classes—the sedimentary series and the rocks of igneous origin. Both are of economic importance and interest as the country rocks of valuable ore deposits, and they will be described in detail in later chapters, while here only the general features of their occurrence will be noted.

THE SEDIMENTARY SERIES.

Description.—The series of sedimentary rocks occurring in the Tintic district comprises nearly 14,000 feet of Paleozoic strata. A complete section is exposed in the region between the towns of Eureka and Mammoth. The lowest formation, the Robinson quartzite, forms Quartzite Ridge, at the western base of the range, and is followed by the Eureka limestone, which extends eastward beyond Eureka Peak. Above the Eureka limestone comes the Godiva limestone of Godiva Mountain, while on the eastern slope of this mountain occurs the Humbug Intercalated series of sandstones and limestones. The ore deposits occur in the Eureka and the Godiva limestones. These are the rocks which form the core of the Tintic Mountains, and the same series is less completely exposed at various points. A fuller description of the four sedimentary formations is given in the next chapter.

Folds.—The main structure of the sedimentary portion of the Tintic Mountains is synclinal. The section referred to in the previous paragraph is that of the western limb of the major syncline, which pitches to the north. The position of the axis, which has a general north-south trend, is on the eastern slope of Godiva Mountain and Sioux Peak. The west limb of this fold is characterized by steep dips, ranging from 45° to 90°, with the beds often vertical or even overturned for a considerable distance across the strike. On the opposite side of the synclinal axis the dips are much less, rarely exceeding 35°. This unsymmetrical character of the fold is in accord with the structure in the Oquirrh Mountains, where, as Emmons states,[1] the east sides of the anticlines exhibit the steeper dips.

Minor folds occur in different parts of this major fold, and are indicated by the changes in strike and dip of the strata. In a few cases, notably on the north side of Homansville Canyon, immediately northeast of Homansville, such minor plications are readily distinguished even when viewed from a distance (Pl. LXXVIII).

The general synclinal structure appears to continue to the south, although much interrupted and hidden by the igneous rocks. In the southeastern part of the Tintic quadrangle an anticlinal axis to the east of the above-described synclinal axis is indicated in the quartzite and limestone there exposed. Yet farther east, beyond the edge of the Tintic quadrangle there appears to be another anticline which pitches southward and is exposed in the canyon of Currant Creek. Thence,

[1] Loc. cit., p. 361.

R.U. Goode, Geographer in charge
Triangulation by S.S. Gannett
Topography by W.T. Griswold and R.B. Marshall

GEOLOGICAL MAP OF THE TINTIC MINING REGION, UTAH

S.F. Emmons, Geologist in charge
Geology by G.W. Tower Jr. and G.O. Smith
Surveyed in 1897

0 1/8 1/4 1/2 3/4 1 Mile

Contour interval 20 feet

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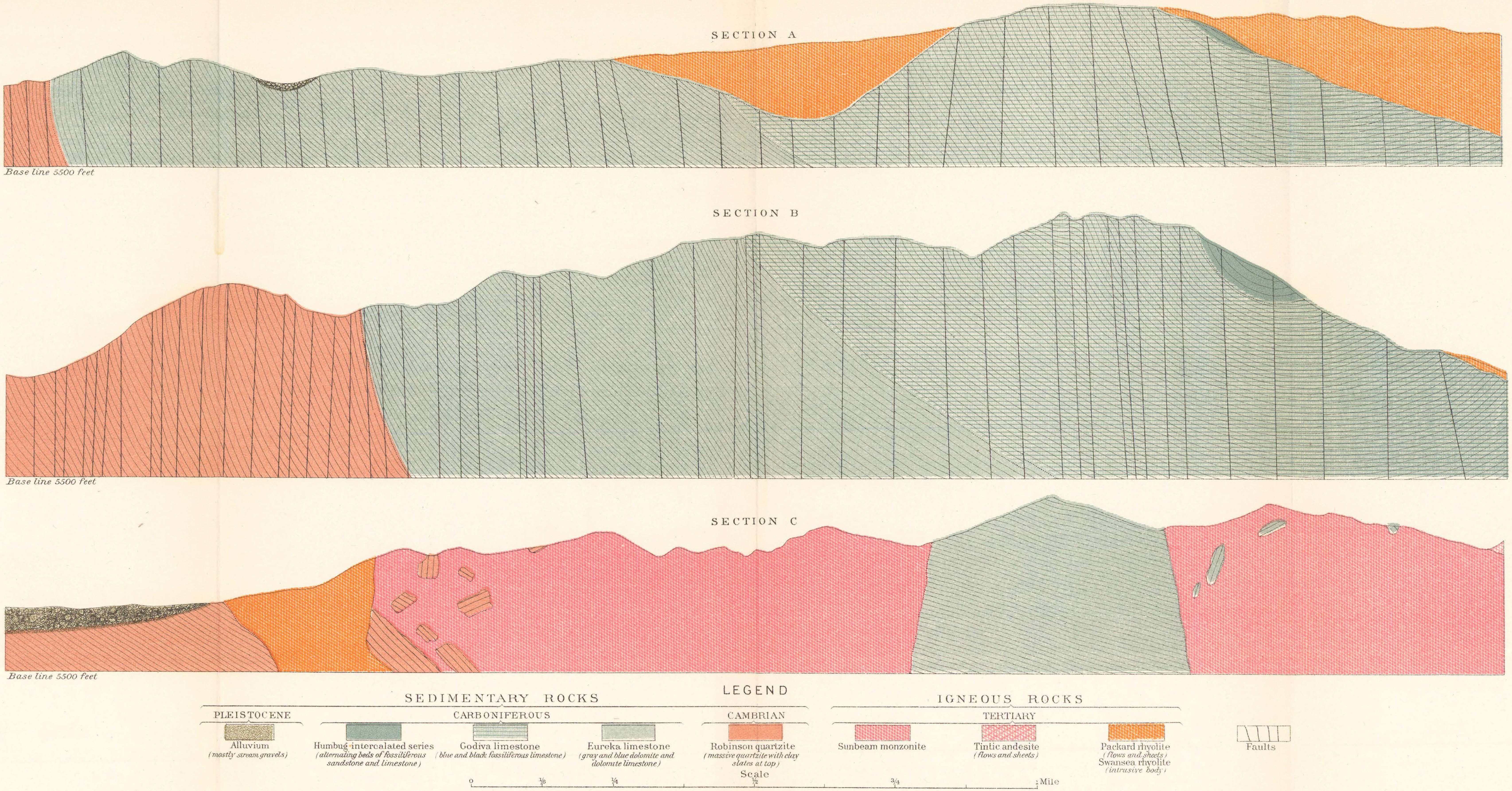


SECTIONS SHOWING STRUCTURE ON LINES A, B, AND C, PLATE LXXVI

JULIUS BIEN & CO. LITH. N.Y.

almost to the base of Mount Nebo, of the Wasatch Range, east dips are seen in the limestone.

West of the main Quartzite Ridge–Godiva Mountain syncline the alluvium of Tintic Valley conceals the Paleozoic strata. The presence of quartzite dipping to the west on the west side of this valley shows the latter to coincide in position with an anticlinal axis.

The Paleozoic rocks which form the core of the Tintic Mountains are thus seen to be closely folded, the axes of the pitching folds having a general north-south trend. This structure appears to extend beyond the topographic limits of the range, both longitudinally into the Oquirrh and Canyon ranges, and transversely, where the connection is with the Wasatch on the east and with the West Tintic or Guyot Mountains on the west.

Faults.—Faulting in this region is of minor importance as compared with the folding of the sedimentary rocks. A number of small faults can be observed at different localities, but the amount of displacement is very small, rarely exceeding a few feet. Other faults shown on the geologic maps, have displacements of 50–400 feet, while one on the quartzite-limestone contact is considerably larger. An important fault cuts the limestone series between the head of Mammoth Gulch and the Northern Spy mine, having a displacement of about 1,000 feet. The strike of this fault is nearly east-west, and it is also characteristic of the other faults that they are transverse to the axis of the range. It is probable also that incident to the folding of these rocks there was more or less adjustment along the bedding planes. Faulting of this nature is extremely difficult to detect, but may have played an important rôle in the development of fissures, and in this connection will be considered in a later chapter.

THE IGNEOUS ROCKS.

Description.—Igneous rocks of several distinct types occur in this district. These are both intrusive and effusive, and include rhyolite, quartz-porphyry, andesite, monzonite, and basalt. Differing considerably in chemical and mineralogic composition, as well as in texture, these igneous rock types, however, show a general relationship, as will be explained later in the fuller descriptions (Chapters III and IV of Part I).

Taken together the igneous rocks cover by far the larger part of the area included within the Tintic quadrangle. In addition to this areal importance, the intrusive types are of economic interest as the country rocks of important ore bodies. These rocks are of added interest in the light they throw upon the later geologic history of the Tintic Mountains. The area has been one of volcanic activity, and the products of that activity have been important factors in the construction of the range.

CHAPTER II.

SEDIMENTARY ROCKS

INTRODUCTION.

The sedimentary rocks exposed within the Tintic quadrangle, which consist mainly of quartzite and limestone, have a total thickness of nearly 14,000 feet.

They have been divided mainly on lithologic grounds into four formations—the Robinson quartzite, the Eureka limestone, the Godiva limestone, and the Humbug Intercalated series—of which the first is supposed to be of Cambrian age and the last two are identified by fossils as belonging to the Coal Measures division of the Carboniferous. The upper part of the Eureka limestone is also Carboniferous, but the age of the lower part has not yet been determined.

ROCK FORMATIONS.[1]

ROBINSON QUARTZITE.

The Robinson quartzite, which includes clay slates and quartzites, forms the lowest member of the stratigraphic series in these mountains. The thickness exposed here is about 7,000 feet, but this is not the total thickness of the formation, for the base has not been uncovered.

The quartzite, white in color, weathering to brownish red on exposed surfaces, is compact and fine grained, with occasional beds of fine quartz conglomerate. Microscopic studies show it to be a very pure quartzite, the individual quartz grains being well rounded and for the most part of very uniform size. Occasionally the grains are somewhat drawn out, as if by dynamic metamorphism. Corroded grains are not common, though present. In rare cases the quartz shows crystal facets. In many of the grains of quartz are particles of a dark material so abundant as to give the individual grains a very dirty appearance. The nature of these particles could not be determined. The lowest beds of quartzite contain some feldspar and muscovite, while nearly all of the beds show zircon and rutile. In one specimen from the upper portion greenish grains were observed tinged with brown on the rim, which were thought to be glauconite.

The quartzite has been divided into narrow, parallel sheets by dynamic action, so that it is possible to determine the stratification only

[1] In the Tintic folio of the Geologic Atlas the Robinson quartzite will be named the Ophir formation, and the Eureka limestone the Mammoth formation. These changes are made to avoid duplication of formation names.

by following well-defined conglomeratic beds and contacts between slate and quartzite. This sheeting commonly forms a small angle with the strike and dip of the stratified rocks.

Several beds of greenish, yellowish, and reddish clay slates occur near the top of the quartzite. Microscopic studies of these slates show, besides the argillaceous nature of the rocks, also glauconitic and sandy phases, and occasionally small laths of biotite, the whole mass being invariably stained with iron.

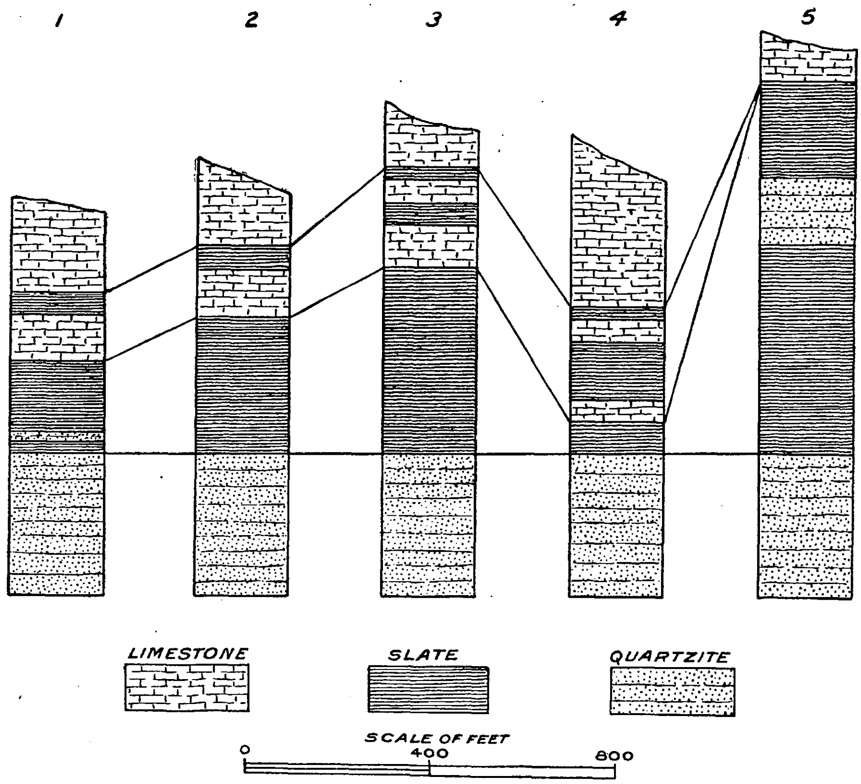


FIG. 81.—Sections showing variations of strata at the top of the Robinson quartzite and the base of the Eureka limestone. 1, Quartzite Ridge; 2, 3, 4, north of Eureka; 5, Long Ridge.

One or two beds of these clay slates occur in the quartzite, one bed separates the quartzite from the overlying limestone, while one or two beds occur in the limestone near its base. In mapping, those beds of clay slate below the limestone have been included in the quartzite, and those beds actually in the limestone have been mapped with it. The beds vary greatly in thickness and have a very perfect slaty cleavage, which oftentimes is at an angle of less than 10° with the stratification and corresponds to the sheeting of the quartzite.

In the lowest sag between Quartzite Ridge and Eureka Peak, a section crossing the strike shows the lowest bed of slate to be 25 feet in thickness. Over this is 25 feet of quartzite, then 150 feet of slate, then

100 feet of limestone, then the upper slate bed, which is about 50 feet in thickness. North of the town of Eureka three sections were made, which show the rapid change of these beds. The first section gave 300 feet of slate resting on the quartzite, succeeded by 50 to 100 feet of limestone, then 50 feet of slate, then the main mass of limestone of the overlying formation. The second section, which was a few hundred feet farther north, gave 400 feet of slate resting on the main quartzite mass, then 50 to 100 feet of limestone, then 40 feet of slate, then 50 feet of limestone, then 25 feet of slate, and finally the main mass of limestone. The third section, still farther north, gave 75 feet of slate resting on the quartzite, then 45 feet of limestone, then 120 feet of slate, then 50 feet of limestone, then 30 feet of slate, and at last the main limestone mass. A section on Long Ridge, east of Goshen Valley, gave 450 feet of slate resting on the main mass of quartzite, then 150 feet of quartzite, then 200 feet of slate, which appears to form the uppermost of the slate beds there.

EUREKA LIMESTONE.

The Eureka limestone includes those beds of dolomitic, cherty, and shaly limestone which immediately overlie the Robinson quartzite. Several beds of clay slate which are near the base of the limestone have been included within the geologic boundaries of this formation. These do not need special description here, for they are similar in every respect to those that have been described as a part of the Robinson quartzite.

The Eureka limestone aggregates 4,000 feet in thickness, and is composed of a great number of beds of dolomite, shaly dolomitic limestone, black dolomitic limestone, and dolomitic limestone with interbedded chert lenses.

Classified by its broader features, this formation may be divided into a dense dolomitic limestone at the base, which varies in color between blue, black, and gray, thus giving the appearance of thin-bedded strata; a mid zone of these dolomitic limestones, separated by an occasional bed of either pure blue limestone or dolomitic limestones with interbedded chert lenses; and finally, at the top, the great thickness of shaly, dolomitic limestone which weathers with a reddish tinge. The individual beds vary from place to place along the strike.

A descending section from the east side of Eureka Peak to Quartzite Ridge, along the crest of the ridge, shows the differences and comparative thickness of the beds which make up this formation, as follows:

Section from the east side of Eureka Peak to Quartzite Ridge.

	Feet.
17. Thinly bedded, impure, grayish dolomitic limestone weathering reddish-gray	850
16. Fine-grained, cherty, bluish-gray limestone	100
15. Coarsely crystalline blue limestone, thinly bedded, and containing many small fragments of a very fine-grained limestone	150

		Feet.
14.	Blue granular limestone, with interbedded lenses and seams of chert	225
13.	Blue granular limestone	150
12.	Brecciated shaly limestone	20
11.	Blue limestone	150
10.	Reddish-gray, shaly dolomitic limestone	50
9.	Fine-grained blue limestone	200
8.	Reddish-gray, shaly dolomitic limestone	50
7.	Dolomitic limestone varying in color from gray to blue, having in places a mosaic appearance because of the unevenness in distribution of the color, and containing occasional fossils and indications of organic life	1,200
6.	Thinly bedded shaly limestone	100
5.	Gray limestone, which contains innumerable seams of calcite	400
4.	Blue dolomitic limestone, finely banded	175
3.	Clay slate	50
2.	Impure dolomite, thinly bedded and varying in color from yellowish-gray to bluish-black (ribbon limestone)	50
1.	Impure, gray limestone	50
	Total thickness	3,970

Microscopic studies add but little to the knowledge of these sediments. They show a great amount of cryptocrystalline carbonate material, also much crystalline calcite and dolomite. In rare cases oolitic and foraminiferal structures and fragmentary crinoid stems were found. In addition to these, widely scattered throughout the various beds, are small quartz grains which have occasional crystal facets, but are for the most part rounded. As they occur in beds which show oolitic and organic structures, they are thought to be original, rather than the result of metamorphism.

The accompanying partial analysis of a specimen taken from bed No. 7 is thought from microscopic studies to show the nature of these strata, as a whole.

Partial analysis of a specimen from bed No. 7 of the foregoing section.

	Per cent.
SiO_2	8.77
Fe_2O_3	.49
CaO	27.22
MgO	18.53
CO_2 (*a*)	41.77
Total	96.78

a Calculated.

A second analysis is of the brecciated and partly crystalline limestone bed No. 15, containing apparent fragments of compact and probably more siliceous nature:

Analysis of specimen from bed No. 15 of foregoing section.

	Per cent.
SiO_2	4.33
Fe_2O_3	.63
CaO	52.34
MgO	.60
CO_2 (*a*)	41.78
Total	99.68

a Calculated.

The great dearth of fossil remains in this formation indicates that for the most part it was formed under conditions unfavorable to organic life. Except in the vicinity of the zones of mineralization, there has not been a sufficient amount of metamorphism to destroy organic remains, and this fact, taken in connection with the lack of fossils and the cryptocrystalline nature of the greater part of the rock mass, indicates that the beds may have been laid down largely through the process of chemical precipitation, or in tranquil waters without strong currents.

GODIVA LIMESTONE.

This formation, about 2,200 feet thick, succeeds the Eureka. As distinguished from the Eureka, however, it is essentially a pure limestone. For 1,200 feet from the base the prevailing colors are gray and blue. The lower portion, however, is further diversified by the occurrence of two or three sandy beds. The upper 1,000 feet of the formation consist mainly of blue crystalline and black carbonaceous beds containing many fossils, chiefly corals and crinoids, with occasional beds rich in chert nodules and lenses.

A section made from between the Mammoth shaft and Mammoth Peak across Mammoth Bluffs gave the following descending sequence:

Section from between the Mammoth shaft and Mammoth Peak across Mammoth Bluffs.

	Feet.
43. Granular fossiliferous blue limestone, nodular at base	150
42. Black fossiliferous limestone	12
41. Gray shaly limestone	22
40. Black fossiliferous limestone	17
39. Granular blue limestone	100
38. Cherty nodular limestone	5
37. Blue granular limestone	40
36. Gray limestone, with scattered chert nodules	85
35. Blue cherty limestone, containing pale blue fossiliferous beds	45

	Feet.
34. Gray-blue limestone, with nodules and stringers of chert	390
33. Black shaly limestone, somewhat nodular at top	100
32. Black massive limestone	30
31. Blue cherty limestone	100
30. Brownish-gray fossiliferous limestone	165
29. Blue limestone	30
28. Light brownish-gray limestone	70
27. Concealed	70
26. Sandy limestone, quartzite at base	10
25. Gray limestone	25
24. Sandy limestone and quartzite	50
23. Gray to blue limestone, with many seams of calcite near top	75
22. Gray limestone	225
21. Dark-gray limestone, well bedded at top	210
20. Faintly bedded gray limestone	80
19. Crumpled, ribbed, gray limestone	10
18. Gray limestone, poorly bedded	100
Total thickness	2,216

The accompanying partial analysis is of a specimen of this limestone taken from the upper beds:

Partial analysis of a specimen from the upper beds of the Godiva limestone.

	Per cent.
SiO_2	0.57
Fe_2O_3	.90
CaO	55.22
MgO	.41
CO_2 (*a*)	43.84
Total	100.94

a Calculated.

Microscopic studies of the various beds of this formation show that it is made up almost entirely of crystalline calcite. Dolomite occurs in some of the beds, but never in sufficiently great abundance to affect the texture of the rock. Aside from the beds of siliceous limestone, there is scarcely an appreciable amount of quartz.

HUMBUG INTERCALATED SERIES.

This formation, which is the uppermost of the Tintic sedimentary series, has been called "Humbug," from the mine by this name, where it is best exposed. It consists of a number of beds of fossiliferous limestones, alternating with sandy limestones and limy sandstones, the individual beds of which do not persist along the strike. Its total thickness is 250 feet.

A descending section on the east flank of Sioux Peak is as follows:

Section on the east flank of Sioux Peak.

	Feet.
54. Brown quartzitic sandstone	12
53. Black fossiliferous limestone	25
52. Brown sandstone	5
51. Blue limestone	4
50. Brown sandstone, in part quartzitic	90
49. Bluish gray limestone	3
48. Sandstone and limestone	50
47. Reddish sandstone	25
46. Gray sandy limestone	6
45. Sandstone	.75
44. Light-brown sandy shale	30
Total	250.75

A second section, made on the east flank of Godiva Mountain, showed a marked difference in the order and thickness of the alternating beds, and indicates that a perfect agreement between any two sections is impossible, owing to the fact that the various beds thin out along the strike and are replaced by other beds.

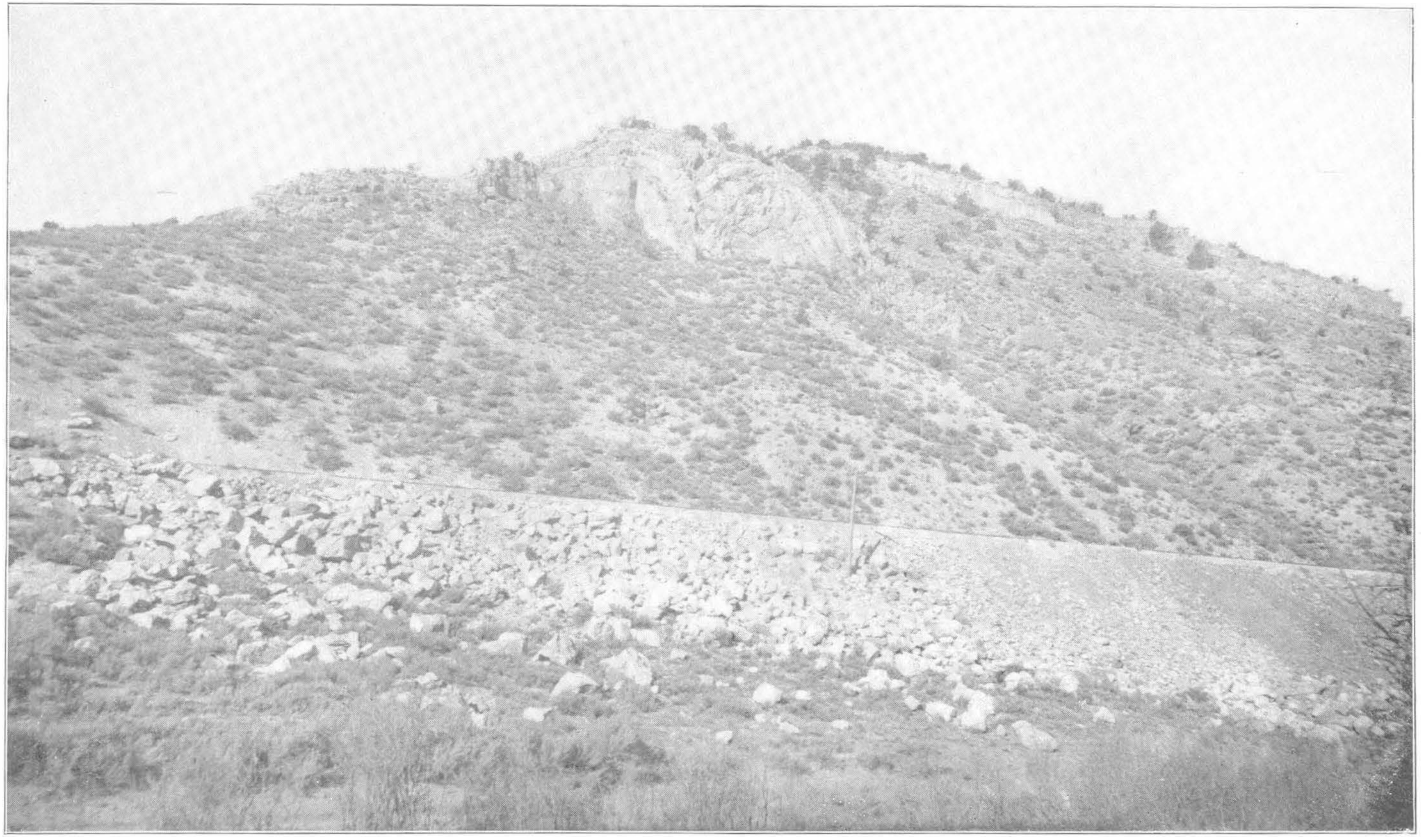
The various beds, though distinct, alternate rapidly and present numerous transitions, which indicate prevailing shallow water conditions and an alternation of strong currents and rapid washing down from the land, with tranquil deposition without strong currents.

The sandstones are greenish in color, weathering to brown, and a slight effervescence upon the application of acid indicates the presence of lime carbonate. Under the microscope they present a uniform appearance and are seen to consist of rounded quartz grains, nearly always separated by cryptocrystalline calcite. The limestone is either blue or dark bluish black, the blue limestone being highly crystalline, while the darker ones are very fine grained and compact in texture. The fossils are either crinoids or corals. The accompanying partial analysis is of one of the sandy limestones:

Partial analysis of a specimen from one of the sandy limestones of the foregoing section.

	Per cent.
SiO_2	17.19
Fe_2O_3	.48
CaO	43.78
MgO	.91
CO_2 (*a*)	35.40
Total	97.76

a Calculated.



MINOR FOLDING IN EUREKA LIMESTONE, NORTH SIDE OF HOMANSVILLE CANYON.

DISTRIBUTION.

The largest area of sedimentary rocks exposed extends from a point just south of Sioux Peak northward beyond the northern boundaries of the quadrangle.

The structure of this area is that of a northerly pitching syncline, whose axis trends about N. 10° W. and runs along the steep eastern slope of Godiva Mountain. The most continuous exposures are those of the Robinson quartzite, on the western limb and along the west flank of the range. These beds usually dip to the east at a high angle, but are sometimes vertical or have a westerly dip. The beds on the eastern limb have a much shallower dip, averaging about 25° W., and project up through the covering of rhyolite at various points on the east slopes of the range overlooking Goshen Valley.

The next largest area of sedimentary rocks is on the east side of Goshen Valley, at the northern end of Long Ridge. This consists of easterly dipping Robinson quartzite, overlain by limestone, and forms part of a large area of sedimentary rocks which extends eastward to the base of Mount Nebo in a second syncline. A part of this exposure is also seen near the mouth of Currant Creek, at the edge of the quadrangle.

Several masses of easterly dipping limestone are found near the southern edge of the quadrangle, and some small masses of quartzite occur in the eruptive areas along the west flank of the southern portion of the Tintic Range. It is probable that these latter are isolated portions of the western limb of the syncline, being on the line of strike with the beds farther north. The areas of both limestone and quartzite either project up through the igneous cover or are caught-up masses.

AGE OF THE SEDIMENTS.

The exact position of these beds in the geologic column is only partially established, since they are separated from well-determined localities by great areas of more recent lake and valley deposits.

The Robinson quartzite, which is the basal member of the stratigraphic column, is probably Cambrian, though it yielded no determinable fossils, either in the quartzite or in the slate beds. It is referred to the Cambrian because of its resemblance to occurrences at other localities in the Wasatch and Basin ranges, especially Ophir Canyon in the Oquirrh Range, where similar and similarly associated great thicknesses of quartzite with clay slates at the top have been found to contain Cambrian fossils.

The determination of the age of the Eureka limestone rests upon very slender paleontologic data. About 1,500 feet from the base of this formation a single fossil was found, which Mr. Girty has determined to be *Productus costatus*, and of which he says:

> The shell . . . is the form identified by Meek[1] as *P. costatus* ? ? var., being not so similar to the individuals figured as to others from the same locality and identified

[1] U. S. Geol. Expl. Fortieth Par., Vol. IV, p. 69, Pl. VII, figs. 4 and 4*b*.

as the same, among which the specimens submitted to me can be exactly matched. Of this formation Meek says[1] "it is with considerable doubt that I have ventured to refer this shell to the variable species *P. costatus*, though it seems to be the form that has generally been identified with that species in our Coal Measures and the Lower Carboniferous rocks of the Mississippi Valley." . . . It is represented in the National Museum collections from a number of localities in the Coal Measures.

This formation is assumed to be more probably Lower Carboniferous than Coal Measures because of the slight thickness of beds between the horizon of these fossils and the underlying Cambrian, in which, if the succession of beds is complete, the Silurian and Devonian should be represented.

In the Oquirrh Range, however, no Devonian has been found, and it has been assumed that there has been a hiatus in the geologic succession, and that the Devonian is not represented there, either through nondeposition or in consequence of an unconformity by erosion. In the Tintic Range the thickness of the stratigraphic series between the solid quartzite and the massive limestone varies so greatly at different points as to suggest that there may have been an unconformity here also. Furthermore, on the north slopes of Eureka Peak well-defined sandy beds were found in the slates, which dip to the east at an angle of 45° to 50°, while the overlying beds of limestone dip to the east at an angle of not less than 70°, but without any apparent difference in the strike of the two formations. This may be the result of dynamic action and may not indicate an unconformity.

The Godiva limestone and the Humbug Intercalated series belong to the Coal Measures of the Carboniferous age. The fossils taken from these strata have been determined by Mr. Girty to belong to the Coal Measures. Those fossils definitely recognized were Syringopora, *Productus punctatus*, and zaphrentoid corals. Concerning them he says:

Syringopora sp. *b* is, I think, the same form identified by Mr. White as *S. multattenuata* McChesney in Wheeler's United States Geographical Survey west of the One hundredth Meridian, Volume IV, 1877, page 100, and a form apparently the same is represented in the National Museum collections from the ridge of Morgans Peak, Utah.

Syringopora sp. *a* is very close to, if not the same as, species in the National Museum collections from Little Cottonwood Canyon, Utah.

While the type represented by *Productus punctatus* begins well down in the Mississippian (at least as early as the Keokuk), and while Syringopora sp. *a* and sp. *b* are quite similar to certain species of Mississippian age, especially to two differing about equally in size from the Madison limestone of Yellowstone Park (*S. multattenuata*, mentioned above, however, is a Coal Measure type), nevertheless stratigraphic considerations seem to indicate that these several localities, at least, belong to the Coal Measures, for even if the locality furnishing *Productus costatus* can properly be referred to the Mississippian series, it is improbable that this series can have attained a thickness of 2,000 or 3,000 feet, or more, so as to include the higher beds as well.

The Humbug Intercalated series overlies the Godiva conformably and corresponds paleontologically with it, the fossil beds containing the same crinoids and corals that were found in the Godiva.

[1] U. S. Geol. Expl. Fortieth Par., Vol. IV, p. 70.

We have, then, in the Tintic Mountains, Cambrian quartzite capped with clay slates, which together are over 7,000 feet thick; immediately over this 6,650 feet of strata, of which the upper 5,150 feet, judging from the fossils, belong to the Carboniferous and most likely to the Coal Measures, making the total thickness of the strata exposed in these mountains about 14,000 feet.

CORRELATION.

The nearest studied exposures of corresponding geologic horizons with which the sedimentary beds of the Tintic Mountains may be correlated are in the Wasatch and Oquirrh mountains. The correlation with either locality is not satisfactory in every respect, but in succession of beds the resemblance to those of the Oquirrh is greater than to those of the Wasatch Range.

Concerning the Paleozoic rocks in the Wasatch Mountains Emmons says[1]:

The thickness of the members of the Paleozoic column, as recognized in the Wasatch Mountains by the geologists of the Fortieth Parallel Survey, was, in round numbers, as follows:

Paleozoic section in the Wasatch Mountains.

System.	Formation.	Average thickness.
		Feet.
Carboniferous (15,000 feet)	Upper Carboniferous limestone (including Permian.)	2,500 to 3,000
	Weber quartzites with a few thin beds of limestone.	5,000 to 7,000
	Wasatch limestone (with Waverley and Devonian fossils at the base.	7,000
Devonian (2,000 feet)	Ogden quartzite	1,000 to 1,250
Silurian (1,000 feet)	Ute limestone	1,000 to 1,250
Cambrian (12,000 feet)	Big Cottonwood quartzite series (clay slates at top).	12,000
Total, about		30,000

* * * * * * *

In the Cottonwood region of the Wasatch Range, and northward from there, the lithological separation of Weber quartzite from Wasatch limestone is sharp and distinct, the one being almost as free from limestone as the other is from siliceous beds. To the southward, however, in the Timpanogos Peak region, the upper part of this great limestone zone consists of a series of alternating beds of quartzite and limestone, which were called the Intercalated series, and which probably in part represent the Weber quartzite.

[1] Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 362.

From this it appears that the Tintic section must correspond to the lower part of the Wasatch section from the Wasatch limestone downward, but the Ogden quartzite and Ute limestone of this section are not recognized here either lithologically or paleontologically.

Concerning the rocks of the Oquirrh Mountains Mr. Emmons says[1]:

> On the north side of Ophir Canyon . . . [the] Cambrian quartzite has been uplifted by the throw of a fault running parallel to the course of the canyon, and at right angles to the axis of the anticline. Above the quartzite . . . are characteristic greenish clay slates, carrying primordial trilobites, and back of these again rise 2,000 feet of limestone cliffs, in which sub-Carboniferous or Waverly fossils have been found near the top of the wall. On the south side of the canyon . . . [is] limestone 2,000 feet in height. . . . Near the summit . . . is an ore-bearing zone, that probably occupies very nearly the same horizon as that which is known in Lewiston Canyon as the Silver ledge. If this assumption be correct, the base of the south wall of Ophir Canyon is at least 1,000 feet lower in horizon than the lowest beds exposed in Lewiston Canyon.

In this same report Spurr says:[2]

> . . . Beginning . . . near the mouth of Lewiston Canyon . . . this conformable series may be divided into (1) the Lower Blue limestone . . . about 200 feet; (2) the Lower Intercalated series, consisting of interbedded limestones and calcareous sandstones, having a thickness of about 600 feet; (3) above this a very thick blue limestone which has been designated the Great Blue limestone, and which has a thickness of about 5,000 feet. . . . Above the Great Blue limestone comes (4) the Upper Intercalated series, consisting of interbedded limestones and sandstones, like the lower series . . . [showing] a thickness of 5,000 to 6,000 feet. There is thus exposed in that part of the Oquirrh Mountains which we have called the Mercur Basin a total thickness of nearly 12,000 feet of strata.

It thus appears that the strata on the south side of Ophir Canyon belong immediately under those described by Spurr in Lewiston Canyon, and may add 1,000 feet to his section, thus making the total thickness below the Upper Intercalated series about 7,000 feet. There is, however, some uncertainty as to the size of the interval between the base of this section and the top of the quartzite in Ophir Canyon.

Concerning the age of the beds exposed in the Lewiston Canyon section, the fossils determined by Mr. Charles Schuchert[3] indicate that the beds below the middle of the Great Blue limestone are of Lower Carboniferous or Mississippian age, while the Upper Intercalated series is of Coal Measures or Upper Carboniferous age, fossils of the intermediate beds forming a gradually changing series.

The sequence in the strata of the Oquirrh and the Tintic mountains is similar, both lithologically and paleontologically, except that the Lower Intercalated series of Mercur is not found at Tintic. Hence it is impossible to compare the relative thicknesses of the various formations. The Paleozoic section represented in the Tintic Mountains probably extends up to the Upper Intercalated series of the Oquirrh Mountains. It is evident that the Robinson quartzite corresponds to the Cambrian

[1] Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 363.
[2] Loc. cit., p. 376.
[3] Loc. cit., p. 377.

quartzite at Ophir Canyon; the Eureka limestone probably includes the Lower Blue limestone and the lower part of the Great Blue limestone of Lewiston Canyon; the Godiva limestone, at least the upper half of the Great Blue limestone; and the Humbug Intercalated series evidently represents the same change in conditions of sedimentation as does the Upper Intercalated series of Lewiston Canyon. If these assumptions be correct, there has been eroded from the Tintic Mountains the greater portion of the Upper Intercalated series, which has a total thickness of over 5,000 feet, and the Weber quartzite represented in Bingham Canyon, with a thickness of 6,700 feet, or at least 12,000 feet of strata.

Of the Canyon Range, to which a hasty reconnaisance trip was made by Mr. Smith, it can only be said that the Cambrian quartzite is evidently represented and the succession of overlying beds is similar.

CHAPTER III.

IGNEOUS ROCKS.

RHYOLITE.

Distribution.—Areally the rhyolite is an important rock in the Tintic mining district. It extends to the north and east of the town of Eureka, and here forms the crest of the range. Its vertical range is over 2,700 feet, from the summit of Packard Peak to the edge of Goshen Valley. The outline of this area is, in places, very irregular, and the contact between the rhyolite and the limestone is, in great part, concealed by surface detritus. East of Godiva Mountain the areas of the two rocks interlock in a complex manner.

Rhyolite also occurs in other parts of the Tintic Mountains. One of these rhyolitic areas lies immediately north of the Tintic quadrangle, and a tongue from it extends within the limits of the quadrangle, on the northeast slope of Pinyon Peak. In the southern part of the Tintic Mountains another mass of rhyolite is found, the northern part of which comes within the Tintic quadrangle. Here, as at the north, the contact with the limestone is often difficult to trace. Smaller patches of rhyolite occur elsewhere in the area mapped, in association with limestone or quartzite.

Description.—The rhyolites of the Tintic Mountains show many variations in appearance, both in the different areas and within the limits of a single area. In color they range from light and dark gray to a bright pink and light purple. On the surface they are often yellowish or rusty, due to the tendency to oxidation of the iron content. The obsidian phase of the rhyolite in certain occurrences is almost black. The different rhyolites are rough, often porous and vesicular.

The megascopic texture of these rhyolites shows three quite distinct varieties. One type is granite-like; the granular appearance of the rock is due to the crowded phenocrysts being so much in excess of the glassy base. This is the nevadite of some authors. Another type is plainly porphyritic, with the phenocrysts of quartz and feldspar less abundant than the cryptocrystalline groundmass. This type corresponds to liparite; it is more quartz-porphyry-like in appearance and more rarely contains glass than the type first mentioned. A third type shows rhyolitic textures of flow banding, phenocrysts being rarely seen. The black obsidian, which is of comparatively rare occurrence, comes under this third type.

The megascopic phenocrysts are quartz, feldspar, and biotite. Of these, the black biotite is often the most prominent. In some specimens of the rhyolite this biotite shows a parallel arrangement of the plates, due to flowage, which is so prominent as to give somewhat of a schistosity to the rock. In other cases the biotite lacks any such parallel arrangement. Quartz appears almost universally as a porphyritic constituent, the angular crystals often projecting from the weathered surface and thus being especially noticeable. Feldspar varies much in amount, and thus in prominence. In some of the most typical of the rhyolites the fresh crystals of sanidine are large and so abundant as to make the rock much lighter colored than other types less rich in feldspar phenocrysts.

Petrographic details.—Studied microscopically, these rocks are plainly rhyolites, even when little of a diagnostic character can be seen in the hand specimen. The quartz is perhaps the most abundant of the phenocrysts, occurring in sharply defined bipyramidal crystals and in round anhedra. The amount of magmatic corrosion has been very great, and few phenocrysts are seen which have not suffered to some extent. Often the phenocrysts have been shattered and the cracks between the fragments filled with glass. Glass inclusions are rarely noted.

Tridymite was observed in one specimen of rhyolite. This mineral occurs in minute scales, some of which are rudely hexagonal in outline. The tridymite aggregates appear scattered throughout the rock, and clusters of scales often project into cavities in the lava. In no case, however, was the mineral recognizable megascopically.

Of the feldspar, the orthoclastic is the more abundant. Besides large phenocrysts of sanidine, fragments of orthoclase are seen, as well as smaller individuals which belong to the groundmass. The plagioclase feldspar is rather acid in composition, is sometimes zonal, and shows twinning, both by the pericline and the albite laws. Few parallel growths of orthoclase and plagioclase were observed.

Biotite occurs in hexagonal plates and shreds of a dark-brown color, as seen in thin section. These plates often show bending and breaking. They vary much in size, being at times very minute, and again equal to and even exceeding the other phenocrysts in size. In one case the biotite appears to be younger than the quartz, as a plate of the former mineral is molded around the pyramidal termination of the quartz phenocryst.

Hornblende was observed in small crystals in the rhyolite from the vicinity of Packard Peak and in that south of Pinyon Creek. Magnetite is universally found in small amounts in the rhyolites, while apatite and zircon are less persistent constituents. The apatite is often associated with the biotite, while all three of these earlier secretions of the magma often occur in intimate association.

In the microscopic textures there is the range from holocrystalline groundmass to the typical glassy base with obsidian characters. The quartz and feldspar mosaics of the groundmass approach the cryptocrystalline character on the one hand, and on the other become nearly microgranitic. The rather stout habit of the feldspars gives an orthophyric texture to the groundmass of certain of the rhyolites. The glass base is usually very light colored and transparent. Flowage is beautifully expressed by the sinuous lines of trichites and microlitic particles of iron oxide, which weave intricate and delicate patterns. Spherulitic crystallization is of minor importance in this glassy base, but a tendency to the formation of microspherulites was noted in at least two cases. Here this form of crystallization was confined to definite bands.

In a number of these rhyolites there is a marked shattering of the phenocrysts, often with only slight displacement of the fragments. In the latter case this is plainly due to the movements in the lava stream during consolidation. In other cases the rock is full of angular fragments of quartz and feldspar, and the shattering doubtless occurred earlier in the process of the eruption of the lava. In one case the rock can best be described as a rhyolitic flow breccia, the rhyolitic glass having in part consolidated sufficiently to be brecciated, and yet the fragments of this glass, which shows delicate flowage textures, have not been greatly displaced since such brecciation. Such shattering of phenocrysts and glassy base might be reasonably expected in the eruption of an acid magma and its consolidation in lava streams.

Chemical composition.—The rhyolite, the chemical analysis of which is given below, is a gray porphyritic variety occurring south of Pinyon Creek. Large crystals of sanidine, with smaller individuals of quartz, biotite, acid plagioclase, and hornblende, are the phenocrysts, the hornblende occurring only sparingly. Tridymite, magnetite, apatite, and zircon are other constituents. The groundmass is for the most part crystalline, with only a small amount of glassy residue. The analysis, by Dr. Stokes, is as follows:

Analysis of rhyolite, south of Pinyon Creek, Tintic mining district, Utah.

	Per cent.
SiO_2	69.18
TiO_2	.69
Al_2O_3	14.37
Cr_2O_3	Trace.
Fe_2O_3	2.52
FeO	.57
MnO	.10
CaO	1.88
SrO	Trace.
BaO	.09

Analysis of rhyolite, south of Pinyon Creek, Tintic mining district, Utah—Continued.

	Per cent.
MgO	.70
K_2O	5.00
Na_2O	3.58
Li_2O	Trace.
H_2O at 110°	.35
H_2O above 110°	.25
P_2O_5	.26
Cl	Trace.
V as V_2O_5	.01
Mo	Trace.
Total	99.55

This rhyolite is seen from the above analysis to approach in composition a trachyte. The abundance of free silica, which has crystallized as phenocrystal quartz, however, justifies the determination of this lava as rhyolitic.

QUARTZ-PORPHYRY.

Distribution.—This rock type is limited to a few occurrences. The principal area is a belt one-fourth mile in width, extending from Robinson to Silver City. Separated from this only by the alluvium of the basin is a mass of quartz-porphyry, which forms the greater part of the hill just on the edge of the village of Robinson. These two areas doubtless belong to the same rock mass. In the southern part of the area this rock has an economic interest, as the country rock of a well-defined ore vein, on which are located two important mines, the Swansea and the South Swansea.

Another occurrence, apparently somewhat connected with this, is on Horseshoe Hill, near the mouth of Diamond Gulch. Other smaller bodies of intrusive rock closely related to the quartz-porphyry are found elsewhere in the Tintic district.

Description.—The quartz-porphyry of the larger area is light-gray in color, often with a green or pink tint. Phenocrysts of flesh-colored feldspar and of clear quartz are more or less abundant and prominent, while in a few cases there are traces of the presence of a darker constituent. The groundmass varies in texture from felsitic to granitic, being in the latter case very fine grained.

Petrographic details.—Examined microscopically, the rock is found to have suffered more alteration than is apparent megascopically. The feldspar phenocrysts are usually clouded and often so completely altered that exact determination is impossible. Both orthoclase and plagioclase are present, the former being more abundant. The feldspars are only imperfectly idiomorphic, and in one specimen it is evident that growth of the phenocrysts was suddenly interrupted by the groundmass crystallization, as small grains of feldspar and quartz project into the outer zone of the larger crystals of orthoclase and quartz.

Quartz is rather more abundant than the feldspar and possesses the usual characters of porphyritic quartz. Many of the crystals were corroded and cracked previous to the consolidation of the rock. The magmatic corrosion is often confined to one side of a crystal, while on the other the crystal boundaries are perfectly sharp. Bipyramidal inclusions of glass occur in the quartz. Biotite is not common as a constituent, but occurs sparingly in irregular plates, often extremely altered. Magnetite is abundant and is probably titaniferous in part. Apatite and zircon are other accessory constituents. In one aggregate of these three earliest secretions pyrite was seen in intimate association. Other occurrences of the pyrite are as grains and crystals in the feldspar and quartz phenocrysts, and especially following cracks in the rock, associated with secondary quartz.

An interesting feature is the occurrence of tourmaline in the quartz-porphyry from the east crosscut on the 350-foot level of the Swansea mine. It is a megascopic constituent, small spots of the black mineral with its radiate structure and silky luster being scattered throughout the rock. In the thin section this quartz-porphyry is characterized by an abundance of quartz phenocrysts, with irregular outlines due to magmatic resorption. The feldspars are badly altered, as is also the cryptocrystalline groundmass. The tourmaline occurs in aggregates of long acicular prisms, with the characteristic cross fractures. It is strongly pleochroic, the ordinary ray giving deep blue and greenish-blue tints, and the extraordinary varying from colorless to light brown. These radiate groups of tourmaline needles in part replace the feldspar and in part occur in the groundmass. In one instance an aggregate was noted abutting against the edge of a quartz phenocryst. This occurrence of tourmaline in a quartz-porphyry has many points of resemblance to that described by Weed and Pirsson from the Castle Mountain mining district, Montana.[1] As remarked by these authors, this mineral is rarely found as a constituent of quartz-porphyry, and the Castle Mountains and the Tintic Mountains are the only known American localities.

The quartz-porphyry of Horseshoe Hill is more difficult of determination, as the rock has been extremely altered. It is fine grained, porous, and considerably bleached. On the weathered surface phenocrysts of quartz can be seen, and rarely large prismatic crystals of pink feldspar. Under the microscope it is evident that both the feldspar phenocrysts and the groundmass have suffered muscovitization. The structure, however, is somewhat preserved in the masses of this secondary mineral, which is very plentiful both in small fibers and in larger plates or shreds.

[1] Bull. U. S. Geol. Survey, No. 139, 1896, p. 99.

Chemical composition.—The quartz-porphyry from the Swansea mine was selected for chemical analysis. This rock is light gray in color, with phenocrysts of feldspar and quartz in a microgranitic groundmass. The orthoclase is somewhat altered. Biotite is a microscopic constituent occurring sparingly in small plates. Secondary pyrite is scattered throughout the rock. Magnetite, apatite, and zircon are other constituents, and a small amount of chlorite is present. The analysis by Dr. Stokes gives the following result:

Analysis of quartz-porphyry (rhyolite) from the Swansea mine, Tintic mining district, Utah.

	Per cent.
SiO_2	71.56
TiO_2	.38
Al_2O_3	14.28
Cr_2O_3	Trace.
Fe_2O_3	*a* .89
FeO	*a* Undet.
MnO	Trace.
CaO	1.18
SrO	Trace.
BaO	.28
MgO	.42
K_2O	4.37
Na_2O	3.00
H_2O at 110°	.36
H_2O above 110°	.79
P_2O_5	.13
FeS_2	2.29
Cl	.06
V as V_2O_5	.02
As	Trace.
	100.01

a Total S is calculated as FeS_2; there is present, however, a trace of sulphide decomposable by acid. All Fe not as Fe_2S calculated as Fe_2O_3.

The above analysis shows this quartz-porphyry to have a composition approximately similar to that of the rhyolite, given on page 634. It is somewhat richer in silica and poorer in the alkalies, but the potash and soda show the same relation to one another. Like the rhyolite, it contains rather more lime than the average member of the granite-rhyolite family. The difference in iron oxides is due partly to the FeS_2 present, as the pyrite appears in part to replace magnetite.

Nomenclature.—These two rocks (rhyolite and quartz-porphyry), with essentially the same mineralogic and chemical composition, evidently belong to the same magma, and, notwithstanding a slight difference in texture, the quartz-porphyry might well be classed with the rhyolite. Such a usage is adopted in the Tintic folio, where this quartz-porphyry is termed the Swansea rhyolite. In view, however, of the intrusive character of this rock and its economic importance, as well as local usage, which distinguishes it from the effusive rhyolite, it has seemed best in this report to use the term quartz-porphyry.

ANDESITE.

Distribution.—The andesite occurs principally in the southeastern part of the Tintic district, outside the area of mining developments. In the southern part of the Tintic Mountains this rock is of very widespread distribution. The crest and both slopes are of andesite, with a few small areas of quartzite, limestone, or rhyolite. Tintic Mountain, 8,214 feet high, the highest peak of the range, is composed of andesite.

Andesite is also found northeast of the mining district, extending beyond the northern boundary of the Tintic quadrangle. Nearly one-half of the area comprised within the limits of this quadrangle, or over 100 square miles, is covered by andesite and its associated tuffs and breccias. It is, therefore, preeminently the igneous rock most characteristic of the Tintic Mountains, although other types are more common in close proximity to the mines. The name Tintic andesite is given to all of these lavas which are andesitic in general composition.

Description.—In view of its occurrence in such large areas in the Tintic Mountains, it is not surprising that the andesite exhibits considerable variation. As will be described in the following chapter, these andesitic lavas were erupted from at least two distinct, although neighboring, vents; and, furthermore, they represent eruptions which took place at different times. The variation is perhaps more noticeable megascopically than microscopically. In one locality the andesite is a loose-textured gray rock; in another it is of a dark-purple color, compact and glassy; or the andesite may be bright green or deep red in color, with prominent phenocrysts. In general, however, the Tintic andesite is not bright colored, but commonly is dark gray, with a marked tendency to purple. Usually quite compact, it however exhibits many of the vesicular and scoriaceous phases characteristic of lavas. In such loose-textured andesites opaline silica often occurs. This sometimes fills large cavities in the rock, but never possesses the play of colors of precious opal. The andesites are almost without exception porphyritic, with both feldspar and the darker constituents as phenocrysts. At times the white feldspar crystals are so much in excess of groundmass as to make the rock closely resemble the monzonite-porphyry, described on page 644.

Although certain of these rocks are very distinct in their megascopic characters, in no case are these persistent enough to enable different flows to be distinguished over large areas. Studied in thin sections these andesites are found to present considerable mineralogic diversity, more especially in the character of the ferromagnesian constituents.

Biotite, hornblende, augite, and hypersthene are present, together or separately. Thus, with a strict separation of the mineralogic types, the Tintic andesite, as this group of rocks is named on the geologic maps, would be found to include mica-andesite, mica-pyroxene-andesite, pyroxene-andesite, augite-andesite, and hypersthene-andesite, any of which may occasionally carry a little hornblende. In a general way, the mica-andesite may be said to be confined to the eastern slope of the central portion of the range. The andesites containing both or either of the pyroxenes cover by far the greater part of the area here considered.

Petrographic details.—Microscopic study of the Tintic andesite shows the groundmass to possess textures typical of lavas of intermediate composition. The groundmass may or may not be in excess of the phenocrysts. Its texture is generally hyalopilitic, the microlites of feldspar and the gray or light-brown, glassy base varying in their relative proportions. Grains and globulites of iron oxide at times render the glass quite opaque. The microlites and twinned laths of feldspar, the less abundant anhedra of augite, and the minute crystals of magnetite usually exhibit fine flowage around the phenocrysts. Certain of the andesites, which perhaps may be better termed andesite-porphyries, are quite holocrystalline, yet the groundmass shows flowage textures and they are quite different in general appearance from intrusive types. The groundmass of the andesites is sometimes spotted, while one specimen shows an eutaxitic mingling of glass of different colors and degree of crystallization. Angular fragments of earlier andesites are found in some of the later flows.

Amygdaloids occur at various points within the andesite area, and in these the amygdules are filled with chlorite, calcite, quartz, and chalcedonic silica.

The most important porphyritic constituent of the andesites is the plagioclase. It occurs in perfectly idiomorphic tabular crystals of good size, grading down to the laths of the groundmass. They are usually twinned by the albite law alone, or by both the albite and Carlsbad laws. The twinning by the latter law is not only evident when the thin section is examined in polarized light, but is also plainly indicated in the outline of the cross section of the feldspar. The plagioclase crystals are often zonal, both in their successive layers of varying composition and in the arrangement of inclusions. In one section the outer zone is of untwinned feldspar, while the core of relatively more basic feldspar shows the usual albite lamellation. Some phenocrysts have inclusion-rich cores, the inclusions being of glass or, more rarely, of augite and apatite. In other cases the inclusions are confined to the outer zone. Extinction angles measured on the compound twins show the feldspar of these rocks to be mostly labradorite. Angles indicating a basic andesine were noted, but the more common extinctions were those of a feldspar with the approximate composition of Ab_3An_4.

In the mica andesite the phenocrysts of biotite are often larger and more prominent than the feldspar. The hexagonal plates are of good size and of a bright-brown color. Resorption is almost universal where the biotite is of minor importance. The black borders are common, while at times the entire phenocryst is thus affected. In the augite-andesite the biotite is sporadic in its occurrence, and only corroded remnants of crystals are seen.

Of the two pyroxenes present in these andesites the monoclinic is the more imporant. Although quite commonly both are present, a large number of specimens collected from various parts of the area of Tintic andesite have augite as the predominant ferromagnesian constituent, while only a few can be termed hypersthene-andesite. The augite occurs in sharply bounded crystals, large and small, light green in the thin section, and at times faintly pleochroic. It shows the common type of twinning in the larger crystals. The augite of the groundmass occurs in round anhedra, in which form it is also found included in the feldspar. In part, at least, the phenocrysts of augite are older than the biotite.

The orthorhombic pyroxene is easily distinguished from the augite by the parallel extinction, as well as by the marked difference in pleochroism and double refraction. The prisms of the former mineral have also the characteristic cross fractures. The pleochroism is in the different shades of green and light brown, but is less marked than in the hypersthenes richest in iron. This fact, together with the large optical angle about the negative acute bisectrix, makes it probable that this orthorhombic pyroxene is a hypersthene, rather poor in its iron content. In certain of the occurrences the hypersthene has been altered to chlorite, while the augite remains perfectly fresh. In other cases the ferromagnesian constituents are represented simply by chlorite, and the forms of the phenocrysts may not be such as to indicate the species of the original mineral.

Hornblende is never more than an accessory constituent in these andesitic lavas, and appears to be more characteristic of the porphyry phase of the andesite. It is brown basaltic hornblende for the most part and often shows resorption borders. The hornblende phenocrysts are much smaller than those of pyroxene.

Olivine was observed in one specimen, but was purely accessory; and in no case do these andesites show any approach to a basaltic type. Quartz is an accessory constituent in two of the hypersthene-andesites, in one instance the quartz being imperfectly idiomorphic. In another andesite, characterized by the presence of both biotite and augite, the quartz anhedra appear to be of the nature of fragments caught up in the light-gray glass. In the andesite-porphyry near the center of eruption the quartz has the form of corroded phenocrysts with reaction rims. Other accessory constituents are magnetite and apatite, which are abundant, and zircon, which only rarely occurs, while ilmenite is probably present. The magnetite is in crystals and grains in the groundmass and associated with the pyroxene and mica. The apatite crystals are often quite large, one needle being over 1.5 mm. in length. Some prisms have the axial inclusions and are slightly pleochroic. This mineral is associated with the magnetite and augite and also occurs included in the feldspar. Secondary minerals in the Tintic andesite are calcite, chlorite, quartz, epidote, serpentine, and pyrite.

Mention should be made of two andesite-porphyries which occur as dikes in the rhyolite. These carry phenocrysts of labradorite, biotite, and augite, while augite is very plentiful in the holocrystalline groundmass. Quartz is rather abundant in one—in phenocrysts—which have suffered some magmatic corrosion. One basal section of quartz exhibits a well-defined cleavage parallel to the rhombohedron. These crystals of quartz may possibly have been derived from the neighboring rhyolite.

Chemical composition.—The specimen selected for chemical analysis was collected on Tintic Mountain and represents a type very important areally and belonging to the latest eruption. It is a compact, glassy rock, dark, and somewhat purplish in color, the phenocrysts of biotite and feldspar showing a general parallelism. Plagioclase, chiefly labradorite, augite, biotite, hypersthene, magnetite, and apatite, occur in a dark-gray glass in which the feldspar microlites are not very abundant. The analysis by Dr. Stokes is given as I in the table below, II and III being analyses of similar rocks from other areas.

Analyses of Tintic andesite (I) and of two other similar rocks.

	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	60.17	59.43	61.58
TiO_2	.87	1.38	.68
Al_2O_3	15.78	16.68	16.34
Fe_2O_3	3.42	2.54	6.42
FeO	2.95	3.48	....
MnO	.11	Trace.	....
CaO	4.69	4.09	5.13
SrO	.09	Trace.	....
BaO	.14	.14	....
MgO	2.52	1.84	2.85
K_2O	4.16	5.04	3.65
Na_2O	2.96	3.72	2.69
Li_2O	Trace.	None.	....
H_2O at 110°	.25	.27	....
H_2O above 110°	1.23	.72	Ign.= .64
P_2O_5	.40	.58	.28
V as V_2O_5	.01	ZrO_2= .08	....
Cl	.04	.05	....
	99.79	100.04	100.26

I. Tintic andesite, Tintic Mountain, Utah. Stokes, analyst.

II. Augite-latite, Dardanelle flow, California. Stokes, analyst; Bull. U. S. Geol. Survey No. 89, p. 58.

III. Pyroxene-andesite, Richmond Mountain, Eureka, Nevada. Drown, analyst; Mon. U. S. Geol. Survey, Vol. XX, p. 264.

The Tintic andesite, as represented by the Tintic Mountain type, is seen from this analysis to be a lava of intermediate composition as regards its silica percentage. It is characterized by a higher percentage of the alkalies and a lower of lime than is usual in typical andesites. Furthermore, as expressed in percentages, the potash much exceeds the soda, which quite distinguishes this rock from members of the diorite-andesite family. These features, on the other hand, are such as to express some relation to the syenite-trachyte family, and this rock from its chemical composition must be placed in an intermediate class. For such a class of effusive rocks, which are in chemical composition about midway between the typical trachytes and the typical andesites Ransome[1] has proposed the name *latite*. Comparison of analyses I and II will show the essential similarity of the Tintic Mountain rock to the augite-latite occurring on the western slope of the Sierra Nevada. It is to be noted that the two rocks agree in having the two alkalies nearly equal in the molecular proportions present, the soda in each case being slightly in excess. This relation of the alkalies also holds in the case of a pyroxene-andesite from Richmond Mountain, Eureka district, Nevada (analysis III). This latter rock is apparently of the latite type and is mentioned in this connection as suggestive of the importance of the latites in the Great Basin region.

All three of the above-mentioned rocks agree in having the mineralogic composition of pyroxene-andesite.[2] It is evident that since these rocks do not contain any noteworthy amount of any potash minerals, the biotite being of only minor importance, they must be characterized by a potash-rich glass. Such an assumption is in accord with the well-known fact that the residual glass of various lavas is relatively richer in potash than in soda. Moreover, in the case of the Sierra Nevada latite, Ransome proved the potash-rich nature of the glass by microchemical tests.[3]

Nomenclature.—While the rock of Tintic Mountain is believed to be a typical latite, it has not been thought best to use that term on the geologic map. This type is, without doubt, the most important in the area under discussion, yet there is so much mineralogic variation in the various parts of the area that it would be unwise to base the nomenclature for the whole area upon the analysis of a single type. The name Tintic andesite is therefore given to all the lavas of the same general mineralogic composition, most of which would doubtless be found chemically to be latites.

[1] Some lava flows of the western slope of the Sierra Nevada, California: Bull. U. S. Geol. Survey No. 89, 1898; also Am. Jour. Sci., May, 1898, 4th series, Vol. V, p. 355.

[2] The Richmond Mountain pyroxene-andesite is fully described by Iddings in Mon. U. S. Geol. Survey, Vol. XX, p. 348.

[3] Op. cit., p. 49.

ANDESITIC TUFF BRECCIA, LONG RIDGE.

TUFF AND BRECCIA.

Distribution.—On the geologic map of the Tintic quadrangle the tuff and breccia are not separated from the andesite. Throughout the andesite area beds of these pyroclastics are found capping or underlying the flows of massive andesite, and the association is so intimate that very detailed mapping would be required to represent the two types separately.

In two areas these fragmental volcanics are especially prominent: Volcano Ridge, southwest of Diamond, and Long Ridge, in the southeastern part of the Tintic quadrangle. In these localities the tuff and breccia cover considerable areas and are hundreds, if not thousands of feet in thickness. The finer tuffs are more characteristic of Volcano Ridge, although a coarse agglomerate also occurs here, and on Long Ridge the coarse breccia is most common.

Description.—These fragmental volcanic deposits occur in great variety, from the finest of stratified tuffs to the very coarse agglomerate breccias. An accompanying plate (Pl. LXXIX) well illustrates the andesitic breccia, which is of common occurrence in the vicinity of Long Ridge. Huge blocks of lava, weighing tons, are mixed with smaller bowlders and pebbles of the same material, and all cemented with a matrix of sand of essentially the same composition. Occasionally blocks of rhyolite are found in these breccias, while those of andesite exhibit a great variety of colors and textures. Some of the fragments are rounded, others extremely angular. These coarse deposits are wholly without stratification, except as lenses of finer material may be included.

The finer-grained pyroclastics, or tuffs, vary in color from brown and green to yellowish white. It is evident that their porous nature facilitates bleaching of these tuffs, and they are thus in general somewhat lighter in color than the equivalent lavas. For the most part they are plainly fragmental, the fragments of lavas of different color being embedded in a lighter matrix. The tuffs are often banded and well bedded, and in other cases possess a marked schistosity (Pl. LXXX).

Petrographic details.—Examined microscopically, these tuffs are found to contain, in addition to the andesite, with characteristic textures, fragments of quartzite and glass. The latter is more rarely noticed, and is in smaller fragments, which show perlitic fractures. Crystal fragments are abundant, feldspar, augite, hypersthene, biotite, magnetite, and quartz being the minerals observed. Feldspar is most abundant, and although more or less altered, can be seen to be plagioclase. The ferromagnesian constituents are often completely altered. Calcite and chlorite are thus present as alteration products. Quartz fragments are rather sporadic in distribution in these tuffs, and may have been in part derived from the rhyolite.

Certain of the tuffs of the finest grain exhibit a banding, which is very noticeable. The occurrence of shreds of mica, with a distinct parallelism, along with angular grains of other minerals, makes it difficult to consider this an ordinary well-sorted waterlaid tuff, as the mica plates would not be deposited along with these other minerals. Such tuffs, moreover, sometimes show a flowage texture, which suggests that these represent mud flows. In such a flow the leaves of mica would assume just such a parallelism as is seen in these tuffs and yet be accompanied by other clastic material of varying grain.

Mention of the agglomeratic deposits of Volcano Ridge will be deferred to the next chapter.

MONZONITE AND MONZONITE-PORPHYRY.

Distribution.—The area lying south of Robinson and Mammoth and extending past Treasure Hill and Diamond to Sunrise Peak is characterized by a rock locally termed "granite" and "porphyry." This belt of monzonite, with its porphyritic phase, is about 4 miles long from north to south and 2 miles or less in width. It lies wholly on the western slope of the range, and is deeply cut by the alluvium-filled Ruby Hollow and Diamond Gulch. The western boundary of this monzonitic mass is hidden by the alluvium of Tintic Valley. However, the occurrences of quartz-porphyry, both at the northern and at the southern end of the belt, may be considered as indicating approximately the western limit of the monzonite.

In the Tintic folio of the Geologic Atlas this rock will be designated as the Sunbeam monzonite, taking its name from the Sunbeam mine, which was the first discovered in the Tintic district.

Description.—In general appearance the rock here termed monzonite closely resembles some diorites. Its color—light to dark gray, slightly greenish or brownish—its evenly granular texture, and the evident importance of the darker constituents are points of resemblance which link it to the diorite. As will be stated later, its chemical and mineralogic compositions, however, show it to be a quite typical monzonite—that is, a rock of intermediate composition between a syenite and a diorite.

The monzonite varies considerably in its megascopic characters within the area indicated upon the map. The variations are due in part to the degree of alteration in the rock, but more especially to differences in texture. In the northern part of the area the rock is perfectly granular, with the lighter and darker constituents very evenly intermingled, and in no instance can the rock be called coarse grained. This granular phase of the monzonite also occurs in different localities throughout the area. With it, especially nearer the southern and eastern edges of the rock mass, are associated porphyritic phases. In this monzonite-porphyry the phenocrysts of feldspar are often very prominent, while the groundmass is plainly holocrystalline. Both the monzonite and the monzonite-porphyry are compact and hard and possess all the characters of intrusive rocks. They are everywhere jointed, and the sharp-edged joint blocks are very noticeable in the talus slides.

BEDDED ANDESITIC TUFF, BIG DOG CANYON.

The more important constituents of the monzonite are plagioclase, orthoclase, biotite, hornblende, and quartz. Accessory constituents are magnetite, apatite, titanite, and zircon, with secondary chlorite, calcite, epidote, and pyrite. The feldspars and the biotite and hornblende are the minerals easily recognizable megascopically.

Petrographic details.—The microscopic texture of these monzonitic rocks varies from hypidiomorphic-granular through panidiomorphic-granular to porphyritic, with a holocrystalline groundmass. The last texture is characteristic of the monzonite-porphyry, in which the phenocrysts are both the feldspar and the biotite or hornblende. In the groundmass of the porphyry there is no glass nor any tendency to flow-textures.

The feldspars are orthoclase and plagioclase, in approximately equal amounts. This mixture of the two feldspars is indeed often recognizable megascopically, the pink tint in the rock being due to the orthoclase. Studied microscopically, the unstriated feldspar is readily separated from the plagioclase. Alteration has clouded the orthoclase somewhat, and this permits a separation from the less affected plagioclase, even in ordinary light. It is only through this alteration that the cleavage of the orthoclase is at all shown. It is rarely idiomorphic, being usually molded upon the other constituents, but is readily distinguished from the clear quartz, which is also interstitial. These plates of orthoclase are often of good size, but even then are wholly allotriomorphic. Where at all idiomorphic, the orthoclase occurs in prisms of a rather stout habit. In one case twinning by the Manebacher law was observed. Quite commonly the orthoclase has a micrographic border, showing the simultaneous crystallization of the quartz and orthoclase. As will be mentioned later, there is good reason for believing the orthoclase in this monzonite to contain varying amounts of soda, but no evidence bearing on this point was obtained from observation of the optical properties. The orthoclase is most prominent in the most typically hypidiomorphic monzonite, and appears especially abundant in specimens poor in quartz. In the monzonite-porphyry the orthoclase is confined to the groundmass.

The plagioclase is usually idiomorphic, rudely so in the more granular phase of the monzonite, but occurring as well-defined phenocrysts in the porphyry. In both cases the outer zone of the triclinic feldspar is commonly indented by small grains of quartz or orthoclase. This is especially apparent in the porphyry, showing that the crystallization of the groundmass began before the completion of the phenocrysts. The plagioclase is usually clear, with only incipient alteration sufficient to express the cleavage. Twinning by both the albite and the Carlsbad laws is characteristic of these triclinic feldspars, while pericline twinning occurs only rarely. Determinations based upon the extinction angles of the compound twins, so abundant in the monzonite and monzonite-porphyry, show the composition of the plagioclase to vary from that of basic andesine to that of basic labradorite, $Ab_1 An_1$ being the most common species. Zonal structure is not of common occurrence. In a few instances the plagioclase crystal has an outer zone of untwinned feldspar which possesses the more altered character of the orthoclase.

Quartz is an important constituent in most of the monzonites. It is the youngest of the constituents, and is therefore usually interstitial. A common form, however, is an anhedron of quartz, with a micrographic border of orthoclase and quartz of a width equal to the diameter of the quartz nucleus. In certain specimens micrographic intergrowths of this nature are very prominent, and the micrographic texture is also common in the groundmass of the monzonite-porphyry.

The ferromagnesian constituents are, in the order of their abundance, biotite, hornblende, and augite. The biotite is less often absent than hornblende or augite, and occurs in hexagonal plates and in irregular shreds. It rarely possesses sharp edges, even when idiomorphic, but appears to have suffered corrosion. The biotite phenocrysts in the porphyritic phase of the monzonite sometimes include small plagioclase crystals. Much of the biotite is bleached, while nearly complete alteration to chlorite is often observed.

The hornblende is light green in color, and not strongly pleochroic. The prisms are often rough in outline and only rarely twinned. In a few specimens the hornblende equals, or even exceeds, the biotite in importance, but usually is subordinate to that mineral. Inclusions of feldspar are at times so abundant in the hornblende as almost to destroy the continuity of the host. Alteration is more common in the hornblende than in the biotite.

In the few occurrences of augite observed in these monzonitic rocks it is light green to colorless in the thin section. The prisms are perfectly idiomorphic, showing the characteristic basal sections with prismatic cleavage.

Of the accessory minerals, magnetite is the most important, being abundant in all phases of the monzonite. It appears more often closely associated with the hornblende than with the biotite. In one case, where very abundant, the magnetite is in part secondary, as it fills cracks which traverse the rock. The magnetite is probably somewhat titaniferous, as secondary material is often associated with it which has the appearance of granular titanite. Apatite is a persistent constituent, occurring with the magnetite, from which the long needles of apaitite often extend. It is also found as inclusions in the feldspar. Zircon and titanite are rarer constituents.

Calcite, chlorite, and epidote occur as alteration products, replacing the ferromagnesian minerals. Epidote also occurs in the center of much-altered plagioclase crystals. Sagenite webs of rutile needles were observed in one extremely altered monzonite. Pyrite occurs, but is not a common constituent in the monzonite even in the vicinity of veins, in which it is a gangue mineral.

Chemical composition.—A typical specimen of the granular monzonite from near the Iron Duke mine, east of Silver City, was selected for chemical analysis. Its constituents are orthoclase, plagioclase, quartz, hornblende, biotite, magnetite, apatite, zircon, and titanite, with small amounts of chlorite and epidote. The analysis, by Dr. Stokes, gave the following result:

Analysis of monzonite from the Tintic mining district, Utah.

	Per cent.
SiO_2	59.76
TiO_2	.87
Al_2O_3	15.79
Fe_2O_3	3.77
FeO	3.30
MnO	.12
CaO	3.88
SrO	Trace.
BaO	.09
MgO	2.16
K_2O	4.40
Na_2O	3.01
Li_2O	Trace.
H_2O at 110°	.31
H_2O above 110°	1.11
P_2O_5	.42
V as V_2O_5	.02
Mo	Trace.
CO_2	.78
Cl	.04
Total	99.83

Comparison of the above analysis with the mean of analyses of the monzonite series given by Brögger[1] shows that the Tintic rock is slightly richer in silica and the alkalis and poorer in lime.

This makes the lime-alkali ratio rather low, so that the Tintic monzonite belongs to the syenitic phase of this intermediate type. It will be noted that in their molecular proportions the potash and soda are nearly equal, so that the orthoclase and albite molecules may be expected to be present in nearly equal amounts, the latter slightly in excess, owing to the presence in this rock of a little biotite, which would also contain potash. A calculation of the mineralogic composition from the above analysis shows the anorthite molecule to be present in only half the

[1] Die Eruptivgesteine des Kristianiagebietes; II, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, Kristiania, 1895, p. 62a.

proportion of the soda feldspar. It is probable, therefore, that a considerable part of the soda molecule is present in the orthoclase. If one-third of the soda feldspar is calculated as thus combined with the potash feldspar, this soda orthoclase would constitute over 32 per cent of the rock, while the plagioclase would amount to about 30 per cent and have the composition of a basic andesine, Ab_4An_3. Quartz would make up 16 per cent of the rock, while there would be 12 per cent of a hornblende rather poor in alumina, and biotite and magnetite would constitute the remainder of the rock. Such a calculation must necessarily be only an approximation, but it is believed that the above fairly well expresses the mineralogic composition of the rock. Quantitatively, as well as qualitatively, it is an orthoclase-plagioclase rock, and thus deserves to be classed among the monzonites.

BASALT.

Occurrence and description.—Although basalt is of common occurrence south of the Tintic Mountains, as well as in other parts of the Great Basin, it was found in only one locality within the Tintic quadrangle. House Butte is a prominent flat-topped hill about 1 mile west of Tintic Mountain. Basalt occurs here in three small areas, the outlines of which suggest intruded sheets. Immediately southeast of House Butte basalt is found on the side of a ravine. In these localities, as elsewhere in the Tintic Mountains, talus accumulations somewhat conceal geologic relations.

Megascopically the basalt is a black, very compact rock, without the vitreous texture of the darker of the andesites. It is very fine grained, and no megascopic phenocrysts occur. Under the microscope the only phenocrysts seen are of olivine and augite, and these are much less important in amount than the groundmass. The olivine occurs in well-terminated prisms and appears quite free from alteration. The augite is also colorless in the thin section, but is readily distinguished from the olivine by its more perfect cleavage and inclined extinction.

The groundmass of the basalt is quite holocrystalline, consisting of a uniform mat of laths of plagioclase feldspar and crystals and anhedra of augite. Magnetite in small crystals and grains is scattered throughout the rock, while apatite occurs in long, microscopic needles. The microlites of feldspar show a distinct flowage around the phenocrysts. Calcite and a yellowish-brown material fill pores in the rock.

RÉSUMÉ.

Five types of massive igneous rocks have been described as occurring in the Tintic district: Rhyolite, quartz-porphyry, andesite, monzonite, and basalt. In mineralogic composition the quartz-porphyry or Swansea rhyolite is almost identical with the Packard rhyolite, differing only in the texture of the groundmass. A mineralogic relation also exists between the Tintic andesite and the Sunbeam monzonite, while the chemical affinities of the four types are seen on comparison of their analyses. No analysis was made of the basalt, which is of little importance in the Tintic district.

Analyses of igneous rocks occurring in the Tintic mining district.

	I.	II.	III.	IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	71.56	69.18	60.17	59.76
TiO_2	.38	.69	.87	.87
Al_2O_3	14.28	14.37	15.78	15.79
Cr_2O_3	Trace.	Trace.	None.	None.
Fe_2O_3	.89	2.52	3.42	3.77
FeO	Undet.	.57	2.95	3.30
MnO	Trace.	.10	.11	.12
BaO	.28	.09	.14	.09
SrO	Trace.	Trace.	.09	Trace.
CaO	1.18	1.88	4.69	3.88
MgO	.42	.70	2.52	2.16
K_2O	4.37	5.00	4.16	4.40
Na_2O	3.00	3.58	2.96	3.01
Li_2O	None.	Trace.	Trace.	Trace.
H_2O at 110°	.36	.35	.25	.31
H_2O above 110°	.79	.25	1.23	1.11
P_2O_5	.13	.26	.40	.42
V as V_2O_5	.02	.01	.01	.02
Mo	None.	Trace.	None.	Trace.
As	Trace.	....	....	....
Cl	.06	Trace.	.04	.04
CO_2	None.	None.	None.	.78
FeS_2	2.29	....	....	....
Total	100.01	99.55	99.79	99.83

I. Quartz-porphyry—Swansea rhyolite.
II. Packard rhyolite.
III. Tintic andesite, or latite.
IV. Sunbeam monzonite.

The Tintic andesite, or latite, Analysis III, is plainly the effusive equivalent of the Sunbeam monzonite, Analysis IV. The slight differences in chemical composition are much less important than the similarity of the two rocks, which is especially striking in those features which may be termed characteristic of the two rocks. Of these may be mentioned the relative importance of the alkalies as contrasted with the lime and the potash-rich character of the rocks. In mineralogic composition and texture the similarity of the latite and monzonite is not so apparent. They both contain labradorite as an essential constituent, but differ somewhat in the character of their ferromagnesian constituents. In the former the pyroxenes are characteristic, with biotite less important and hornblende only accessory. In the latter biotite and hornblende are the common constituents, while augite is of rare occurrence. In the monzonite orthoclase and quartz are quite important constituents, but, as has been stated in the preceding descriptions, in the latite quartz is very rarely found, while orthoclase was not detected in any thin section examined. It will be remembered, however, that in the monzonite the orthoclase and quartz were the last minerals to crystallize, and therefore in the effusive equivalent the consolidation of the glassy base prevented the crystallization of these minerals.

The rhyolitic rocks, I and II, contain 10 to 12 per cent more silica than the monzonite-latite type and are much poorer in the alkaline earths. The monzonite and latite are slightly richer in alumina and contain considerably more of the oxides of iron. The titanic and phosphoric acids are also more important in the latter type. The chemical characteristic of this group of four rocks is the constant molecular ratio between the potash and soda. This is nearly 1:1 in every case, the soda being always slightly in excess. This relation of the alkalies may be regarded as the best chemical evidence of the consanguinity of the igneous rocks of the Tintic Mountains. It is to be noted, also, that both the rhyolitic type and the monzonite-latite type approach trachyte in mineralogic and chemical composition. This is of interest in view of the absence of typical trachyte among the lavas of the Great Basin.[1]

The succession and geologic relations of these igneous rocks will be discussed in the next chapter.

[1] Hague and Iddings: Am. Jour. Sci., 3d series, Vol. XXVII, 1884, p. 463.

CHAPTER IV.

VOLCANIC CENTERS.

INTRODUCTORY.

The later period in the history of the building of the Tintic Mountains was one characterized by volcanic activity. The range as it now stands is composed for the most part of volcanic rocks, and the geologic problems are in great part those relating to vulcanism. This vulcanism not only has left its imprint on the topography and surface geology but is also closely connected with the genesis of the ore deposits in the igneous rock. A clear understanding of the true succession of eruptions and the real nature of the activity is, therefore, essential in this connection.

Volcanic materials are relatively loose and incoherent and therefore easily removed by erosion; thus, the evidences of volcanic activity are apt to be ephemeral in character. In the Tintic area, however, the long-continued activity, in its varied phases, has left sufficient traces to furnish data for a quite complete history of the vulcanism. Volcanic centers can be distinguished and the connection of the intrusive and effusive rocks traced. In the following description of such centers the three areas will be considered in the order of the eruptions which respectively characterized them.

PACKARD PEAK.

On referring to the geologic map of the Tintic quadrangle, it will be seen that the principle mass of rhyolite is in the northern part of the area mapped. Here the crest of the range is of rhyolite, and Packard Peak forms the center of the area.

Rhyolitic flows.—It is not commonly the case that flows can be distinguished in the rhyolite. Often the glassy rhyolite, with its abundant phenocrysts, stands up like granite, appearing perhaps even more massive. Along the lower slopes on the eastern side of the range somewhat of a flowage structure can be seen in the outcrops. The extreme contortion to which such a lava flow is sometimes subjected is splendidly exhibited on Goshen Slope (Pl. LXXXI). As has been noted in another place, the microscopic flowage texture is characteristic of the rhyolitic lava. Small amounts of rhyolite tuff also occur on these lower slopes, along the southeastern edge of the rhyolite area.

The absence of any bedded structure in the central portion of the area, and the great thickness of the rhyolite in the vicinity of Packard

Peak suggests that this is the center of an eruption which was of the nature of an outwelling of viscous lava, rather than of an explosive ejection of volcanic material. Very little truly fragmental material is found in association with these rhyolitic flows, yet much of the rhyolite shows traces of flow brecciation, such as might be expected to occur in the eruption of a highly viscous lava. Such a location of the rhyolitic center is further supported by the relations of the rhyolite to the underlying Paleozoic strata.

Directly south of Packard Peak, on the northern end of Godiva Mountain, the Tetro tunnel cuts the rhyolite limestone contact (Pl. LXXXII). Here there is a considerable thickness of angular blocks of limestone, a heavy talus deposit covered and somewhat cemented by the rhyolite. Similar relations are seen in the workings of the Gemini mine, southwest of Packard Peak, where the contact is cut. Along the eastern slope of Godiva Mountain there are similar contact breccias, a number of these occurrences being seen immediately below the road between the Utah and Sioux mines. Here it is evident from the manner in which these breccias blanket the present surface, that the old talus-covered slope of the limestone was essentially the same as that exposed to-day. The prerhyolitic topography of the limestone areas was much the same as the present, except that the lower slopes now hidden by the rhyolite were doubtless much steeper. Thus, the broad gulch in which the town of Eureka is situated was deeper and more canyon-like. Such a restoration of topographic features at the time of the eruption of the rhyolite, and the present distribution of the rhyolite, point to Packard Peak as the probable center of eruption.

Related intrusions.—West of Packard Peak there occur in the limestone, and in one case near the quartzite contact, small masses of acid igneous rock, which appear to be intrusive. A well-defined dike of porphyritic rock, wholly decomposed, has been encountered in the workings of the Gemini mine, near the rhyolite contact. Otherwise this Eureka area is remarkably free from dikes.

South of Robinson occurs the large belt of quartz porphyry which in chemical and mineralogic composition, and often in megascopic appearance as well, closely resembles the Packard Peak rhyolite. This quartz porphyry appears to be in intrusive contact with both the limestone and the quartzite. The entire absence of rhyolite on the summit and the southwestern slope of Godiva Mountain makes it extremely improbable that this dike was directly connected with these rhyolitic flows to the northeast. It more probably represents an intrusion of the same magma, through another channel which may have connected with less important surface flows. On Horseshoe Hill a small amount of rhyolitic tuff is associated with the quartz porphyry believed to be a continuation of the larger Swansea area. Later eruptions have rendered the interpretation of the acid igneous rocks less easy in this part of the area than in the Packard Peak area.

FLOW CONTORTION IN RHYOLITE, GOSHEN SLOPE.

Other centers of eruption were located in other portions of the Tintic Mountains. As far as known, however, the rhyolites of the other areas are similar to those of this area, and were erupted under similar circumstances. Therefore, the area described may be considered as typical of the rhyolitic eruptions in the Tintic Mountains.

VOLCANO RIDGE.

The volcanic cone.—Volcano Ridge is a spur which extends westward from the main divide of the Tintic Mountains about 2 miles south of Diamond. At its eastern end this ridge is made up of the flows of Tintic andesite, which connect with those forming Buckhorn Mountain in the main range. Farther west, however, an extensive series of bedded tuffs occurs, and the western half of Volcano Ridge is seen to be the remnant of a deeply eroded volcanic cone. Erosion has so well exposed the different parts of the old volcano that the character of the eruption and the sequence of its products can be quite definitely determined.

The volcanic center is indicated in two ways. The thick beds of fine and coarse greenish tuffs have dips of 10° to 20°. These pyroclastics have sheets of andesite interbedded with them, and their strikes express a roughly semicircular arrangement. The area covered by this series of tuffs is something over 2 square miles and clearly represents a section of a volcanic cone. The point indicated as the center from which these fragmental deposits dip is approximately the nose of this ridge, and examination of this locality furnishes the second piece of evidence as to the position of the volcanic vent.

The western end of Volcano Ridge has an elevation of over 7,000 feet, and thence the descent is sharp to Tintic Valley. At this point the bedded tuffs give place to a rock which is strikingly agglomeratic. On the knob just east of the end of the ridge limestone blocks of cobblestone size are abundant in the coarse tuffaceous material. As the nose of the ridge is reached blocks of quartzite become more abundant than those of limestone. Several large masses of white vitreous quartzite occur, standing 20 to 30 feet above the dark green and gray volcanic material. These blocks are plainly embedded in the latter material, as the softer material has been eroded away in several cases so that the lower surface of the quartzite block is exposed. Pl. LXXXIII shows the largest of these blocks.

Rhyolitic material is also found on the slopes at this locality, and is extremely fragmental in character. The agglomerate here in its coarsest phase contains fragments of rhyolite, andesite, quartzite, limestone, and shale, while the finer portions are seen under the microscope to contain mineral fragments as well as particles of glass, the latter exhibiting somewhat of an ash structure.

With this agglomerate are associated irregular sheets and dikes of andesite, the whole presenting rather confused relations. This intimate mixture of lava and pyroclastic material is such as might be expected at or near a volcanic vent. Dikes of andesite-porphyry are also prominent on the slopes of Volcano Ridge.

On the extreme end of Volcano Ridge, not far above the valley level, there occurs a mass of quartzite several hundred feet in diameter. This, and a much larger area of quartzite somewhat over a mile distant to the southeast, doubtless represents uncovered portions of the underlying quartzite which was engulfed in the flows of lava and deposits of volcanic ejectamenta. The presence of the three kinds of sedimentary rock in the agglomerate shows that the point of eruption was close to the contact of the Robinson quartzite and the Eureka limestone.

It is probable that the Volcano Ridge vent was but one of several eruptive centers, as extremely coarse breccias occur in the volcanic series on Long Ridge, about 9 miles to the southeast. On Volcano Ridge, however, the relations are best exposed, and this volcanic center is more fully described, since it is believed to be typical of the earlier eruptions of andesite in the Tintic Mountains.

Relation to rhyolitic eruption.—The age relation of the two classes of eruptions is clearly indicated. The included fragments of rhyolitic lava in the breccia, along with those of the sedimentary rocks, suggest that the Horseshoe Hill occurrence of rhyolite had a greater extent to the south before it was covered by the andesitic material erupted at this point. In the following section it will be shown that the observed relations between the later andesite and the rhyolite are in accord with this determination that the rhyolite antedates the andesite of Volcano Ridge.

ROBINSON-SUNRISE PEAK.

Monzonite area.—Extending south and east from the hills immediately south of the town of Robinson is the area of Sunbeam monzonite and monzonite-porphyry. The area is rudely triangular in outline, with Sunrise Peak at the southern angle. This monzonite covers over 8 square miles and occurs only on the western slope of the Tintic Mountains. Since this rock is in contact with nearly every other rock which occurs in the Tintic district, a study of the contacts of the monzonite throws considerable light upon the general geologic problem.

Northern contact.—The Sunbeam monzonite along the northern side of this area is in contact with both the Eureka and the Godiva limestones, and also with the Swansea rhyolite or quartz-porphyry. The relations with the limestone are plainly intrusive, the monzonite cutting across the point of the northward-pitching syncline in the limestone. The line of contact is quite irregular, and from observations both at the surface and in prospect tunnels it seems quite evident that the contact plane is for the most part approximately vertical. Along this contact there is a certain amount of metamorphism of the limestone, but it is somewhat remarkable that no dikes or sheets of the intrusive rock are seen extending into the limestone strata. At a few

LIMESTONE TALUS UNDERLYING RHYOLITE.

points tongues of the monzonite project from the main mass, but these are of such a form as to constitute details of the contact rather than distinct dikes.

The contact with the quartz-porphyry extends southward from a point back of the Mammoth Mill. In many placės both rocks are so altered as to be distinguished only with great difficulty. The monzonite shows rapid variations in its texture near the contact, and upon this observation is based the belief that the monzonite is the younger rock. There is evidence in the manner of occurrence of the two rocks that the quartz-porphyry or Swansea rhyolite was an earlier intrusive along much the same fissure as that taken by the monzonite.

Inclusions of older rocks.—While apophyses from the monzonite into the limestone appear to be wholly wanting, yet the inclusions of the older rocks in the igneous rock are quite characteristic of this intrusion. In the northeastern part of the monzonite area several large inclusions of limestone are found, while blocks of limestone occur in the monzonite-porphyry on the east side of Sunrise Peak, nearly 4 miles from the nearest limestone outcrop. One mass of quartz-porphyry or rhyolite occurs within the monzonite area and appears to be an inclusion.

Inclusions of quartzite are much more abundant than those already mentioned. The monzonite is nowhere at the surface in contact with the Robinson quartzite, but blocks of the latter rock occur at various elevations within the monzonite area. Thirteen such blocks were sufficiently large to be mapped on the large-scale map of the Tintic district. The vertical range of these outcrops of quartzite, as well as their wide variation in strike and dip, rather precludes the hypothesis that they represent uncovered portions of the quartzite in place, or that they are remnants of an arch of sedimentary rock over a laccolithic mass. Moreover, in the case of one of the occurrences of quartzite—that near the Robinson triangulation station—a prospect tunnel on the slope below has made it possible to trace the lower surface of the block, which is about 100 yards in its longest diameter. Thus it is seen, beyond possible doubt, that the block was caught up in the monzonite magma.

Southern contact.—Sunrise Peak is a conical hill, rising over 1,400 feet above Diamond Gulch, which bounds it on the north and west. On the east it connects with a narrow spur from the main range, while on the south it is separated by a small valley from Volcano Ridge. Along the bottom of this valley the monzonite is in contact with the tuff series, described in a previous section of this chapter. The contact is mostly covered by the alluvium of the dry stream bed, but as one approaches the head of the valley two well-defined dikes of monzonite-porphyry can be seen cutting across the bedded tuffs. These are plainly apophyses of the Sunrise Peak monzonitic mass, and one of them can be traced in the other direction, southeast, to a point where it evidently connects with a flow of the Tintic andesite. This flow overlies the bedded tuffs, and belongs apparently to the series of horizontal flows which form Buckhorn Mountain and the rest of the main divide, extending southward to Tintic Mountain.

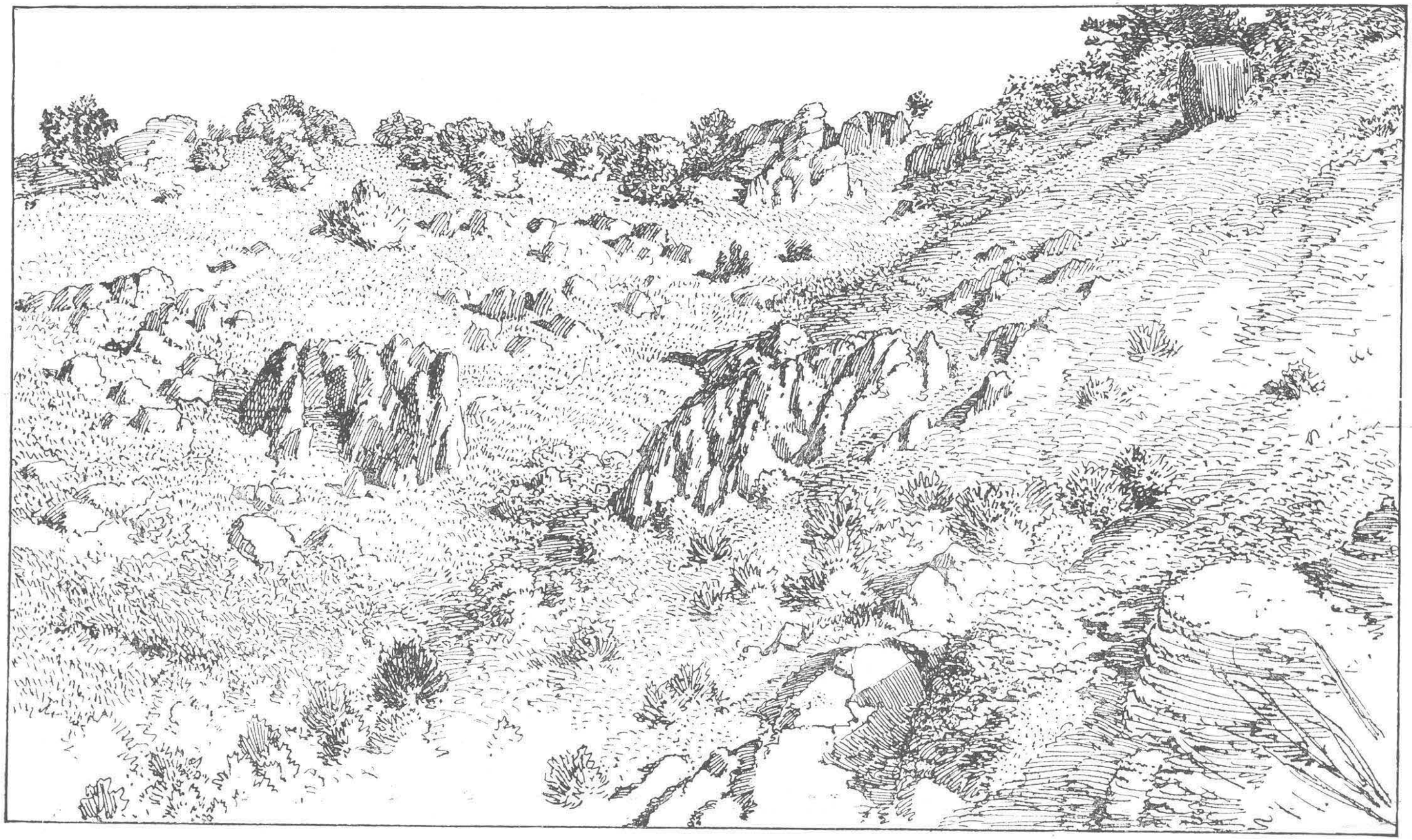
On the spur connecting Sunrise Peak with the main part of the range the monzonite-porphyry of the peak exhibits a perfect gradation into the andesite to the east. An attempt to separate the two rocks at this point only proves how arbitrary any such distinction must be. At a lower level, in the gulch to the north, however, the line between the monzonite and the tuffs can be sharply drawn. The tuffs are exactly similar to those on the opposite side of Sunrise Peak, being plainly bedded and having the same dip. These features are well exhibited in Crystal Canyon, where on the one side are beds of green tuff dipping northeast at an angle of 15° and overlain by the horizontal flows of andesite, while on the other is the more massive monzonite-porphyry. Northward from the junction of Crystal Canyon and Water Canyon the tuff disappears beneath the andesite, and again the line between the monzonite and the andesite can only be drawn arbitrarily.

RELATION OF THE SUNBEAM MONZONITE TO THE TINTIC ANDESITE.

The relations which have been described above clearly indicate that the monzonite and monzonite-porphyry are younger than the andesitic series of Volcano Ridge. The monzonitic mass represents a stock or neck which in its southern part broke across the outer part of the volcanic cone, the center of which can be seen on Volcano Ridge. Through this new vent, which evidently was of the nature of a broad fissure extending about 4 miles to the north, later flows of andesitic lavas were erupted. Thus it is that on the eastern side of the monzonitic mass the monzonite-porphyry shows such a perfect gradation into the andesite of the flows.

Petrographic evidence.—Microscopic and chemical study of the two rocks fully corroborates the field evidence. The analyses cited in the previous chapter showed the chemical identity of the Sunbeam monzonite and the Tintic andesite or latite. In the selection of material for the analysis of the latter rock special care was taken to secure that from a flow believed to have been erupted from the Sunrise Peak vent, although occurring at some distance from it. The monzonite sample came from well within the intrusive mass, and therefore strongly contrasted with the lava in texture and mineralogic composition. These differences in the physical conditions of consolidation may have played some part in causing the slight differences in chemical composition of the two rocks.

Comparative study of the thin sections of the monzonite-porphyry and of the andesite or latite from the Sunrise Peak contact showed that the dike rock differs from the lava primarily in groundmass characters. Both rocks are porphyritic, but the groundmass of the monzonite is



QUARTZITE BLOCK INCLUDED IN ANDESITIC VOLCANIC MATERIAL, VOLCANO RIDGE.

The pyramidal quartzite mass is seen in the background, at the head of the ravine.

holocrystalline and granular, while in the andesite it is hyalopilitic with flowage well expressed. Mineralogic differences are hardly less important in these two rocks so closely connected in the field. Augite is the ferromagnesian phenocryst in the lava, but hornblende is the corresponding constituent in the rock of the dike. These mineralogic differences of the two rocks have been mentioned in the previous chapter.

It may be stated that the Sunbeam monzonite is characterized by the textural gradations throughout the rock mass. Such variations in the texture of the rock are so great as to suggest that the rock did not consolidate at great depth, since if it had done so the conditions of crystallization would be much more uniform. In the northeastern part of the area the monzonite is most typically granular. To the south and east the rock becomes porphyritic and the textural variation is continued through the monzonite-porphyry into the andesite or latite. This tendency toward the texture of the effusive rock is not only found along the outer edges of the area mapped as Sunbeam monzonite, but it is noticeable also that in a few localities within that area the rock approaches the andesitic type on the higher levels. Such is the case, for example, on the upper slopes of Treasure Hill.

It is evident, therefore, that the separation of the monzonite from its effusive equivalent is not strictly logical, since the two are connected by all possible transitional types and form a geologic unit. In the preparation of the geologic map of the area it seemed advisable, however, to group together the different andesitic lavas, tuffs, and breccias, separating them from the plainly intrusive monzonite and monzonite-porphyry. It must be admitted that thereby two volcanic series of different ages are grouped together, while the effusive and intrusive rocks belonging to the same eruption are separated.

RÉSUMÉ.

At least three distinct eruptions of volcanic material are recorded in the Tintic Mountains. The first was the rhyolitic, and Packard Peak probably represents the principal center for the extrusion of this acid lava. With the effusive rhyolite is connected in time the intrusive quartz-porphyry or Swansea rhyolite. Next came the eruption of andesitic material, mostly fragmental. A portion of a dissected volcanic cone of this nature can be seen on Volcano Ridge. Following this earlier eruption of andesite was the intrusion of monzonite and the eruption of its effusive equivalent through the same vent. Andesite from this latter eruption caps the rhyolite at a number of localities, as well as the beds of andesitic tuff ejected from the Volcano Ridge vent.

CHAPTER V.

ALTERATION.

GENERAL FEATURES.

Under the term *alteration* are included all the changes which a rock has undergone subsequent to its formation. The term is given the broadest and most general meaning possible, and by an "altered" rock is meant simply a changed rock. To alteration is due all the differences between the lava that has just cooled and the lava as it is found to-day on the flanks of the Tintic Mountains, or between the freshly consolidated limestone and the crushed and silicified limestone occurring in some parts of the Tintic district. Such changes express the effect of varying conditions, and the nature of these conditions has determined the nature of the alteration. Thus alteration comprises changes both mineralogical and structural, and these are effected by agencies both chemical and physical. The processes of alteration may act under superficial conditions within the range of our observation, or the processes may be such as to operate only at greater depths, under conditions known to us only through inference.

It is natural, therefore, to divide the processes of alteration into those included under the term *weathering* and those comprised under the term *metamorphism.* The former includes the superficial reactions, the latter the abyssal. The separation of the two classes of phenomena is not always an easy task; indeed, in many cases the same rock has been subjected to both kinds of alteration.

In a mining region the results of these alteration processes are of special interest, and in the later discussion of the Tintic ore deposits and their genesis the subject will be again touched upon. In this place the general facts of the alteration of the rocks of the district will be given, irrespective of their bearing on the economic problems.

METAMORPHISM.

Under the head of metamorphism will be discussed such changes as take place under conditions of increased pressure and temperature. Metamorphism is thus an effect of hypogene energy, and comprises all recrystallization in rocks at considerable depths. It especially characterizes rocks of great age in a region which has experienced many vicissitudes of geologic history. As will be seen in a following chapter, the Tintic Mountains are in great part composed of comparatively young rocks and their history has been relatively simple. Metamorphic processes proper, therefore, have been less important here than in many regions, although the closely related processes of ore deposition are of greatest moment.

Three types of metamorphism need to be discussed in connection with the rocks of the Tintic district—dynamic metamorphism, hydrometamorphism, and contact metamorphism. The first is preeminently physical in all its aspects, while the others are chemical.

DYNAMIC METAMORPHISM.

The processes included under this head are those of crushing and shearing, whereby pressure finds relief in motion. Changes in the megascopic and microscopic structures of the rock result from this kind of metamorphism.

The igneous rocks of this region have been little affected by dynamic action. The processes of mountain folding antedate their eruption, and later disturbances have been slight. The absence of peripheral granulation or of undulatory extinction in the phenocrysts of quartz in the more acid of these rocks proves that no crushing has taken place. Occasional cracks cemented with secondary quartz are seen traversing the rock, but these are only local and unimportant.

The closely folded Paleozoic rocks, on the other hand, have had a more eventful history. The strata have been deformed, and the deformation has taken place with rupture. Faults and fissure systems have been developed, which will be discussed in other chapters. Sheeting and crushing along certain zones have reduced massive limestone to a shale-like rock, or where the process has been accompanied by other action the rock has been decomposed to a plastic clay. It may be remarked, however, that the principal importance of dynamic metamorphism in these rocks comes from the opportunity such action affords for other processes to work. Therefore the results of this kind of metamorphism are not easily separated from those to be considered later under other heads.

HYDROMETAMORPHISM.

In the processes included under this head water is the principal agent. Such metamorphic action takes place under conditions that obtain at moderate depths below the level of ground water, and thus the temperatures and pressures are not high. This is the form of metamorphism designated by Lindgren[1] "common hydrometamorphism." With this is doubtless associated metamorphism in which the waters are more correctly thermal. Thus, in the more extreme phases, the metamorphic action is of a hydrothermal nature. The difference, as expressed in the metamorphic products, is one of degree rather than of kind, and both processes will be considered together.

The changes due to hydrometamorphism are mineralogic in character.

[1] Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 91.

Rock textures may be preserved intact while a considerable exchange of rock substance has been effected. The process is that of metasomatosis, and the mineralogic changes have been, moreover, of a pseudomorphic nature. In the igneous rocks of the Tintic Mountains metamorphic action of this character has been nearly universal in a small degree. In certain fairly well-defined areas the Sunbeam monzonite has suffered extreme alteration.

As was stated in the detailed descriptions of the igneous rocks secondary minerals are of common occurrence. The chief ones resulting from hydrometamorphism are chlorite, epidote, muscovite or sericite, serpentine, talc, magnetite, and pyrite. Of these, chlorite is the most common, resulting from the alteration of the ferromagnesian constituents of the igneous rocks. In one case it was seen to replace a crystal of feldspar which preserved its zonal structure. Epidote also occurs as an alteration product of both the feldspar and the pyroxene or amphibole.

The alteration products of the orthoclase are rather confused mineral aggregates, doubtless sericitic in nature. It is noticeable that in the Sunbeam monzonite the orthoclase is less stable than the plagioclase. The two feldspars are readily separated on this basis alone. In the andesites carrying both pyroxenes the monoclinic appeared to be the more stable form. The chlorite from the alteration of pyroxene has quite commonly the optical characters of pennine.

Pyrite occurs usually in sharp crystals, disseminated throughout some of the monzonite and quartz-porphyry. In no case could this mineral be taken as of primary origin. Its intimate intergrowth with magnetite in a few cases loses force as an argument in this connection from the fact that in one specimen the latter mineral is plainly itself secondary, occurring in secondary cracks traversing the rock. Although apparently occurring within crystals of quartz and of feldspar, the pyrite crystals are most abundant along the joint planes and other cracks in the rock.

In the northern half of the monzonite area there are several large areas of bleached rock. While in some cases the true nature of the rock is somewhat difficult of determination, in others the rock examined, either megascopically or microscopically, is seen to have the same texture as the fresh monzonite. The rock is therefore not at all disintegrated, however great the chemical change may have been. A specimen of this bleached monzonite from the vicinity of the Tintic or Dragon iron mine was selected for chemical analysis. This rock is light gray in color, somewhat yellowish in places. The white opaque feldspars are the more prominent constituents. Microscopic examination shows that the feldspars are completely altered, as are also the ferromagnesian constituents. Sagenite webs of rutile needles appear in areas which probably represent former biotite crystals. Quartz seems to have been added; at least this mineral is much more abundant than in the fresh monzonite. An analysis of this material by Dr. Stokes is given as II in the table which follows, while I is the analysis of the fresh monzonite from a locality not far from this area of altered rock.

Analyses of monzonite from the vicinity of the Tintic or Dragon iron mine.

Constituents.	I. Fresh monzonite.	II. Altered monzonite.	III. Percentage of gain for entire rock.	IV. Percentage of gain for each constituent.	V. Percentage of loss for entire rock.	VI. Percentage of loss for each constituent.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	59.76	71.14	9.44	15.76	....	....
TiO_2	.87	.75	....	....	0.14	15.90
Al_2O_3	15.79	16.24	0.00	0.00	0.00	0.00
Fe_2O_3	3.77	.94	....	....	2.87	75.93
FeO	3.30	.16	....	....	3.15	95.30
MnO	.12	Trace.	....	....	.12	100.00
CaO	3.88	.25	....	....	3.65	93.77
SrO	Trace.	Trace.	....	....	....	....
BaO	.09	.05	....	....	.04	44.44
MgO	2.16	1.12	....	....	1.07	49.72
K_2O	4.40	4.96	.43	9.68	....	....
Na_2O	3.01	.07	....	....	2.94	97.67
Li_2O	Trace.	Strong trace.	....	....	....	....
H_2O at 110°	.31	.49	.16	53.22	....	....
H_2O above 110°	1.11	2.74	1.57	140.99	....	....
P_2O_5	.42	.32	....	....	.11	26.19
V_2O_5	.02	.02	....	....	....	....
CO_2	.78	None.	....	....	.78	100.00
Cl	.04	Trace.	....	....	.04	100.00
SO_3	None.	.26	.25	....	....	....
Total	99.83	99.51	11.85	....	14.91	....

For a better comparison of the fresh and altered rock the two analyses should be recalculated upon a common basis. To secure this it may be assumed that of the constituents present in considerable quantities the alumina is least subject to change. The position that alumina is the most resistant to leaching processes has been taken by investigators in the subject of weathering.[1] In the case of hydro-metamorphism it is believed the assumption is equally well founded, and here seems also warranted by the comparison of the two analyses.

For the determination of percentages of the gain and loss the analyses

[1] G. Roth, Allegemeine chemische Geologie, 3d ed.; G. P. Merrill, Rocks, Rock-weathering, and Soils; C. H. Smyth, jr., Weathering of alnoite in Manheim, N. Y.: Bull. Geol. Soc. Am., Vol. IX, p. 263.

are recalculated to totals of 100, and then, taking the alumina as a constant constituent, analysis II is again recalculated so that it equals analysis I in alumina.

Such an assumption gives as a result a shrinkage through the alteration—that is, 100 parts of the fresh rock have been reduced to 96.94 parts of the altered rock. With the loss in certain constituents there has been a gain in others, and columns III and V in the above table give the percentage of such loss or gain for the entire rock. This loss or gain is also calculated in percentages of each constituent in the fresh rock (See IV and VI of the table). It is believed that these results afford a basis for a clearer and more correct idea of the changes that have taken place in the bleached monzonite than could be obtained from a simple comparison of the analyses I and II.

The most prominent fact brought out in the table above is that the monzonite has been silicified as well as leached. The process of silicification is one characteristic of metamorphism rather than of the superficial action of water in weathering. Furthermore, there has been no formation of carbonates in the altered rock, but in fact the CO_2 present in the fresh rock, doubtless traceable to the presence of a small amount of calcite as a weathering product, is not found in the metamorphosed monzonite.

In the behavior of the iron oxides the process of alteration in the monzonite is strongly contrasted with the process of weathering, in which Merrill[1] believes the oxides of iron to be, like the alumina, very refractory and least liable to loss. In the present case the iron has been reduced 75 and 95 per cent—a loss which is expected to a certain extent from the bleached condition of the rock. Magnetite, so abundant in the fresh monzonite, has wholly disappeared from the altered rock. Other constituents, such as lime and magnesia, which are also prominent in the monzonite, have suffered a similar loss, the magnesia being the less affected of the two.

The most noticeable feature in the process, perhaps, is the wholly different behavior of the two alkalies. The soda has almost altogether disappeared, while the potash, on the contrary, even shows a considerable gain. The percentage of gain in the potash may be too high, since such a calculation as the present can not be regarded as more than an approximation to a true expression of the changes which have been effected in the rock. It is evident, however, that the solutions were of such a character at this point as to deposit some potash as well as silica. A similar case of introduction of potash with the removal of soda was observed by Lindgren[2] in the altered wall rock of the gold-quartz veins of Nevada City and Grass Valley. The alteration in the California occurrence differs, however, from that here discussed, in that it was also characterized by the addition of carbon dioxide and a loss

[1] G. P. Merrill, Rocks, Rock-weathering, and Soils, p. 208.
[2] Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 148.

in silica, while the iron and the alkaline earths were not greatly affected.

Hydration is a further characteristic of the alteration of the monzonite in the Tintic district, the percentage of gain for H_2O above 110° C. being 140. In the cases of the constituents occurring in only small amounts it is perhaps unwise to place too much stress upon the comparison of the two analyses. Losses are indicated in most cases, except that SO_3 has been added.

In short, the metamorphism which has affected these areas of monzonite has consisted in the introduction of silica, potash, and water in an amount equal to over 11 per cent of the original rock, and in the removal of the iron, lime, magnesia, soda, and other less important constituents to the extent of about 15 per cent of the original rock.

It is difficult to determine the relation of this hydrometamorphism to the genesis of the ore bodies. In the field no constant relation could be observed between the occurrence of the bleached monzonite and the veins. In the case of the rock specially considered here the specimen was collected in the immediate vicinity of the Tintic iron mine, and the area of bleached rock includes several precious-metal veins of minor importance. In the neighboring deposit of iron ore, an analysis of which is given on page 690, the mineralizing solutions were plainly quite different in their action. The leaching of the iron, which characterized the metamorphism of the monzonite, may indicate the ultimate source of the metal of these deposits of iron ore. The discussion of this point, however, belongs to a later chapter.

The hydrometamorphism of the sedimentary rocks was not investigated except in the case of the immediate wall rocks of the veins, and is considered later in that connection.

CONTACT METAMORPHISM.

Along the contact of the limestone with the Sunbeam monzonite and the Packard rhyolite, mineralization is common. Silicification and the introduction of more or less iron characterize these contact deposits, which are described in Chapter II, Part II, under the name of jasperoid. It is not believed that contact metamorphism has been a factor in their genesis, but rather that the contact with the igneous rocks afforded favorable condition for deposition by subsequent mineralizing solutions.

At a few points along the limestone-monzonite contact, especially on North Star Hill, the limestone shows effects of the monzonite intrusion. These consist in the recrystallization of the limestone, which is in places quite marble-like, and in the presence of the lime silicates, garnet, and wollastonite, as well as secondary quartz.

The only other mineral characteristic of contact metamorphism found in the district is tourmaline, which occurs in the Swansea mine. As has been stated in the description of the quartz-porphyry or Swansea rhyolite, this mineral does not occur in connection with the vein, but in a crosscut. Its occurrence is well over toward the contact with the monzonite. Two explanations of its origin are possible. In its occurrence, as studied in the thin sections of the quartz-porphyry, it plainly crystallized subsequently to the consolidation of the rock. It may represent the result of metamorphism by the intrusive monzonite. Metamorphism of this character, however, was not detected at any point along the contact of the monzonite with other rocks or around the quartzite inclusions in the monzonite. It is believed, therefore, that the tourmaline originated within the quartz-porphyry itself. Mineralizers of the nature of boron vapors are commonly active near the periphery of intrusive masses; and the eastern edge of the quartz-porphyry area may be coincident with its eastern contact before the intrusion of the Sunbeam monzonite along the same fissure. A similar pneumatolitic origin is given for the tourmaline in the Castle Mountain occurrence.[1]

WEATHERING.

The processes of superficial alteration deserve mention in any consideration of the geology of the Tintic district. Rock weathering has furnished the material for the extensive deposits to be described in the following chapter, and these processes continue to modify the surface aspects of the region. Moreover, the same processes that have affected the rocks have worked important changes in the ores lying nearest the surface. The zone of this alteration of both rocks and ores is that above the ground-water level. Within this zone the action is that of oxidation, hydration, and carbonation, all of which results from the chemical activity of the surface waters and the included gases. Such reactions, therefore, as take place within this zone are referable to agents of surface origin. At the surface itself other agencies are also active, which are more limited in the range of their activity. Under this head would be included temperature changes, the mechanical action of water, and frost action.

That phase of weathering which is operative below the surface has resulted in a certain amount of decomposition of the mineral constituents. This has not been accompanied by any appreciable physical changes in the rock, except in places where there has been crushing, due to dynamic metamorphism. Furthermore, the mineralogic changes are such as grade almost imperceptibly into those already described under the head of hydrometamorphism. The formation of the hydrous oxides of iron which discolor many of the rocks, and the separation of calcite in some of the igneous rocks, are processes which are doubtless operative in this zone of weathering.

At the surface the action is for the most part physical rather than chemical. Disintegration of the rock mass takes place with comparatively little decomposition of the mineral constituents. Thus, in the

[1] Weed and Pirrson, Bull. U. S. Geol. Survey No. 139, p. 102.

areas of igneous rocks coarse mineral sands are of frequent occurrence. Frost action and the sudden changes of temperature are probably most effective in this rock disintegration. Wind erosion is also an important factor on exposed points. In addition to the strong dust-laden winds so common in this region, whirlwinds are of almost constant occurrence along the mountains and in the bordering valleys during the hottest days of summer. The results of erosion of this nature are strikingly seen in the rhyolite areas on the eastern slopes of the range, where there are caves in the solid rock.

Of the igneous rocks, the monzonite is the most resistant to these atmospheric agencies, while the rhyolite is slightly less resistant than the andesite. The monzonite and monzonite-porphyry is broken into angular blocks, which form a protective mantle. The andesite breaks into angular fragments considerably smaller than the monzonite blocks. There is also more tendency to disintegration into sand, due to the more porous character of the lava. This andesitic sand is washed from the slopes and accumulates in hollows. Where the lava flows are quite distinct, benches occur on the slopes, due to the varying degree of resistance of the different flows. The rhyolite weathers like the andesite. The andesitic tuffs resemble the shale and sandstone of the sedimentary series in their forms of weathering.

In resistance to weathering action the sedimentary rocks stand in the following order: Quartzite, limestone, sandstone, shale. The shale and sandstone yield readily to both frost action and solution, the latter removing the cementing material and thus disintegrating the rock. The limestone is broken into fragments by the frost on exposed points, and also suffers a certain amount of solution. This corrosion of the lime is most apparent where the Godiva limestone contains chert nodules, which stand out relatively unaffected. Small caves occur on the vertical cliffs of limestone at several localities, but these are closely related to fissures, and may be like the caves so often encountered in the mines of the region, and not the results of purely surface erosion. In either case the solvent action of surface waters has doubtless been of chief importance in their origin. Quartzite seemingly is affected both by temperature changes and by frost. There is little or no rounding of the outcrops on the exposed summits, although on the lower slopes there is some corrosion.

CHAPTER VI.

THE SURFICIAL FORMATIONS.

Mention has been made in preceding pages of the thick mantle of disintegrated rock material which covers so large a part of the Tintic area. This constitutes one of the most unfavorable conditions for geologic work and has often seriously interfered with the discovery of the indications of ore, yet the subject is one of interest and worthy of brief treatment in this place. These surficial formations have been deposited in three different ways, and may therefore be classed, with respect to origin, as alluvial, lacustrine, and colluvial.[1]

TINTIC VALLEY ALLUVIUM.

Tintic Valley is bordered by alluvial cones which extend down from every ravine and valley along the western edge of the Tintic Mountains. These cones of stream-deposited material become flatter as they emerge from the mouths of the ravines, and here better deserve to be termed alluvial fans. The slopes nearer the valley axis are gentle, although the grade is sufficient for the transportation of coarse material. The exceptionally large proportion of run-off, due to the cloud-burst character of the rainfall of this region, gives to these occasional streams a greater transportation capacity than might be expected. The angularity of most of the rock fragments found near the middle of the valley also affords evidence as to the manner of transportation. Their journey from the rock slope to the outer edge of the alluvial fan has been a comparatively rapid one, and they have suffered less from the corrasion incident to transportation in a well-defined stream channel.

To a certain extent these alluvial fans are being trenched at present by deep arroyos. This dissection affords opportunity for better examination of the alluvium of the valley. The structure is that characteristic for such deposits—a stratification sometimes imperfect, but usually readily distinguished. Gravel and coarse sand are often interbedded. The freshness of all this detrital material is noticeable, since, as has been described in the last chapter, rock disintegration in the Tintic Mountains has been far in excess of rock decomposition.

In several cases the alluvial deposits extend far up into the range, following the different drainage lines, and their distribution is therefore greater than can be represented on the geologic map. In sinking the wells near Homansville alluvium was found in one instance to a

[1] This term is applied by Merrill to deposits of the nature of talus and cliff débris, in which gravity is the transporting agent. Rocks, Rock-weathering, and Soils, 1897, p. 319.

depth of 65 feet, consisting of interbedded gravel and clay, the latter in beds a few inches in thickness. Another well was sunk over 250 feet before bed rock was reached. The alluvium filling the valleys on the east side of the range is similar to that described above and does not require special mention.

LAKE BONNEVILLE BEDS.

Goshen Valley is about 1,000 feet lower than Tintic Valley and is covered by deposits of a different character. The Pleistocene lake which covered the eastern part of the Great Basin extended into this valley, and the fine material now covering the surface was deposited from the waters of Lake Bonneville. The alluvium which doubtless covered the lower valley in pre-Bonneville times as it yet covers Tintic Valley has been hidden from view by lacustrine deposits, which are finer grained and more evenly distributed.

The Bonneville shore line, which marks the highest water level, is well developed at the head of Goshen Valley, at an elevation a few feet above the 5,100-foot contour. The terrace here is mostly cut in the alluvial material extending down from the small ravines which indent the mountain slope. As can be seen by reference to the map of the Bonneville Basin accompanying Mr. Gilbert's monograph,[1] this area formed a part of Utah Bay, an almost land-locked arm of the lake. Thus the waves which beat on this shore had but little fetch and were less efficient, and the shore line is not so deeply carved as at more exposed points, like the northern end of the Oquirrh Mountains. Yet the terrace marking the Bonneville level is readily observed, and is the more apparent as it forms the line of division between two types of topography. Above, the rock has been sculptured into bold outlines, which even the surface accumulations of rock detritus do not conceal; below, the lines are softened, and the gentle, even slopes of the lacustrine deposits afford a marked contrast even with the alluvial cones above. One interesting feature in the Bonneville shore is a bar constructed across a reentrant angle in the shore, forming a natural reservoir.

Faint traces of other shore lines can be detected, but at the level at which the water stood at the Provo stage the slope shows no break such as might be expected to indicate the Provo shore line, which is so strongly marked at other localities. There is, however, within the limits of the Tintic quadrangle a conspicuous topographic feature which is connected with the Provo shore line. Currant Creek emerges from its canyon immediately east of the boundary of the area here mapped, and from the mouth of this canyon extends a large delta, which forms a noticeable interruption in the broad concave sweep at the head of Goshen Valley. The surface of this delta lies just above the 4,700-foot contour, and thus approximates the level of the Provo shore

[1] Lake Bonneville, by G. K. Gilbert: Mon. U. S. Geol. Survey, Vol. I, Washington, 1890.

line. Below, the delta face has a steep slope to the valley bottom. Currant Creek has now cut a deep channel in its old delta.

When the water stood at the Bonneville stage, Currant Creek Canyon was a narrow strait connecting the water in Juab Valley with that in Goshen Valley. With the fall of the lake level to the Provo stage there was a marked change of conditions. Currant Creek began to drain Juab Valley, having its point of discharge at the head of Goshen Valley. Here the delta was doubtless quickly built, the upper surface of which may be taken as indicating the Provo water level. The uniform fineness of the material composing the Currant Creek delta is due probably to the fact that all coarser sediments were deposited in the lakelike expanse of the stream in Juab Valley above the canyon.

Sections of the wave-built terraces seen within the area show well-bedded sand, fine and well sorted. A few beds of coarse gravel a few inches thick occur interbedded with the sand. These can be traced upward to the talus at the base of the steep slope of limestone, and indicate alternation of conditions, now the locally derived limestone fragments being deposited on the beach, and now the finer shore drift. On the upper surfaces of the uppermost pebbles of these beds calcareous tufa has been deposited.

Dunes of drifting sand occur along the western edge of Goshen Valley east of the mouth of Pinyon Canyon.

TALUS DEPOSITS.

This group of deposits includes the rock detritus which occurs in the form of talus slides and avalanche streams. This material is heterogeneous and unstratified, and owes its removal from the original rock mass primarily to the action of gravity. Creep, due to the action of frost and snow, may occur in these talus slides, while on the steepest slopes avalanches of snow doubtless have been effective in the transportation of the rock fragments to lower levels. Well-defined avalanche streams occur in some of the sharply cut V-shaped ravines, making the cross section resemble more the letter W, with the central ridge considerably lower than the sides. These rock streams have apparently not yet come to rest, judging from the comparative absence of vegetation.

The mantle of talus material has accumulated to a great thickness in many places on the slopes of the Tintic Mountains. Both in the limestone areas and on the hills of monzonite prospect tunnels show this disintegrated rock to cover the solid rock to a depth of 50 and even 100 feet. So compact is this unconsolidated material that roof and walls remain standing untimbered for many years in these deserted tunnels. In gulches where stream erosion has cut trenches in the débris the high angles at which the walls stand also show a considerable degree of cohesion in this material.

The occurrence of such large amounts of talus material is a phenomenon resulting from the climatic conditions. Physical disintegration of the rock mass is rapid on these barren slopes, exposed at this altitude to sudden and considerable changes of temperature. The amount of loose material thus furnished is too great for the agents available for its transportation. Accumulation has thus continued until on the lower slopes a balance is reached where the mantle has become in great part protective. On the steepest slopes, however, gravity is effective in the removal of the rock fragments, and additions to the talus accumulations below still continue to be made.

The cementation of the loose fragments and sand into such coherent masses is a process also connected with the aridity of the region. As has been shown, chemical decomposition of the products of weathering is slight. Sufficient water does not circulate through these deposits to thoroughly leach out the soluble parts of the rocks, and what water is present is without doubt a less active solvent than that charged with the humus acids, such as would be present were the region covered with vegetation. However, a certain amount of solution does take place, though the dissolved material may not be removed far. Capillarity brings such solutions to the surface, and on evaporation the salts in solution are left near the surface and here act as a cement. This calcareous cement is readily noticed in many of the deposits of this nature, and seems a sufficient explanation of their exceptional compactness.

CHAPTER VII.

GEOLOGIC HISTORY.

SEDIMENTATION (PALEOZOIC).

The geologic history recorded in the rocks of the Tintic Mountains begins with Paleozoic sedimentation. Nothing is exposed below the Robinson quartzite, the oldest member of the series of 14,000 feet of Paleozoic sediments in the Tintic section. The reference of this quartzite to the Cambrian period is based purely upon lithologic and stratigraphic correlation, as was shown in Chapter II. The position of the Cambrian shore line and the conditions which governed the deposition of these sediments can only be inferred.

In the first place, it is to be noted that there is in the Paleozoic section of the Tintic Mountains no stratigraphic break, such as a marked unconformity or extensive conglomerate. These would be expected if there had been any considerable uplift or subsidence to record. The absence of coarse material in any of the sediments is worthy of note, a few pebbly bands in the quartzite being the only exception. The sediments are all such as to show that their deposition at no time occurred near a shore line. The nearest exposures of Archean or Algonkian rocks at the present time are in the Wasatch Mountains, north of Salt Lake City, and on Antelope Island, immediately north of the Oquirrh Range.

As compared with the rocks of the Wasatch section, referred to on page 629, the Tintic sediments above the top of the Cambrian quartzite are characterized by their general calcareous nature. In the former section arenaceous and argillaceous rocks greatly predominate, occurring throughout the series, while in the Tintic section, above the Robinson quartzite and associated shales, only 110 feet of sandy limestone and quartzite occur with the 6,500 feet of limestones. This points to the existence of a deepening sea over the Tintic area after Cambrian time. While the Wasatch arenaceous sediments were deposited nearer shore, the conditions were here more favorable for limestone deposition.

The Eureka and Godiva limestones, in part dolomitic, aggregate 6,600 feet and record a long interval of sedimentation under conditions essentially uniform. The former limestones are, as a rule, thinner bedded, and hence appear at times rather shaly. Similar thin-bedded limestones also appear in the Godiva series, which contain rather purer limestones than the Eureka.

In both formations individual beds are often distinct for long distances along the strike, a fact which is taken as indicating the persistency of conditions over considerable areas. The limestones are not rich in fossils, and therefore the conditions do not appear to have been especially favorable to organic life. This is also noticeable from the fact that the fossils found are from a few well-defined beds. In such occurrences, while the rock is quite fossiliferous, the range in species appears decidedly limited.

A break in these uniform conditions of limestone sedimentation seems to have been inaugurated with the deposition of the lower beds of the Humbug Intercalated series. Here arenaceous, argillaceous, and calcareous beds occur in succession, and, as has been already noted in the detailed description of the series; the sandstones are usually calcareous and the limestones sandy. The conditions of sedimentation, therefore, became more varied; the depth of water was doubtless somewhat lessened, with the result that arenaceous as well as calcareous material was contributed to the area of deposition. Changing currents were able only partially to perform the task of sorting this heterogeneous material and more or less mixed sediments were deposited. Moreover, the beds thus deposited could not be expected to be very persistent along the strike.

The section of sedimentary rocks exposed in the Tintic district thus records unbroken sedimentation from early to late Paleozoic. Beginning with the deposition of well-washed sand, the succeeding sediments were calcareous muds, followed by more argillaceous and arenaceous sediments.

UPLIFT AND EROSION (MESOZOIC).

This area of Paleozoic sedimentation is believed to have been raised above sea level early in Mesozoic time. The sediments which were deposited during the Triassic, Jurassic, and Cretaceous periods along the east front of the present Wasatch Mountains are not found to the west. The uplifted area extended 300 miles westward from the Wasatch Range,[1] while the southeastern shore of the Mesozoic continent was not far from the southern end of the Tintic Mountains. In post-Jurassic time the young continent received an important addition on its western edge—an uplift, which was accompanied by a marked plication, producing folded ranges. How far to the east this zone of post-Jurassic folding extended it is difficult to prove.[2]

In the Tintic Mountains, as has already been stated, the Carboniferous strata have suffered compression to a considerable extent. In the Canyon Range, immediately south of the Tintic Range, the early Tertiary conglomerates show only a moderate tilting, while the Carboniferous limestones continue the folds of the Tintic Mountains. This marked unconformity between the Tertiary and Paleozoic rocks makes

[1] Clarence King, U. S. Geol. Expl. Fortieth Par., Vol. I, p. 732.
[2] King, op. cit., pp. 733–734.

it evident that the mountain-building movements which resulted in these folds were of Mesozoic age. No data are available, however, on which to base any more exact time determination for the folding of the rocks of this area.

This post-Carboniferous uplift inaugurated a decided change in the history of the area. Erosion was substituted for sedimentation, and the new land area immediately began to have its surface wasted away. It appears probable that many thousand feet of Carboniferous strata have wholly disappeared from the Tintic region, and their erosion was pre-Tertiary. The close folds that characterize the lower Carboniferous rocks of the Tintic Mountains could not have been produced after this erosion had removed any considerable part of the overlying strata. This necessity of the lower Carboniferous rocks remaining at a sufficient depth to be in the zone of folding may be considered as perhaps indicating an early, rather than late, Mesozoic period of mountain building.

If there has been further uplift of the Tintic Mountains, it is presumably of a different type, the result of strictly vertical action without compression or plication. Such a type of dynamic action is believed to have contributed more or less to the mountain building of the Great Basin.[1] In the Tintic Mountains there is little evidence of a later uplift of this kind, and it is probable that it was of minor importance.

VOLCANIC ACTIVITY (TERTIARY).

The Tintic Mountains had been deeply carved by erosive processes, portions of the range being reduced nearly to the valley level, when vulcanism began its task of rejuvenating the mountain range. Deep canyons were filled with volcanic material, thus restoring in great measure the topographic continuity of the range.

Volcanic activity in the Tintic Mountains began with eruptions of rhyolitic lava. In the vicinity of the present town of Eureka this eruption was of the nature of an outwelling of viscous lava from a vent probably marked by the largest mass of rhyolite in the area—Packard Peak, which rises about 1,400 feet above the gulch to the south. From this center the lava flowed downward and partly filled the deep canyon north of Godiva Mountain and Eureka Peak. The rhyolite also flowed off to the southeast down the Goshen Slope, which at the commencement of this eruption was doubtless much steeper.

Probably contemporaneous with the Packard Peak eruption was the intrusion of the quartz-porphyry or Swansea rhyolite between Robinson and Silver City. There is evidence that at its southern end this intrusion reached the surface, since on Horseshoe Hill fragmental rhyolitic material is found. The line of this intrusion appears to have been near the contact between the Robinson quartzite and the Eureka limestone, although at its northern end the intrusive rock has extended into the limestone.

[1] Gilbert, U. S. Geog. Survey W. One Hundredth Mer., Vol. III, p. 42. King, op. cit., p. 744.

Eruptions of rhyolite occurred in other parts of the Tintic Mountains, as was noted in Chapter IV; and rhyolite also occurs on the western side of the Tintic Valley.

Following the rhyolitic flows were the andesite eruptions, of a quite different character. Fragmental material was ejected in great quantities, and typical composite cones of lava flows and tuff and breccia beds were constructed. The remnants of one such cone can be seen on Volcano Ridge.

A later eruption of andesite took place in the Diamond area, and its flows overlie the fragmental deposits. In this way the latter seem to be less widely distributed. The later eruptions of andesite were plainly less explosive in character, and appear here to have taken the form of a quiet extravasation of lava from a fissure, the outlines of which are approximately defined to-day by the area of monzonite and monzonite-porphyry. Moreover, this fissure eruption appears to have followed, in a general way, the old line of weakness taken by the Swansea rhyolite. The Volcano Ridge cone also shows a definite relation to the quartzite-limestone contact.

The period of volcanic activity in the Tintic Mountains can not be very exactly determined. A Tertiary age is given to the products of this activity on the basis of general relations. To the south, where the wash of the southern part of the Tintic Mountains enters the valley of the Sevier River, there occurs a red conglomerate, which is correlated with the Eocene conglomerate (Wasatch) to the northeast. Examination of the pebbles of this conglomerate failed to detect the presence of rhyolitic or andesitic material. The quartzite and limestone pebbles from the older part of the Tintic and Canyon ranges are plentiful. In the recent alluvial material contributed to this locality from the Tintic Mountains the volcanic detritus is rather abundant. On this account the rhyolite and andesite are believed to have been erupted after the deposition of the conglomerate, thought to be of Eocene age.

North of Tintic Valley, on the divide between it and Rush Valley, there is an occurrence of limestone, which contains much fine volcanic material.[1] This is thought to be of later Tertiary age, and field work at this locality, which is outside the area here considered, might furnish data for a more definite determination of the age of the volcanic rocks, which are so important in the Tintic Mountains.

EROSION WITH DEPOSITION OF SURFICIAL FORMATIONS (LATE TERTIARY AND QUATERNARY).

Erosion began its work even before the cessation of volcanic activity. The rhyolitic flows were somewhat eroded previous to the first eruption of andesite, and the volcanic cone of Volcano Ridge had begun to be carved by atmospheric agencies before the intrusion of monzonite cut across one side of the cone and the flows of andesite covered the earlier

[1] Emmons, U. S. Geol. Expl. Fortieth Par., Vol. II, p. 455.

volcanic deposits. Erosion has since then continued without interruption, and to-day the region is again one of marked relief, although the products of the Tertiary vulcanism had concealed to a large extent the earlier works of erosion.

An exact measure of the postvolcanic erosion can not be easily given. On the lower slopes of Godiva Mountain the lower breccia of the andesite and rhyolite flows is exposed in such a manner as to indicate that in the upper portion of the mountain the limestone has not been greatly eroded. The volcanic material which once covered the base of the mountain on the eastern and northern sides has been removed in great part. However, in the upper part of Eureka Gulch the bottom of the prevolcanic canyon has not yet been reached. In the southern part of the Tintic Mountains it is evident that a large amount of the volcanic rock has been removed by erosion. Buckskin Mountain has been carved from horizontal flows of andesitic lava, and Tintic Mountain is a sharp peak of andesite flows which were once continuous with those of Buckskin Mountain. The andesite that must have once covered the holocrystalline monzonite of Sunrise Peak and the area to the north has almost wholly disappeared. On Treasure Hill some of the rock is so andesitic in texture that it probably represents a remnant of this mantle, but even here erosion has removed a large mass of material.

Furthermore, the amount of erosion in the Tintic Mountains is difficult of exact determination on account of the deposits of alluvium and talus, which so effectually conceal the solid rock over large areas. In Tintic and Goshen valleys, which bound the range on the west and east, the alluvial and lacustrine deposits are so deep as wholly to prevent any determination of the real amount of rock erosion in these valleys. Even well up in the mountains the mantle of alluvium is considerable. Thus, in the basin at Homansville the "deep well" shows the alluvium to be over 250 feet deep. Such extensive surficial deposits, however, afford some measure of the amount of detrital material contributed by the processes of erosion. Alluvial fans have been spread all along the western flank of the range, filling up Tintic Valley to its present level. On the east similar deposits once extended out into Goshen Valley, and are now only concealed by the lake beds, detrital material also derived from these mountains.

Alluvial deposits of this character and extent testify to climatic conditions favorable to both erosion and transportation. At present the agencies of transportation are inadequate, so that the rock detritus accumulates in talus deposits. It is evident, therefore, that a period characterized by greater precipitation preceded the present one of aridity. Further evidence of this is afforded by the lacustrine deposits of the now extinct Lake Bonneville. An arm of this lake occupied Goshen Valley, and the lake beds were deposited, covering the alluvium of the valley. This body of water later disappeared, the climate becoming too arid for its preservation. Since the departure of the Bonneville waters these deposits have remained practically undisturbed. The Currant Creek delta was trenched by that stream as the lake level was lowered, until now Currant Creek has regained its old rock bed in the canyon above the delta and also has cut down over 100 feet into the delta deposits, thus affording a measure of post-Bonneville erosion. The lowering of Lake Bonneville, with the sudden change of water level, at first caused an increase of efficiency in other streams tributary to the lake. In Tintic Valley there are stream terraces which are referable to this period of marked activity. In the rich bottom lands of this valley there is little other evidence of the stream that once flowed there. Along the edge of the valley trenching of the alluvial fans still continues.

RÉSUMÉ.

Four distinct epochs in the geologic history of the Tintic Mountains are recorded.

In Paleozoic time the area was one of sedimentation, thousands of feet of arenaceous and calcareous sediments being deposited in the deep waters of the sea, and at a distance from the shore.

In Mesozoic time these sediments were lifted above the sea level and the horizontal beds were compressed into close folds. Atmospheric agencies immediately began to wear away these rocks, so that a marked relief was given to the Tintic Mountains.

In Tertiary time volcanic eruptions of tuff and lava in different parts of the area added greatly to the mass of these mountains, and the results of the Mesozoic erosion were largely concealed.

Since the volcanic eruptions ceased, erosion has cut deeply into the accumulations of volcanic material. The products of this erosion have been deposited as alluvium and lake beds in the valleys and as talus on the upper slopes.

PART II.—MINING INDUSTRY.

CHAPTER I.

THE FRACTURES.

INTRODUCTION.

The fractures observed in the rocks of these mountains belong to two distinct periods. First, are those in the sedimentary rocks, the beginning of which was in the deformation of these strata and which have continued to form, at least until the beginning of the volcanic activity; and, second, those in the igneous rocks, which are more recent in origin and which resemble joint plane structure.

FRACTURES IN THE SEDIMENTARY ROCKS.

Distribution.—In the sedimentary rocks the fractures are very extensive and may be seen in almost every outcrop. They are most abundant in the vicinity of the three great N.–S. ore zones, the Eureka zone, which has been traced from the Gemini mine through the Bullion-Beck and Eureka Hill mines to the Centennial Eureka mine; the Mammoth zone, which has been traced from the Eagle mine through the Grand Central and Mammoth mines to the Ajax mine; and the Godiva-Sioux Mountain zone, which extends from the northern end of Godiva Mountain along the east flank of Godiva and Sioux mountains to Dragon Gulch, and has been followed almost continuously by the workings of the Godiva, Uncle Sam, Humbug, Utah, Sioux, Northern Spy, Carissa, Boss Tweed, Red Rose, and North Star mines. The fractures are most readily traced in the more resistant beds of limestone and in the quartzite.

Direction.—The great majority of the fractures occur in the NE. and SW. quadrants, but the most persistent vary only a few degrees east or west of the meridian.

The fractures of the NW. and SE. quadrants are not so abundant as those of the NE. and SW. quadrants. They result either from slipping along the bedding planes of the strata or from the release of pressure at some local sharp flexure in these strata. The fracture planes are nearly vertical, but some few dip E. or W. at an angle which is rarely less than 70°, the east-dipping fracture planes being more frequent than those dipping to the west.

Principal fractures.—The N.–S. fractures, including variations of not more than 10° east or west of the meridian, the N. 15° E., the N. 25°

E., and the E.–W. are the most abundant and the strongest fractures. These fractures are almost always vertical.

Of these the N.–S. are by far the most important. The Robinson quartzite is so profoundly sheeted by these as to conceal the bedding in most places.

The N. 15° E. fractures are the commonest planes at an angle with the N.–S. fractures, and the N. 25° E. and the E.–W. fractures are easily recognized because they cross the stratification. The Spy-Ajax fault, which crosses from Mammoth Gulch to the Northern Spy mine, is the most important of these and has a displacement of 1,000 feet. Along the contact of the Robinson quartzite and the Eureka limestone there are many E.–W. fractures which have faulted the contact to the east or the west, in several cases as much as 200 feet, but usually less than this. Similar fractures were observed in the Godiva limestone, where they intercept a bed of shaly limestone, which, because of its large content of carbonaceous matter, gives off a fetid odor when freshly broken, and is called "stinkstein."

Subordinate fractures.—NW., N. 55° W., N. 20° W., and NE. fractures, while constantly present, are much less persistent than the other fractures of the stratified rocks. These fractures are usually vertical, but those which are parallel to the strike of the rocks also parallel the dip, and therefore dip to the east, and in rare cases to the west at high angles.

Of these the N. 20° W. and the N. 35° W. are the most abundant. The N. 20° W. fractures result largely from the slipping of the individual beds of the strata past each other, thus forming open spaces of small dimensions.

The N. 35° W. fractures are confined to a small but very sharp flexure in the stratified rocks along Eureka Gulch, passing between the Bullion-Beck and the Eureka Hill shafts. At this point the beds turn sharply from a N. 20° W. strike at the south end to a N. 75° W. strike, only to resume the N. 20° W. strike a very short distance north. Where the beds depart from their normal strike the N. 35° W. fractures have been formed, together with much brecciation of the strata.

Intersections.—The relations of the various fractures to one another are very complex and difficult of comprehension. So far as it is possible to judge, the majority of the fractures cross but have not faulted each other. The exceptions to this that have been noted are along Quartzite Ridge and the Spy-Ajax fault, where N.–S. fractures are faulted by E.–W. fractures; also in the mines of Eureka and Godiva Mountains, where N. 25° E., NE., and E.–W. fractures are seen occasionally to break the continuity of the other fractures.

Relations to structure.—The N.–S. fractures, which are by far the most common, are parallel to the axis of the syncline and also are most abundant on the west limb of this syncline, where the strata are nearly vertical. On the east limb, where the strata dip at low angles which rarely exceed 25°, they are not common.

The NNE. and NE. fractures are most common at the southern end of the syncline, where they cross the beds at nearly right angles.

The E.-W. fractures are found in the central and northern parts of the area of stratified rocks.

The NNW. fractures follow closely the bedding planes of the western limb of the syncline, and the NW. fractures are found in the zone of a sharp flexure of the strata along the western end of Eureka Gulch.

The NNE., NE. and E.-W. fractures cross the stratification and appear to have formed mostly subsequent to the N.-S. fractures and consequently to the folding.

The NNW. fractures, which are parallel to the bedding, resulted at the time of the folding of the strata and as a result of the folding.

The NW. fractures are also dependent on the folding, since they are confined to the zone of sharp flexuring of the strata.

Relations to ore bodies.—The most pronounced fractures trend north and south, and this is the general direction of all of the ore bodies. There are, however, many small ore bodies and portions of large ore bodies which follow the other fractures, so that as a result there is no fracture direction known which does not at some place carry ore or vein matter. As contrasted with the main direction of the ore bodies, however, these others form only a very small part.

The fractures which fault ore bodies are very few, and since they have courses parallel to ore-bearing fractures, it is only possible to distinguish these as later fractures when they actually cross ore bodies.

Age.—The fracturing of the sedimentary rocks has resulted from the dynamic action which deformed the stratified rocks of the Tintic Mountains, and was greatest before the mineralization of these rocks, for the ore bodies follow every fissure direction known.

There are but few fractures which fault the ore bodies, and as these do not enter the igneous rocks, they may be considered older than the latter.

As the youngest strata are of Carboniferous age, it is probable that their deformation and subsequent mineralization occurred during the Jurassic age. At all events, it was prior to the Tertiary, which was the period of volcanic activity.

Differences in the ages of premineral fractures are suggested by the fact that some of the fractures, though mineralized, fault others. Along the Spy-Ajax fault, which trends E.-W., the fractures on either side do not match, a fact which indicates that the fracturing at an angle with the main fractures was subsequent to the N.-S. fracturing. Such conditions as those described can, however, readily result simultaneously, as demonstrated by Daubrée[1] and others in their experimental studies with glass and other substances, and in the absence of definite data, such as secondary deposits in certain fissures and the lack of these deposits in others, no definite conclusions can be reached.

[1] A. Daubrée, Géologie Expérimentale, p. 310.

The fractures which fault the ore bodies trend N. 25° E., NE., and E.-W., and are of later origin than the mineralization and than the great majority of the fractures, but they appear to be older than the volcanic activity, for in no case have they been traced into the igneous rocks.

The E.-W. fractures found in tracing the contact of the Robinson quartzite and Eureka limestone have not intersected any of the known ore bodies; hence their chronologic relation to ore deposition is not determined. They are undoubtedly older than the volcanic rocks, because in the northern part of the district they have been found to stop at the contact.

The facts which are clearly indicated are an early series of fractures trending NNW. and NW., connected with the deformation of the strata, which were later intersected by a series of cross fractures trending N.-S., NNE., NE., and E.-W., and which may have been produced by the forces which tilted the axis of the syncline. The interrelations of the fractures indicate that they have not been, except in a few cases, planes for any considerable rock movement. They preceded the mineralization. A very few fractures followed the mineralization and preceded the igneous activity.

THE EUREKA FRACTURE ZONE.

Primary or premineral fractures.—Though fractures are present on every hand, their greatest development near Eureka is in the zone which includes the workings of the Gemini, the Bullion-Beck, the Eureka Hill and the Centennial Eureka mines. The fractures here found belong to both the principal and the subordinate series.

The fractures in the Centennial Eureka, which is the most southerly of these mines, belong principally to the N.-S. system, though ore is found occasionally on NW. and NE. fractures. In the Eureka Hill the fractures adjacent to the Centennial Eureka are also for the most part N.-S., yet going north they give way slowly to N. 10° to 35° W. fractures as far north as the Bullion-Beck shaft, beyond which point in the Bullion-Beck and Gemini N.-S. and N. 10° to 15° E. fractures again predominate.

The greatest fracturing has been between the Bullion-Beck and the Eureka Hill shafts, where fractures of all the directions are common. To the south, though nearly as many fractures exist, there are fewer fracture directions, the N.-S. being the most common, and to the north there are neither so great a number of fractures nor so many fracture directions as in the other portions of the zone, the principal open spaces being parallel to the bedding planes of the strata.

The ore bodies in this fracture zone follow the fracture planes in their varying directions. In the Centennial Eureka their general course is N.-S., with minor irregularities due to their departure on intersecting fissures. In the Eureka Hill mine, at the south end, they also trend

N.–S., but turn gradually to the west, and between the Eureka Hill and Bullion-Beck shafts are mainly N. 35° W. North of the Bullion-Beck shaft in this and the Gemini mines they trend N.–S. or a few degrees east or west of N.–S.

In the two southern mines the ore bodies are fairly continuous and have a great vertical range, but in the Bullion-Beck and Gemini mines, especially north and east of the Bullion-Beck shaft, they are less continuous and have but small vertical range, so that the ore in this northerly portion of the zone consists of a number of lens-shaped bodies scattered widely along the length, breadth, and depth of the ore zone.

Secondary or post-mineral fractures.—The later fractures observed in this zone were very few in number. E.–W. fractures were found in all of the mines. One N. 25° E. fracture was found in the Centennial Eureka mine, while one or two NE. and NW. fractures were observed in the Eureka Hill and Bullion-Beck mines.

MAMMOTH ZONE.

The Mammoth fracture zone has its strongest development in the Mammoth and Ajax mines and extends northward through the Grand Central and Eagle mines.

Primary or premineral fractures.—The fractures are almost entirely premineral, and of these the N.–S., including variations of 10° east or west, are the most numerous and most conspicuous. The other fractures trend N. 15° E., N. 25° E., NE., N. 20° W., NW., and E.–W. The N. 25° E. and the NE. are common to all the mines of this zone and are especially well seen in the Ajax, where they have been extensively mineralized. The N. 15° E. fractures are peculiar to the Mammoth, and in this mine, together with the N.–S. fractures, have been the planes of the heaviest mineralization.

There is one great E.–W. fracture, the Spy-Ajax fault, which crosses this zone and has displaced the strata on the south side 1,000 feet eastward. Adjacent to this, on both sides, are many parallel fissures, some of which are ore bearing.

The N. 20° W. and the NW. fractures have their greatest development in the Grand Central, and are largely the result of slipping along the planes of stratification.

Like the Eureka zone, this zone trends almost due N.–S., and the ore bodies follow nearly continuously the axis of the zone. At the southern end of the Ajax there are two ore bodies which unite on the hill slope north of the mine entrance, but the largest bodies of ore occur at the intersections of the N.–S. with the NE. fractures. Near the surface these bodies dip E. at a low angle, but in depth soon become vertical. Between the Ajax and the Mammoth mines the Spy-Ajax fault crosses, and though this is a primary fault, it has influenced the movements of the ore solutions or their deposition, so that the exact relations of the ore bodies to the north with those south of this fault are not clearly understood, at least no connection between the two has been established. At the southern end of the Mammoth the ore forms a large irregular elliptical-shaped chimney at the intersection of several fissures and sends off fingers to the east, but the main channels are N.–S. or N. 15° E. These ore bodies stand nearly vertical. In the Grand Central the ore follows N.–S. fractures in part. Its main axis, however, is N. 15° to 30° W., and nearly parallel to the strike and dip of the strata. In the Eagle the ore body trends a few degrees W. of N., parallel to the stratification but with vertical dip.

The vertical range of the ore bodies varies greatly. The chimney in the Mammoth has been continuous for more than 1,600 feet, while the ore bodies which follow simple N.–S. fractures have a much smaller vertical extent and are largest near the surface. In the Grand Central the top of the great ore body now being worked seems to have been nearly a thousand feet below the surface. The Ajax and Eagle ore bodies, on the other hand, diminish in size below the surface, though it is probable that future development will discover other ore bodies in all of these mines.

Secondary or post-mineral fractures.—The only observed post-mineral fracture is in the Mammoth. This trends N.–S., and includes an irregular band, varying in width from 20 to 100 feet, of broken angular fragments of limestone. It is popularly known as "The Dike."

GODIVA-SIOUX MOUNTAIN ZONE.

Beginning at the North Star and continuing northeast to the east side of Sioux Mountain, thence northward to Godiva Mountain, and finally north-northwest to the north side of this mountain, is a continuous zone of fracture that has been extensively cut by mine workings and has yielded a very considerable amount of ore.

Primary or premineral fractures.—At the south end the most prominent fracture planes strike N.–S. and N. 25° to 35° E., while in the central portion N.–S. and N. 15° E. fractures are more abundant, and at the north end the N.–S. and N. 15° to 30° W. fractures prevail. They are all vertical.

At the south end, N. 20° to 45° W., fractures, though present, are very much less conspicuous than the N.–S. and N. 25° to 35° E. fractures, while at the north end the reverse relation is true, the NNE. and NE. fractures being subordinate to the NNW. and NW. fractures. In the midzone, along the slopes of Sioux and Godiva mountains, the NW. and NE. fractures are almost entirely absent, and the fissures which do not parallel these mountains are at right angles to the axis of them and are E.–W. fissures. There seems, therefore, to be in these fractures a more definite arrangement than in the other two zones, and the curving around the mountain range of these fractures is in all probability a dynamic phenomenon closely connected with the folding of the range.

The ore bodies in this zone follow the fractures; that is, they are NNE. at the south end, N.–S. along the east flanks of Godiva and Sioux mountains, and NNW. at the north end of Godiva Mountain. At the south end, however, the ore zone is composed of several short ore bodies, while in the central portion where the general trend is N.–S., with minor departures into intersecting fractures, there is a single ore body which has been followed continuously from the Carissa to the Utah mines, a distance of 5,000 feet. Beyond this to the north the ore bodies are less regular than elswhere, being short, lens-shaped bodies which pitch S. or E.

At the south end the ore bodies are nearly vertical, but in the Northern Spy, Sioux, and Utah mines, though vertical or with a steep westerly dip in the lower levels, at the contact of the Godiva and Humbug Intercalated formations, they have departed from the fractures and followed the bedding planes of the strata which strike nearly N.–S. and dip E. at angles of 25° to 65°.

Secondary or post-mineral fractures.—Post-vein fracturing is slight and is principally seen in the Utah mine, where an E.–W. fault has displaced the ore body between the Utah and the Humbug.

FRACTURES IN THE IGNEOUS ROCKS.

Distribution.—The fractures in the igneous rocks are almost entirely confined to the quartz-porphyry and monzonite areas, and are most abundant in those rocks which are coarsely granular, so that from a maximum development between Silver City and the Sunbeam mine they become few and insignificant east of this point.

On Treasure Hill and Sunrise Mountain, to the north and south of Diamond, respectively, are a few important fractures in the porphyritic monzonite.

Direction.—The monzonite and quartz-porphyry are traversed by a very complex series of nonpersistent joint planes, and in the studies of the fractures only such have been noted as have been planes of movement or mineralization, or both.

There is not so wide a range in direction of the fissures in the igneous rocks as obtains in the sedimentaries. The great majority of them are in the NE. and SW. quadrants and trend between N. 15° and 55° E., the most abundant being the N. 15° E. and the N. 35° E. The other fractures of these quadrants trend more to the east and average about N. 70° E.

The fractures which have been mineralized are always vertical, or nearly so. It is not uncommon for these to dip to the east at one point and to the west at a point less than 100 feet below, or vice versa. The dips rarely are less than 80°.

The fractures of the NW. and SE. quadrants are almost exclusively limited to the mines north of Silver City, and trend N. 10° W. There are also a few fractures in this area which trend N.–S.

Principal and subordinate fractures.—There appears to be no marked difference in the importance or prominence of these fractures, for, while in certain localities the N. 10° W. and N.-S. are the more important, in other localities they are either wanting or subordinate to the NNE. and NE. fractures. Thus, in the mines north of Silver City—the Swanseas, Park, Four Aces, and Silver Bow—N. 10° W. and N. 15° E. fractures predominate; in the mines along the north side of Dragon Gulch N. 20° to 35° E. fractures predominate, and in the mines to the east of Silver City—the Martha Washington, Sunbeam, Undine, Joe Daly, and others—N. 25° to 45° E. fractures predominate; but all the fractures die out near the sedimentary rocks.

Secondary fractures.—The important intersections of the fractures of these rocks are very few. In the Swanseas two were noted which displaced the vein-bearing fractures about 10 feet in each case. These trended N. 55° W. and N. 70° E.

Age.—The igneous rocks are of Tertiary age and probably Miocene; hence it is only possible to say that the fractures in the igneous rocks are late Tertiary or early Quaternary in age.

RELATION OF FRACTURES TO GEOLOGIC STRUCTURES AND TO ORE BODIES.

In the sedimentary rocks the principal fracturing, as has been already stated, is N.-S. and NNE. The N.-S. fissuring, largely on the west flank of this syncline, parallels the axis of the syncline, which is the structural feature of the stratified rocks of these mountains. The NNE. fissuring is most pronounced at the south end of the syncline.

The ore bodies follow the N.-S. fissures largely, but turn from them into all the other fissures for short distances, only to return to the N.-S. fissures.

The fissures which break the continuity of the ore bodies are comparatively few in number.

In the igneous rocks the fractures are confined almost entirely to the more solid types—the monzonite and the quartz-porphyry—while the glassy andesite and the glassy rhyolite are but slightly fractured. In the former there is a great amount of jointing, and certain of these joint planes have been emphasized by dynamic activity, which must have been slight, because the most conspicuous fractures are small and nonpersistent, and also because the lavas show only slightly inclined flow structures.

CHAPTER II.

THE ORE DEPOSITS.

GENERAL FEATURES.

The ore deposits of the Tintic mining district may be grouped under three heads: First, those of the sedimentary rocks; second, those of the igneous rocks; and third, the contact deposits.

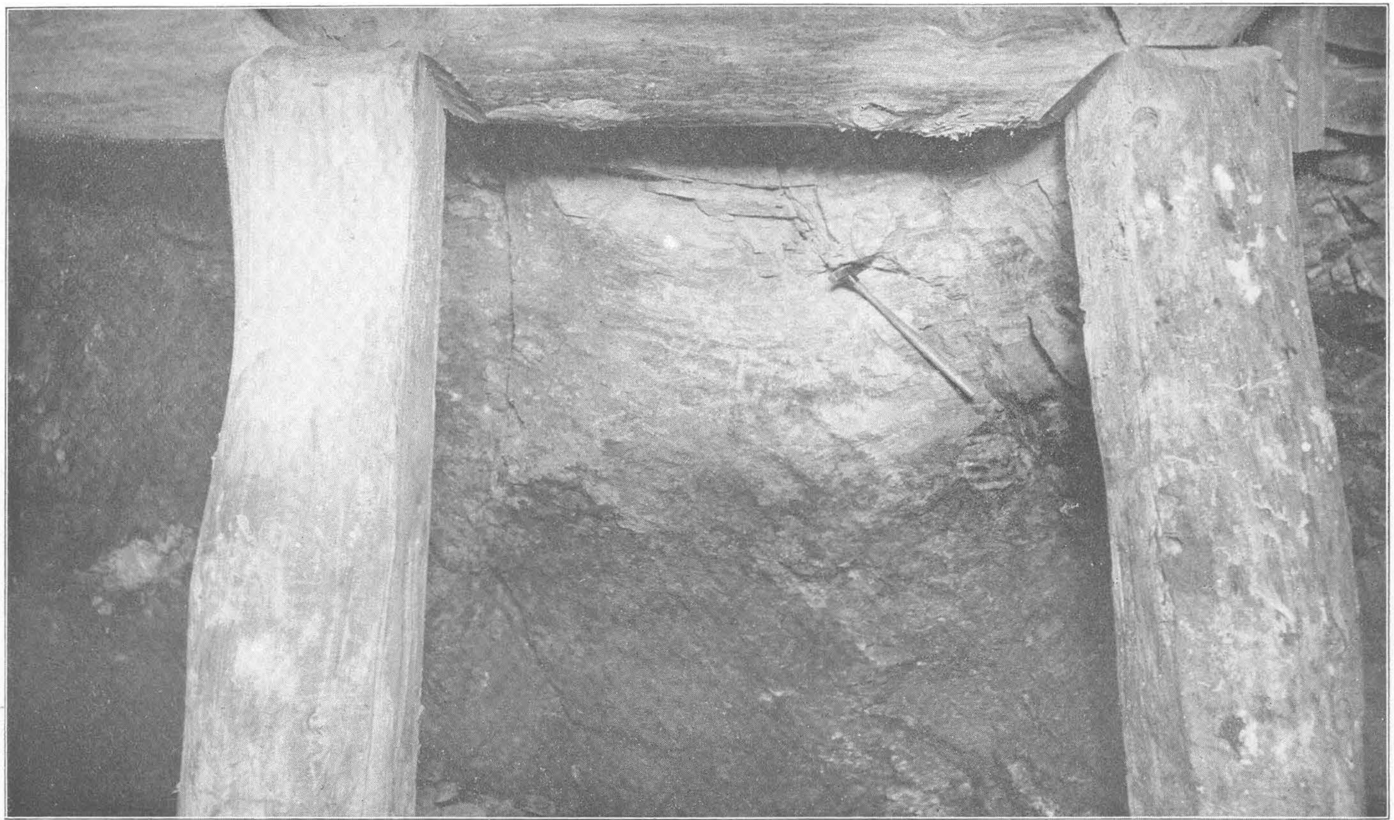
The deposits in the sedimentary rocks occur in three zones—the Eureka, the Mammoth, and the Godiva–Sioux Mountain zones. The Eureka zone, which crosses Eureka Gulch west of the town of Eureka, has a N.–S. trend and has been traced from the Gemini on the north through the Bullion–Beck and Eureka Hill to the Centennial Eureka on the south. The Mammoth zone has been traced with slight interruptions from the Eagle mine on the north through the Grand Central to the Mammoth and Ajax mines at the head of Mammoth Basin. This zone has a N.–S. trend. The Godiva–Sioux Mountain zone begins at the northeast end of Godiva Mountain and extends along the east slope of this and Sioux Monntain to the North Star mine on the southwest flank of Mammoth Mountain. For the most part it parallels the other two zones, but at either end bends to the west. It includes the Godiva, Uncle Sam, Humbug, Utah, Sioux, Northern Spy, Carissa, Red Rose, Boss Tweed, and North Star mines.

The deposits in the igneous rocks are not grouped, but consist of a great number of short veins striking N.–S. and NE.–SW., widely scattered through the granular igneous rocks. The principal mines are the Swansea, South Swansea, Sunbeam, Martha Washington, Treasure Hill, and Homestake.

The contact deposits follow the contact of the igneous and the sedimentary rocks. The Tintic iron mine on the north side of Dragon Gulch is the most notable of the contact deposits.

The ores are essentially composed of quartz, barite, pyrite, galena, sphalerite, enargite, silver, and gold minerals, together with the oxidation products of the metallic minerals; but quartz greatly predominates over the other minerals in the deposits of the sedimentary rocks, while the sulphides are in greater proportion in those in the igneous rocks.

In the stratified rocks the ground-water level is less than 5,100 feet above sea level, or more than 1,200 feet below the collar of the Bullion–Beck shaft, which has reached the lowest depth, though it is not the deepest shaft as reckoned from the shaft collars. The ores in the sedimentary rocks are hence largely oxidized. In the igneous rocks the



HORIZONTALLY BANDED ORE, EUREKA MINE, 300-FOOT LEVEL.

ground-water level varies between 5,500 and 6,500 feet above sea level and between 200 and 700 feet below the surface, being deepest in the Swanseas, which are near the stratified rocks, so that in these deposits the ores are completely oxidized at the surface and unaltered below water level, the line of separation of the two being very sharp.

In the stratified rocks the metallic minerals are scattered through the quartz-barite gangue, which in some cases fills irregular spaces and chambers along fissure planes, and in others replaces the country rock. In the igneous rocks the metallic minerals occur in lenses and pockets in the gangue minerals, resembling banded structures filling definite fracture planes. In most of the zones of ore deposition lead-silver ores predominate, especially at their northern ends, and copper and gold ores either equal or predominate over the lead-silver ores at the southern ends. Thus the Gemini, at the northern end of the Eureka zone, is a lead-silver mine, while the Centennial Eureka, at the southern end of this zone, produces as much copper as lead and a great deal more gold than the Gemini. The Godiva and Uncle Sam, at the northern end of the Godiva–Sioux Mountain zone, are lead-silver mines, while the North Star, at the southern end of this zone, is a copper-gold mine. In the Mammoth zone there are no distinctly lead mines at the north end, yet the Ajax, at its south end, has been a very rich copper mine. This phenomenon also holds in a somewhat modified form for the mines in the igneous rocks; though the mines are not grouped as in the sedimentary area, yet all the northern mines are exclusively lead mines and all the southern mines carry considerable copper locally.

VALUABLE METALS.

Gold.—This metal is confined almost entirely to the deposits of the sedimentary rocks, and is distinctly recognizable in these deposits only as native gold. As far as known, native gold is found only in the Mammoth, Grand Central, and Eagle, and is not common even in these mines. It appears to be either so finely divided or in such chemical combination that panning fails, as a rule, to give even a color. While tellurium is known to be present in the ores, it has not been found combined with the gold. Oxidation has extended so completely through the ores that the pyrite has been completely decomposed, and hence all traces of an original association of gold and pyrite are lost.

The studies of the thin sections of unoxidized ores fail to show any trace of gold or gold minerals, and in the original state it seems highly probable that the gold was combined with enargite or pyrite. The proof of this is largely negative and rests upon the occurrence of gold in these unaltered ores and the failure to find any gold-bearing mineral in the sections studied.

Silver.—This metal, which is common to the deposits in both the sedimentary and the igneous rocks, is more commonly found with galena than with the other minerals, though the richest silver ores in the deposits of the sedimentary rocks are cerargyrite oies, which are comparatively free from other metallic minerals. In such ores the cerargyrite is an alteration product and has separated from the other minerals through difference in solubility, so that it occurs as a coating to vein and country rock breccias.

Silver also occurs with the unaltered copper minerals, but is not often seen in this association, presumably because the copper minerals are the first to be decomposed by oxidizing solutions.

Lead and copper.—These metals are widely distributed throughout the ore bodies in both the sedimentary and the igneous rocks, and in the oxide zone are usually distinct, though the lead greatly predominates over the copper. Lead is always abundant in the ores, whereas copper rarely exceeds the lead, and in many of the mines is entirely wanting. Only lead ores are found in the more northerly mines of each of the ore zones save the Mammoth, whereas the copper content at most only equals the lead content in the mines at the southern end of these zones.

Sulphides and sulpharsenides.—These are common to the veins of the igneous rocks and are seen in the sedimentary rocks only sparingly and as residual bodies in the upper workings. They become, however, gradually more abundant with depth. In the igneous rocks they form from 50 to 80 per cent, averaging probably 75 per cent, of the mass of the vein, whereas in the sedimentary rocks they vary between 5 and 90 per cent, but average probably less than 20 per cent of the unaltered ores. There is no regularity in proportion either in the igneous or in the sedimentary rocks. They are not common in the wall rocks, though sometimes present.

In spite of the depth to which oxidation has extended, it is apparent that the metals were originally deposited as sulphides and sulpharsenides. Galena has been the most abundant mineral in the sedimentary rocks and pyrite in the igneous rocks. Enargite, together with chalcopyrite, and tennantite, the original copper minerals, are more abundant in the sedimentary rocks than in the igneous rocks. Sphalerite, or zinc blende, occurs only occasionally.

The average proportion of silver to gold by weight in the ores is about 400 to 1, but it varies in the different mines, being in the Mammoth more nearly 20 to 1; in the Centennial Eureka, 100 to 1; in the Eureka Hill, 250 to 1; in the Bullion-Beck, 350 to 1; and in the Gemini, 2,000 to 1, according to the reported outputs of the various mines.

Though no special tests were made of unaltered ores, the above figures doubtles give a more faithful representation of the proportion of silver to gold than a few special tests could, for they are the ratio established by years of production and would not have differed materially even though there had been no oxidation.

An average of 240,000 tons of ore, reported production of the majority

(A.)

(B.)

H. H. Nichols

JULIUS BIEN & CO. LITH. N.Y.

(A.) SECONDARY COPPER ORE
(B.) BRECCIATED LIMESTONE CEMENTED WITH SECONDARY ORE

(A.)

(B.)

H. H. Nichols.

JULIUS BIEN & CO. LITH. N.Y.

(A.) STALACTITE OF MELACONITE AND MALACHITE COATED WITH CALCITE
(B.) ALTERED LIMESTONE SHOWING RESULTING SHRINKAGE

of the mines, shows that the relative metallic constituents of the four important metals in these deposits are as follows:

		Per ton.
Gold	ounce	0.1356
Silver	ounces	52.4400
Copper	pounds	11.2000
Lead	do	270.0000

From the preceding paragraph it will be seen that the average value of the ores is close to $40 per ton. In the Centennial Eureka the ores average about $80, but this value would be much less had this company extracted its milling ores. It is rare that a Tintic ore worth less than $10 per ton can be mined, and the general rule seems to be that all ores worth between $10 and $25 per ton are milling ores, and that those worth more than $25 per ton are smelting ores. The lower-grade ores, however, when rich in lead or copper, though not containing high values in silver and gold, often yield a better profit by smelting than by milling.

THE PRODUCTS OF OXIDATION.

The ores of the stratified rocks are completely oxidized to a depth of several hundred feet from the surface, and partially oxidized to the very lowest points reached by the mine workings. As a result, but little of the vein matter as originally constituted is visible, the various minerals being decomposed according to their differing stabilities and solubilities by the oxidizing solutions, which were probably for the most part surface waters containing oxygen and carbon dioxide.

Of the vein minerals, enargite has been the most easily decomposed. Galena is somewhat more stable than enargite. In the decomposition of these, the two principal ore minerals of the deposits, much, if not all, of the gold and silver has been freed.

Enargite passes through a very great range of hydrous arsenical compounds to the oxides, and finally to metallic copper, as many as twenty-two definite copper minerals having been recognized in these mines. Occasionally traces of chalcopyrite have been found which, like enargite, changes to metallic copper, forming, however, instead of hydrous arsenical compounds, bornite and chalcocite before oxidation.

Galena passes into cerussite, which is a very stable mineral, and forms great bodies of ore in many of the mines; only occasionally has this been found altered to minium.

Silver, which existed in the ore bodies either chemically combined in galena and enargite or in the form of sulphide of silver, alters to cerargyrite; in all the mines, but especially in the Gemini, large bodies of brecciated vein and country rock have been found, the individual fragments of which are coated with cerargyrite.

The unusual number of secondary minerals in the deposits of the sedimentary rocks is accounted for by the dry climate and the great depth of the permanent water level. In the igneous rocks the secondary minerals are comparatively few in number, but in this area the level of ground water is near the surface.

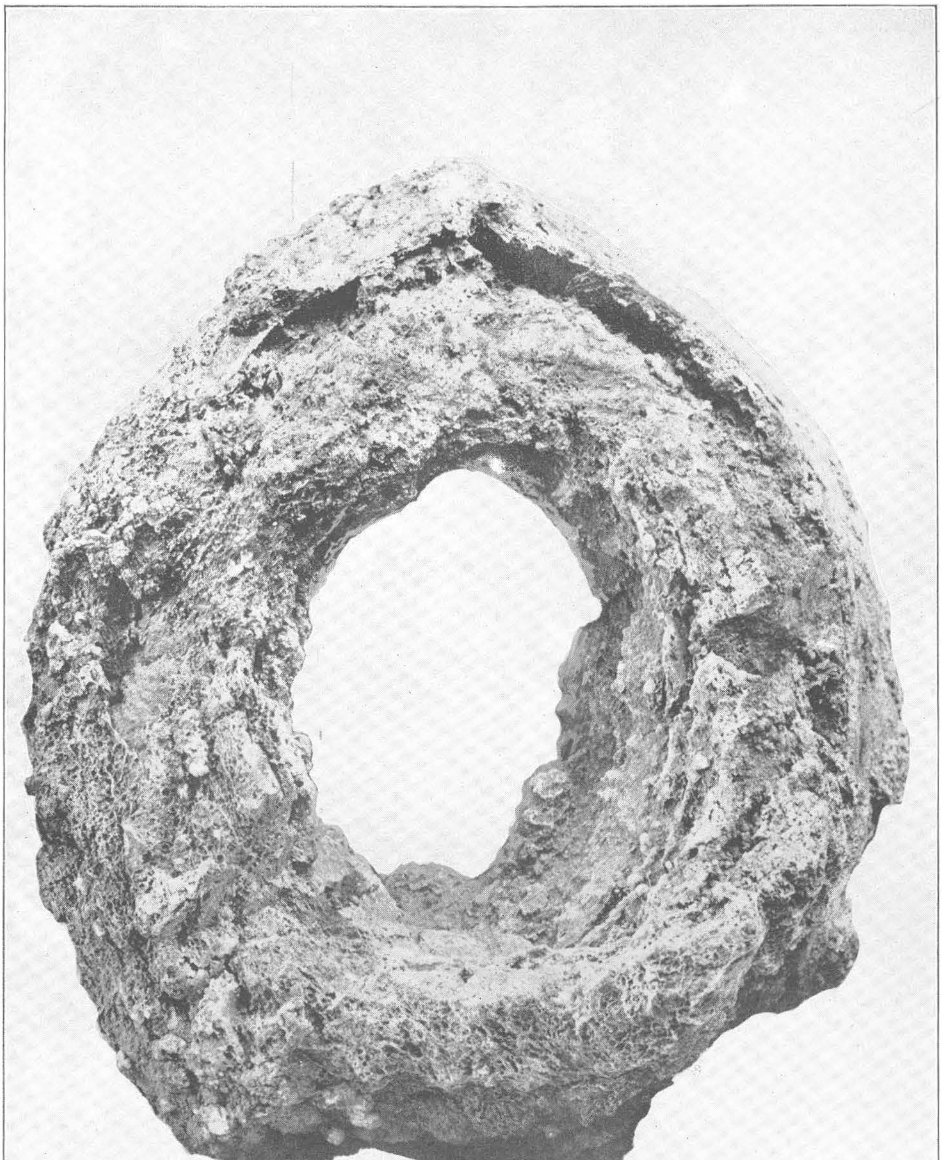
As a result of the difference in solubility and stability of the oxidized minerals, the metals are largely separated and form bodies of ore principally valuable for some one of the three metals, copper, lead, or silver. In the Eureka Hill, Mammoth, Ajax, Carissa, and Northern Spy, very large bodies of secondary copper ore have been encountered which carry but little of the other metals. In the Eureka Hill, Bullion-Beck, Utah, Sioux, and Mammoth, similarly large bodies of lead ore are found which carry no copper and but little silver; and in the Gemini, Bullion-Beck, and Eureka Hill, large bodies of very rich silver ore were found without the other metals. Those ore bodies which are valuable for only one of the metals occur filling caves or in zones of brecciated vein and country rock adjacent to the original ore bodies. Thus, in the Ajax mine, small caves occur at an angle with the original vein planes, the sides of which are coated with thin incrustations of stalactites and stalagmites of the copper oxides. Pl. LXXXVIII, fig. *d* (specimen No. 73), is a photographic reproduction of a specimen from the Bullion-Beck 600-foot level, showing quartz from which the heavy metals have been leached. It is very porous and barren of values. In the Eureka Hill 900-foot level (Pl. LXXXV, A; specimen No. 98) there is much secondary copper ore which, under the microscope, shows the transitions from cupreous aresenate to metallic copper. The gradual reduction from one mineral to another follows cleavages and fractures and gives a marked dendritic appearance to the specimen. In another case the secondary minerals follow a fracture which is at right angles to the plane of mineralization. They rapidly die out below and on either side of the point of its intersection with the plane of original mineralization.

ORE STRUCTURE.

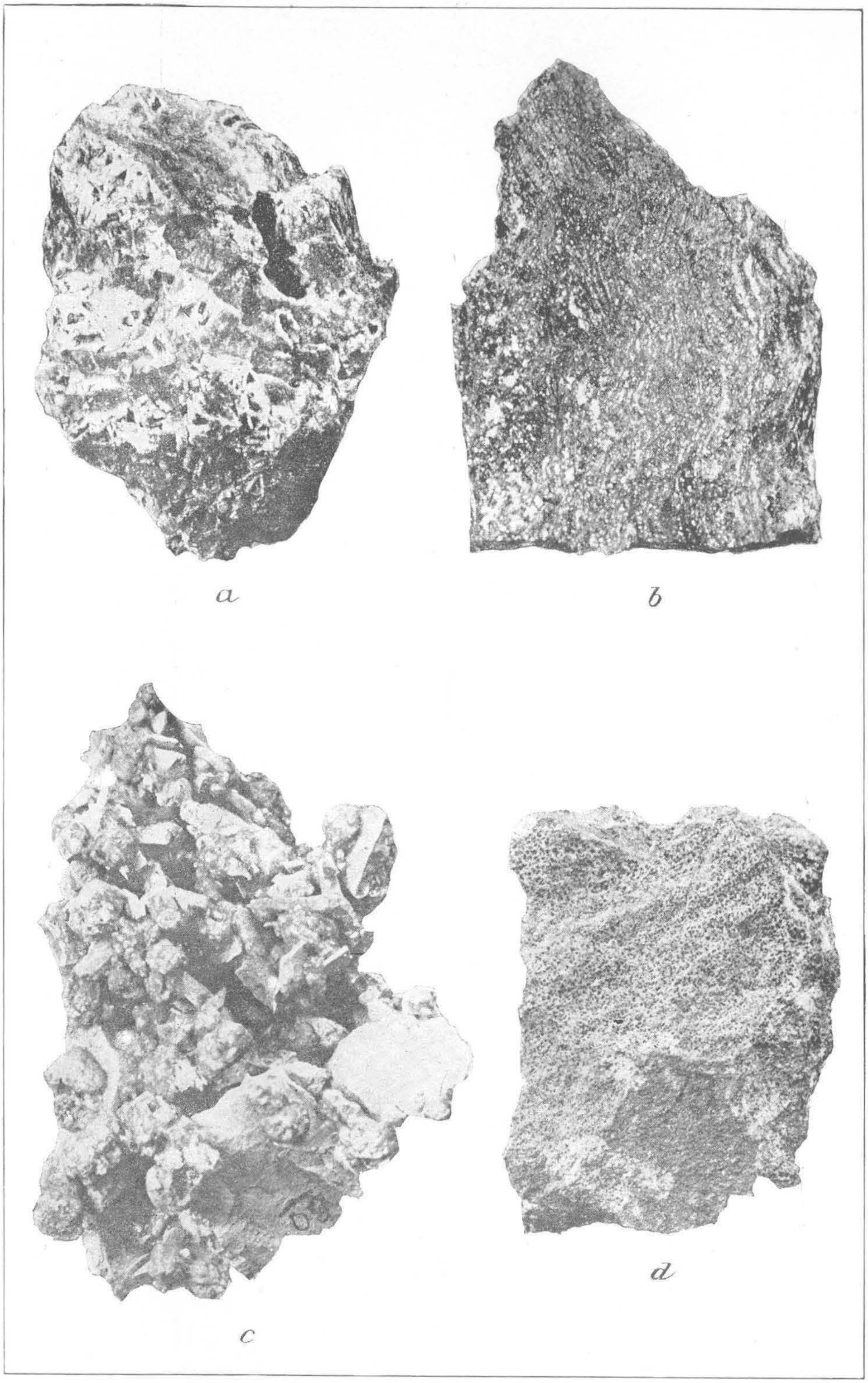
The original ores are either massive, or banded, or imitate the texture, color, and structure of the inclosing rocks. The banded structures occur both in the sedimentary and in the igneous rocks, and are largely the result of variations in the amount of silica. The massive structures are more common in the sedimentary rocks, as are also the pseudomorphic structures.

A peculiar banded structure (Pl. LXXXVII) occurs in the Sioux mine, where alternating bands of quartz and quartz and barite form overlapping concentric ellipsoids, in some cases 6 by 8 inches in diameter. Some of the bands are quite porous, and indicate that originally other minerals, presumably sulphides, were present. The arrangement of the bands suggests that they were deposited around small pipes in the vein or country rock, where the ore-bearing solutions broke out into the open spaces in the rocks.

In the Eureka Hill mine, 300-foot level, a large cave deposit (Pl. LXXXIV) was found, consisting in alternating bands of quartz and



ORE IN OVERLAPPING CONCENTRIC ELLIPSOIDS RESEMBLING GEYSER FORMATIONS.



a

b

c

d

SPECIMENS OF ROCKS FROM MINES.

a, Honeycombed structure of barite in jasperoid, Eureka Hill mine; *b*, secondary banding in galena, due to decomposition of galena along narrow parallel lines, South Swansea mine; *c*, brecciated leached limestone cemented with calcite, Gemini mine; *d*, siliceous vein material from which heavy metals have been leached, Bullion-Beck mine cerussite. These bands are horizontal, and at right angles to the stratification of the limestone.

In the Mammoth much ore was found which preserves the texture, color, and structure of the limestone, with occasional quartz pseudomorphs after calcite.

Finally, in the igneous rocks widely banded structures are found, consisting of alternation of bands of quartz and pyrite, quartz and galena, and quartz, pyrite, and galena.

The examples from the Sioux, the Eureka Hill, and the igneous rocks are illustrations of the filling of preexisting spaces, while the example from the Mammoth is a metasomatic change of country rock by vein mineral.

The secondary nature of much of the ore is shown (Pl. LXXXV, B; specimen 225, Northern Spy mine) by the formation of chrysocolla, malachite, and azurite in narrow cracks in the limestone. These cracks also contain fragments of this limestone. It is also shown by the occurrence (Pl. LXXXVI, A) of stalactitic growths of melaconite and malachite coated with calcite. Another secondary phenomenon (Pl. LXXXVIII, *b*; specimen No. 469, South Swansea) is in the igneous rocks. It consists of a finely banded galena ore, in which the individual bands of galena are separated by galena highly pitted with anglesite.

THE CONTACT DEPOSITS.

This class of deposits is widely distributed over this area and has induced a large amount of exploration, from which but comparatively little return has resulted. These deposits occur on or directly related to the contact of the igneous rocks and the limestone. They are for the most part replacements of the limestone at this contact, and extend into the limestone, but they have also been noted in the limestone at a considerable distance from the contact. The most striking of these deposits are the Tintic and the Black Stallion iron mines. In the Sacramento and the Emerald are examples of the same kind of deposit at a distance from any known contact.

They consist of great masses of siliceous rock, heavily impregnated with hematite and limonite, and contain only very small amounts of the precious metals locally. The relative amount of silica and iron varies greatly. At the Tintic and the Black Stallion iron mines iron is in sufficient amount to constitute an iron ore. On the southwest slopes of Mammoth Peak, near the New East Tintic Railroad, are great masses of this silicified rock projecting 15 or 20 feet above the surface, in which hematite and limonite occur in small pockets. The original rock here was undoubtedly limestone, but this has been replaced largely by silica and forms jasperoid.[1]

This jasperoid is similar in every respect to the cryptocrystalline

[1] "Jasperoid" is a name given by Spurr to siliceous replacements of limestone and dolomite. Mon. U. S. Geol. Survey, Vol. XXXI, 1898.

quartz which has already been described as occurring in the other metallic deposits. It is compact, microgranular in texture, but sometimes contains quartz crystals, especially in cavities. Spots and masses of limestone and dolomite are found through the finer portions, which represent the unreplaced portions of the country rock. The jasperoid assumes all the features, as to both texture and color, of the limestone which it replaces, and can frequently be told from it only by its greater hardness and failure to effervesce upon the application of acid.

Hematite and limonite occur both in dust-like grains in the jasperoid and, in the Tintic iron mine, in large cavernous bodies with horizontal shelly structures of a botryoidal nature. Pl. LXXXIX is a photographic reproduction of a face of hematite in the upper level of this mine, and shows the structure of the iron ore.

The following analysis, by George Steiger, shows that the ore is mainly limonite:

Analysis of ore from the Tintic iron mine.

	Per cent.
SiO_2	3.25
CuO	None.
TiO_2	None.
Al_2O_3	.76
Fe_2O_3	80.02
FeO	.24
MnO	Trace.
CaO	.42
BaO	None.
MgO	.30
Water 100° —	1.71
Water 100° +	12.30
SO_3	.47
S	.10
P_2O_5	.78
Total	100.35

The universal removal of iron from the igneous rocks in the vicinity of these deposits indicates a probable source of the iron. The structure of the iron, together with the fact that it is mainly limonite, shows that the deposit was made comparatively near the surface by thermal springs.

Precious metals have not been found in these deposits generally. The prospectors on this contact north of Eureka have found occasional values varying from 0.02 to 0.2 ounce in gold to the ton, and the Tintic iron mine is reputed to carry a constant value in gold of from 0.1 to 0.3 ounce to the ton. The small pockets of high-grade ore found in these mines are probably included fragments of preexisting veins, as will be described later.

HORIZONTALLY BANDED STRUCTURE OF A BOTRYOIDAL NATURE IN CAVERNOUS MASSES OF LIMONITE, TINTIC IRON MINE.

THE MINERALS OF THE ORE DEPOSITS.

GANGUE MINERALS.

Quartz .... SiO_2. Hexagonal; colorless and white prisms and pyramids.
Chalcedonite.............. SiO_2. Cryptocrystalline; amorphous.
Barite .... $BaSO_4$. Orthorhombic; brownish white; tabular crystals.
Calcite.................... $CaCO_3$. Rhombohedral; when residual without crystal outline.
Dolomite.................. $MgCO_3$. Rhombohedral; when residual without crystal outline.
Selenite................... $CaSO_4$. Monoclinic; slender rods inclosed by hematite.

ORE MINERALS.

Native gold .... Au. Isometric; brilliant yellow.

SILVER MINERALS.

Stephanite .... Ag_5SbS_4. Orthorhombic; iron black.
Argentite .... Ag_2S. Isometric; blackish lead gray.
Cerargyrite .... AgCl. Isometric; waxy films; usually brown.
Native silver .... Ag. Isometric; silver white.

LEAD MINERALS.

Galena.................... PbS. Isometric; lead gray; in crystalline masses.
Anglesite .... $PbSO_4$. Orthorhombic; colorless crystals lining cavities in massive galena.
Cerussite .... $PbCO_3$. Orthorhombic; white in acicular crystals or earthy.
Minium .... Pb_3O_4. Pulverulent; vivid red; streaked with yellow.

COPPER MINERALS.

Enargite.................. Cu_3AsS_4. Orthorhombic; grayish to iron black; one pronounced cleavage.
Tetrahedrite .... $Cu_8Sb_2S_7$. Isometric; flint gray, iron black; massive.
Tennantite................ $Cu_8As_2S_7$. Isometric; flint gray, iron black; massive.
Chalcopyrite .... $CuFeS_2$. Tetragonal; brass yellow; cuts with knife.
Bornite .... Cu_3FeS_3. Isometric; copper red to brown; massive.
Chalcocite .... Cu_2S. Orthorhombic; blackish lead gray; conchoidal fracture.
Olivenite................. $Cu_3As_2O_8 . Cu(OH)_2$. Orthorhombic; various shades of green, wood brown, occurs in cavities in altered limestone and vein rocks and on enargite.
Clinoclasite .... $Cu_3As_2O_8 . 3Cu(OH)_2$ Monoclinic; bluish green; radial fibers.
Erinite................... $Cu_3As_2O_8 . 2Cu(OH)_2$. Mammillated crystalline groups; dark emerald green.
Tyrolite.................. $Cu_3As_2O_8 . 2Cu(OH)_2+7H_2O$. Orthorhombic; bright green; micaceous.
Chalcophyllite .... $7CuO . As_2O_5 . 14H_2O$. Rhombohedral; bright green rosettes.
Conichalcite .... $(Cu, Ca)_3As_2O_8 . (Cu, Ca)(OH)_2+1/2H_2O$. Resembles malachite closely.
Chenevixite .... $Cu_2(FeO)_2As_2O_8+3H_2O$. Massive; greenish to yellowish mottled ore.

Lettsomite	$4CuO. Al_2O_3. SO_3. 8H_2O$. Orthorhombic; sky blue capillary crystals.
Brochantite	$CuSO_4. 3Cu(OH)_2$. Orthorhombic; dark green acicular and wedge-shaped crystals.
Mixite	$20 CuO. Bi_2O_3. 5As_2O_5. 22H_2O$. Slender radiating crystals; bluish green; velvet.
Chrysocolla	$CuSiO_3+2H_2O$. Cryptocrystalline; green, blue-green, turquoise blue.
Malachite	$CuCO_3. Cu(OH)_2$. Monoclinic; green; usually incrusting and botryoidal.
Azurite	$2CuCO_3Cu(OH)_2$. Monoclinic; blue; thin incrustations and crystals.
Melaconite	CuO. Monoclinic; black; massive.
Cuprite	Cu_2O. Isometric; red; massive and in crystals.
Native copper	Cu. Isometric; red; massive small spots in copper ores.

IRON MINERALS.

Pyrite	FeS_2. Isometric; brass yellow; very hard.
Scorodite	$FeAsO_4+2H_2O$. Orthorhombic; green to brown prisms and octahedrons.
Pharmacosiderite	$6FeAsO_4. 2Fe(OH)_3+12 H_2O$. Isometric; brown (green) cubes.
Jarosite	$K_2O. 3Fe_2O_3. 4SO_3. 6H_2O$. Rhombohedral; indistinct brown crystals.
Utahite	$3Fe_2O_3. 3SO_3. 4H_2O$. Rhombohedral; orange yellow micaceous scales.
Borickite	$Ca_3Fe_2(PO_4)_4. 12 Fe(OH)_3+6H_2O$. Massive brown; reddish brown.
Hematite and limonite	Fe_2O_3 and $2Fe_2O_3. 3H_2O$. Stalactite; botryoidal; massive; reddish brown.

ZINC MINERALS.

Sphalerite	ZnS. Isometric; resin-like masses; with dodecahedral cleavage.

BISMUTH MINERALS.

Native bismuth	Bi. Rhomohedral; reddish; silver white.
Bismutite	$Bi_2O_3. CO_2. H_2O$. Amorphous; straw color; greenish white.

SULPHUR.

Native sulphur	S. Orthorhombic; yellow.

DESCRIPTION OF MINERALS.

GANGUE MINERALS.

Quartz is an abundant and omnipresent mineral of these deposits. As true vein quartz it is found in the deposits of the sedimentary and igneous rocks, but is more plentiful in the deposits in the limestone, where it frequently forms great masses with so little of the metallic minerals as to be of no value.

From the microscopic studies it appears that quartz in crystals and crystallized masses has been deposited at various intervals from the beginning of these veins to the present day. It is found containing all

BARITE IN QUARTZ AND JASPEROID, EUREKA HILL MINE, 500-FOOT LEVEL.

the other vein minerals and also contained by them. In the Eureka Hill mine one specimen showed corroded crystals of quartz, the surface of which was covered with black dust. This was subsequently enlarged by the addition of quartz, which perfected the outline of the original quartz crystals. Another specimen from a filled cave in limestone was bedded horizontally and at right angles to the limestone, and was composed largely of crystallized quartz which had been enlarged, as in the previous case. A third specimen showed quartz coating crystals of secondary calcite. A fourth showed quartz lining cavities in galena. A fifth showed it as a wall rock, to which crystals of barite were attached, younger crystals of quartz clinging to the tabular surfaces of the barite crystals. A sixth specimen showed quartz formed on the rough surfaces of copper carbonate.

An equally important form of quartz of common occurrence in these deposits is composed of cryptocrystalline masses of silica, stained red by iron oxide or black by carbonaceous matter. It is very dense and has no visible texture. Under the microscope this material has the same single and double refraction as quartz. It is in very small particles, which give the effect of the microgranular groundmass of rhyolite. These small grains vary in size from very minute up to recognizable quartz crystals. Small veins of quartz traverse these masses frequently. Within the areas are irregular patches of carbonate of lime or magnesia, which indicate that this fine quartz replaces the original limestone or dolomite.

Chalcedonite occurs occasionally in subsequent growths about quartz crystals, arranging itself in radial fibers which behave much like spherulitic fibers.

Barite is next in importance to quartz. It is irregularly distributed through the veins, and seems to have been preceded only by the original quartz. It has been observed constantly as a honeycomb of tabular crystals, coated with quartz crystals, the spaces between the crystals being filled with every mineral known to these deposits. The largest mass of barite seen is in the Carissa, where, at the junction of two veins, it forms a nearly solid body 25 feet wide, 40 or more feet long, and 50 feet in vertical extent. Similar large masses are seen in the North Star mine. Pl. XC is a face in the Billings stope, Eureka Hill mine, 500-foot level. It shows the honeycomb structure of barite throughout the vein mass. A more detailed illustration of this structure is seen in Pl. LXXXVIII, *a*.

Calcite and *dolomite* appear under the microscope as residual and as secondary minerals in the deposits in the stratified rocks. As residual minerals they are constantly seen in spots and irregular patches throughout the cryptocrystalline quartz, and presumably represent unreplaced portions of the country rock. They are without crystal outline and are recognized by their high single and double refraction, their cleavages, and their effervescence with HCl. Special tests of vein rock made in the laboratory of the Survey by Mr. Steiger showed in one case 1.06 per cent, in another 8.88 per cent, and in a third 76.43 per cent of these carbonates.

Secondary calcite occurs in crystals lining cavities in the original vein, forming a crystal coating over all the oxidation products of the veins and finally filling fractures in the country rock at a distance from the ore deposits; it appears to have been derived from the immediate country rock and to have been precipitated in contact with air in the open spaces of the veins and adjoining country rock. Abundant proof of such leaching of the country rock is found in the immense number of caves in the limestone. On the 300-foot level of the Gemini, at the extreme northern end, is a cave which follows the bedding approximately and has a vertical depth of nearly 200 feet. In places it is 25 feet wide and from 50 to 100 feet long. Somewhat north and west of this in the same mine is a series of caves which follow well-defined fracture planes and make spheroidal and irregular pipe-like cavities in the limestone. Pl. LXXXVIII, *c*, represents a specimen taken from the bottom of one of these caves. It consists of angular fragments of partially leached limestone cemented by calcite. Pl. XCI represents a face on the 500-foot level of the Emerald. It shows a fissure in the limestone similar to the one last mentioned, which has been entirely filled with calcite.

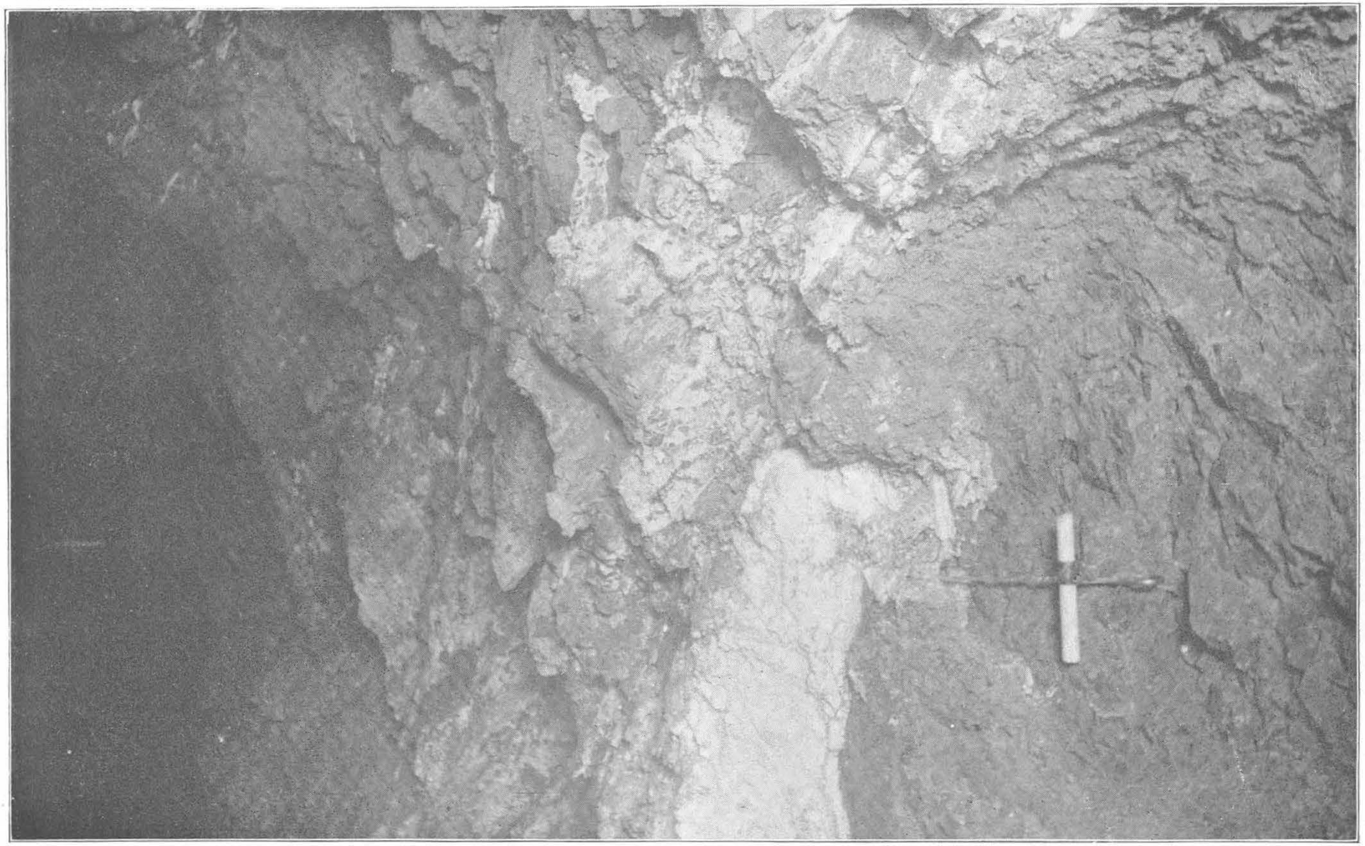
Selenite forms large slender crystals in open spaces of the veins of the Ajax and has been coated extensively with hematite. It is the result of the oxidation of sulphide ores and country rock (see fig. 91.)

ORE MINERALS.

Gold.—Free gold is rarely seen in Tintic ores, the most notable exception being in the Mammoth, where in one large stope in the upper levels of the mine a considerable amount of high-grade ore was found which showed an abundance of free gold.

In those mines which yield gold nothing definite as to its association or combination can be made out. On account either of its mechanical subdivision or of its chemical combination, its condition is such that the ordinary method of panning seldom yields a color. There is a class of ores which carry a large amount of small crystals of barite that are apt to be rich in gold, but this is not invariably the case. Special tests which have been made on the gold-bearing ores have shown the presence of small amounts of tellurium; that gold is combined only with tellurium, is very uncertain. It may also have been associated with pyrite, which is its most common association, for, although this mineral is rare in the oxidized ores, it was probably abundant in the original deposit.

Argentite and *stephanite*, which have been found but rarely, occur in small pockets in galena ores, which the microscopic studies show are made up of minute patches of these minerals inclosed by galena. The



FISSURE IN LIMESTONE FILLED WITH CALCITE WHICH INCLOSES FRAGMENTS OF LIMESTONE, EMERALD MINE, 500-FOOT LEVEL.

best specimens come from the Humbug mine, where the great mass of the galena does not carry much silver.

Cerargyrite, or horn silver, is almost invariably found in films and crystals coating fragments of vein and country rock and without any considerable amount of the other metals. Especially large masses of horn silver have been found in the Centennial Eureka and Gemini mines; but it is found constantly in the oxidized zone of all the mines.

Native silver is seen only in highly decomposed portions of the ore deposits near the surface. It has never been a common mineral.

Galena and its oxidation products, cerussite and anglesite, are the most abundant metallic minerals of these deposits. Galena is found in quantity in every mine of the district. It rarely has crystal outlines, but occurs in crystalline masses disseminated through both vein matter and limestone.

In the Uncle Sam, on Godiva Mountain, ore has been taken out by the hundreds of tons which carried 75 per cent galena and very little quartz or other vein mineral.

In the mines in the igneous rocks galena occurs most often as lens-shaped masses associated with pyrite, sphalerite, and quartz.

In the mines at Eureka and Mammoth galena is found in large masses of irregular form, but more often widely disseminated through quartz, and is mined primarily for its silver content.

Finally, galena seems to be present in the original copper ores, but not in those that are the result of reprecipitation from other portions of the deposits. In the Bullion-Beck mine it is seen forming the shell of an ore shoot, the center of which is composed of enargite and galena. It is not common in ores rich in barite. It is one of the original minerals and its association with quartz and pyrite proves it to be among the earliest-formed minerals.

Anglesite has been observed in several mines, but most abundantly in the Eureka Hill, where crystals three-quarters of an inch in length were found. It forms in cavities of galena ore. It is colorless and sparkles almost with the brilliancy of the diamond. It is the result of decomposition of galena.

Cerussite is found in great abundance. It is common to all the veins and occurs in aggregated crystals, as well as in amorphous masses. It is seen in the quartz and jasperoid, filling both fractures and cavities in the vein and country rocks, and in pseudomorphs after galena. Particular interest attaches to this mineral from the fact that it has been the cause of much misinterpretation of the ore bodies in the district. I refer more particularly to the deposits in the sedimentary rocks, where the ground-water level has not been reached and the processes of oxidation have extended to a depth of more than 1,600 feet. In these mines the occurrence of cerussite is not necessarily indicative of a body of galena at a lower level; it is rather the result of oxidation of overlying bodies of the mineral, the product of oxidation having been leached from above and precipitated below the original body of galena, both in the zone of original mineralization and adjacent to it. Amorphous cerussite is also found filling cracks and crevices in secondary formations occurring in caves in the limestone.

Minium is an occasionally seen resultant from the decomposition of the other lead minerals.

Enargite is the most important of the copper minerals, for it is the mother mineral from which all of the copper minerals, save chalcopyrite, tetrahedrite, and tennantite, are derived. It is not found abundantly except in the lower levels of the deep mines and in some few of the mines in the igneous rocks near Diamond, where the ground-water level is but a short distance below the surface. A specimen from the Homestake shows a number or crystals fully one-half inch in length. These are iron black in color and have at least two cleavages.

The Ajax, Carissa, Boss Tweed, and Centennial Eureka mines have produced a large proportion of the copper of the district. Studies of the specimens taken from these mines show enargite in pitted crystalline masses without crystal outline, which have two cleavages, one well marked, the other faintly marked. It is invariably coated with several oxidation products.

The enargite is not always pure, but often contains chalcopyrite, pyrite, and quartz. Its origin is apparently later than most of the quartz and pyrite, but prior to all the other minerals, save possibly galena, with which its relation is somewhat uncertain. In the Bullion-Beck a large chimney of siliceous ore was noted in which galena formed the main mass of the outer portion and enargite and galena the heart.

Tennantite and *tetrahedrite* are minerals of somewhat uncertain occurrence, so far as observed by the writers. From the Boss Tweed, Centennial Eureka, and Black Dragon specimens were obtained which, from the color and luster, were thought to be tennantite or tetrahedrite. Examinations of thin sections of these under the microscope showed that the specimens from the two first-named mines were not enargite, while the associated decomposition products, mixite and olivenite, clearly indicated the presence of arsenic; hence the presence of tennantite is inferred. The specimen from the Black Dragon showed no arsenical decomposition product, but had decomposed to chalcocite, together with a very small amount of pyrite; hence it is supposed to be tetrahedrite.

Chalcopyrite is a rare mineral in this district. It was observed under the microscope but twice. It appears to be an original mineral, deposited synchronously with quartz and pyrite. It has been altered extensively, in one case to bornite and in another to chalcocite and pyrite.

Bornite is found only as a decomposition product from chalcopyrite, and, like chalcopyrite, is a very rare mineral.

Chalcocite is the result of the decomposition of tetrahedrite and chalcopyrite; possibly, also, of bornite. It is not a common mineral.

Olivenite is one of the first products of oxidation of enargite. It occurs in acicular crystals, varying in color from pale to dark-olive green. It is also found in compact, fibrous masses of a wood-brown color. A specimen from this district analyzed by W. F. Hillebrand[1] gives the following composition:

Analysis of olivenite from the Tintic district.

	Per cent.
CuO	55.40
As_2O_5	40.05
P_2O_5	0.06
H_2O	3.39
Fe_2O_3	0.25
CaO	0.16
ZnO	Trace.
Quartz	0.40
Total	99.71

The ferric oxide of the analysis was derived from a little adhering hydrated cupriferric arseniate, and the calcium and zinc oxides from attached conichalcite.

The mineral forms around masses of enargite or lines cavities in altered limestone, and is frequently coated with other copper minerals, calcite, or even quartz.

Clinoclasite is distinguished from olivenite by its monoclinic crystal form and its more uniform color, which is dark-bluish green. Frequently the crystals are grouped in radial aggregates and produce a rough, shining, plated surface. Its composition has been determined by W. F. Hillebrand[2] as follows:

Analysis of clinoclasite from the Tintic district.

	I.	II.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
CuO	62.34	62.54	62.44
ZnO	0.06	0.04	0.05
As_2O_5	29.59	29.60	29.59
P_2O_5	0.05	*a* 0.05	0.05
H_2O	7.73	7.72	7.72
Fe_2O_3	0.12	0.12	0.12
SiO_2	0.06	*a* 0.06	0.06
Total	99.95	100.13	100.03

[1] Bull. U. S. Geol. Survey No. 20, 1885, p. 83.
[2] Bull. U. S. Geol. Survey No. 55, 1889, p. 45.
a Assumed the same as in I.

Its association and mode of occurrence are the same as for olivenite.

Erinite has been recognized in these ores rather less frequently than the other rare copper minerals. It is dark-emerald green in color, in mammillated crystal groups, lining cavities and closely associated with enargite, azurite, and clinoclasite. Analyses of two samples of this ore by Hillebrand[1] gave the following composition:

Analyses of erinite from the Tintic district.

	Per cent.	Per cent.
CuO	a 57.67	57.51
ZnO	1.06	0.59
CaO	0.32	0.51
MgO	Trace.	Trace.
As_2O_5	33.53	31.91
P_2O_5	0.10	....
H_2O	7.22	9.15
Fe_2O_3	0.14	0.20
SO_3	....	....
Total	100.04	99.87

a Mean of 57.61 and 57.74.

Tyrolite.—Specimens of tyrolite from the Mammoth and the Ajax are of a very brilliant green, which is intensified by the micaceous cleavage and radial structure. It has been analyzed by Hillebrand:[2]

Analyses of tyrolite from the Tintic district.

	I.	II.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
CuO	45.20	45.23	45.22
ZnO	....	0.04	0.04
CaO	6.86	6.82	6.84
MgO	0.05	....	0.05
As_2O_5	28.84	28.73	28.78
P_2O_5	Trace.	....	Trace.
H_2O	17.26	....	17.26
SO_3	(?)	(?)	(?)
Total	98.21	....	98.19

[1] Bull. U. S. Geol. Survey, No. 55, 1889, p. 40.
[2] Ibid, p. 41.

Chalcophyllite from this district is known to the writer only from the description of Hillebrand and Washington.[1] They speak of it as occurring in the form of small hexagonal plates arranged in rosettes, differing from the radial arrangement of the tyrolite. It is bright apple green in color, having a pearly luster and a perfect basal cleavage. It is uniaxial, with negative double refraction.

Conichalcite resembles malachite strongly. Its color is pistachio to emerald green. It is reniform and massive, coating the surfaces of the decomposed copper arseniates. Hillebrand's analysis of a specimen from the Ajax is as follows:[2]

Analysis of conichalcite from the Ajax mine.

	Per cent.
CuO	28.68
CaO	19.79
MgO	0.54
ZnO	2.86
Ag	0.30
As_2O_5	39.94
P_2O_5	0.14
H_2O	5.52
Fe_2O_3	0.36
CO_2	0.97
Quartz	0.90
Total	100.00

Hillebrand states that the Fe_2O_3 is derived from attached gangue, CO_2 from combined lime.

Chenevixite, as reported by Cross and Hillebrand and by Bixby, is a compact, greenish, opaque mineral, scattered in irregular patches throughout some portions of such ore as occurs in hard lumps, giving a mottled appearance to a broken surface. It has little or no luster. The color is olive-green, sometimes shading into a greenish-yellow after exposure.

[1] Bull. U. S. Geol. Survey No. 55, 1889, p. 43.
[2] Bull. U. S. Geol. Survey No. 20, 1885, p. 84.

Hillebrand's analyses are as follows:[1]

Analyses of chenevixite from the Tintic district.

	I.	II.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
CuO	26.41	26.21	26.31
CaO	0.44		0.44
MgO	0.16		0.16
F_2O_3	27.37		27.37
Al_2O_3	0.66		0.66
As_2O_5	35.08	35.20	35.14
P_2O_5			
H_2O	9.41	9.25	9.33
Quartz	0.40		0.40
Total	99.93		99.81

Lettsomite (cyanotrichite) is reported by Dana from the Ajax mine. It occurs in druses forming a velvety lining composed of short capillary crystals, sometimes as spherical globules. Its color is clear smalt blue, sometimes passing into sky blue. It is strongly pleochroic. Genth's analysis is as follows:[2]

Analysis of lettsomite (cyanotrichite) from the Ajax mine.

	Per cent.
CuO	49.54
Al_2O_3	15.45
Fe_2O_3	0.91
SO_3	12.60
H_2O	21.50
Total	100.00

Brochantite was not observed by the writer. It is described by Hillebrand and Washington[3] as occurring in two distinct forms. The first, ordinary brochantite, is of prismatic habit, the crystals having a dark-green color and being transparent. The second is light green in color and had curved double wedge-shaped crystals. None of the crystals were more than 2 or 3 millimeters long.

Mixite occurs in pale bluish-green hair-like crystals, arranged in radial clusters and often forming a very soft velvet coating to tabular crystals of barite. It is associated with olivenite and bismutite, and

[1] Bull. U. S. Geol. Survey No. 20, 1885, p. 85.
[2] Am. Jour. Sci., 3d series, Vol. XL, 1890, p. 118.
[3] Bull. U. S. Geol. Survey No. 55, 1889, p. 47.

has been found in the Mammoth, Boss Tweed, Ajax, and Carissa mines. Hillebrand's analysis of a specimen from the Ajax is appended:[1]

Analysis of mixite from the Ajax mine.

	I.	II.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
CuO	43.89	43.88	43.89
ZnO	2.79	2.62	2.70
CaO	0.26	0.26	0.26
Bi_2O_3	11.14	11.22	11.18
As_2O_5	27.78	28.79	*a* 28.79
P_2O_5	0.06	....	0.06
H_2O	11.04	11.04	11.04
SiO_2	0.36	0.48	0.42
Fe_2O_3	0.97	....	0.97
	98.29	....	99.31

a The higher value was undoubtedly nearer the truth than the lower.

Chrysocolla occurs in abundance in irregular masses in decomposed vein and country rock. It is of varying color, from blue to green. Several specimens of unusual purity were found. It results from the decomposition of all the copper minerals heretofore mentioned.

Malachite is plentiful as the result of decomposition of the hydrous arsenates and arseniates, and especially of olivenite and clinoclasite. It occurs in crystals and amorphous masses. In the Eureka Hill mine it was found forming a crystalline coating to cavities in the limestone and attached to the other copper minerals.

Azurite is not so abundant as malachite. It is commonly found in crystals attached to solid masses of copper sulphides.

It is highly probable that malachite is the result of oxidation of sulph-arsenides, and azurite of sulphides of copper, and their occurrence indicates the presence of enargite or tennantite in the former case and chalcopyrite or tetrahedrite in the latter case.

Melaconite is found abundantly in irregular masses, coal black in color and without crystalline outline. It results from the decomposition of all the other copper minerals except cuprite and native copper.

Cuprite is always intimately associated with melaconite, into which it merges by almost insensible degrees. It results from the reduction of melaconite.

Native copper is found in nearly all of the mines, but in extremely small amounts, as the result of oxidation. A specimen from the Boss Tweed showed a mass of native copper inclosed by cuprite, and in the thin section the transitions from enargite, olivenite, malachite, melaconite, and cuprite to metallic copper were distinctly seen.

A specimen from the Eureka Hill, which megascopically appeared to

[1] Bull. U. S. Geol. Survey No. 55, 1889, p. 45.

be a residual mass of decomposed limestone, stained brown with iron oxide and greatly eaten by mineral-bearing solutions, was coated with massive malachite and finely crystallized olivenite and clinoclasite. Under the microscope this was seen to contain minute spots of native copper.

Pyrite in the deposits in the sedimentary rocks has been found in very small quantities. It occurs principally in small, ragged crystals and patches, which are invariably coated with iron oxide. It is one of the earliest-formed minerals, and where best preserved is inclosed by quartz. It is also found in irregular masses with the copper sulphides and sulpharsenides, and in such cases is derived from these minerals. The great amount of iron oxide in all the ore deposits in the sedimentary rocks shows that pyrite must have been an abundant mineral in the original vein filling.

Pyrite is well preserved in the veins of the igneous rocks below the water level. It is disseminated through all parts of the veins, and impregnates the country rocks freely for a distance varying from a few inches to several feet. It also occurs in lenses, filling joint planes in the monzonite and porphyry, which have no connection with any known body of ore. In the veins proper the pyrite, though associated with galena and quartz, is more frequently separated into lenses of pure pyrite. In several cases bodies 100 feet or more long, 25 to 50 feet high, and 1 to 5 feet thick were observed in the Swansea mines. It is the almost universal constituent of the veins at the ground-water level.

Scorodite occurs in lake-green to olive-brown crystals, which are usually in forms of octahedral habit or prisms of the orthorhombic system. It is also amorphous and earthy.

Pharmacosiderite occurs in brown cubic crystals attached to ferruginous quartz. It is sometimes straw yellow and pale green in color. The crystals are so small that it is often overlooked or confounded with jarosite and scorodite.

Jarosite occurs in druses of minute crystals, in nodules, or as an incrustation with coralloidal surface. Its color is yellow- or clove-brown, and the crystals, when recognizable, are rhombohedral. Genth's analyses[1] of specimens from the Tintic district are appended:

Analyses of jarosite from the Tintic district.

	Per cent.	*Per cent.*
SiO_2	0.08	0.29
Fe_2O_3	50.41	51.16
Na_2O	9.23	.33
K_2O		9.05
SO_3	29.60	28.93
H_2O	10.68	10.24
Total	100.00	100.00

[1]Am. Jour. Sci., 3d series, Vol. XXXIX, 1890, p. 73.

Otherwise than by chemical analysis these rarer minerals are hard to distinguish, for their crystals are very minute and the amounts obtainable very small. They are common to nearly every mine of the district.

Utahite occurs in fine scales, orange yellow in color, and usually aggregated. It has a soft, silky luster. It is found in the Eureka Hill Bullion-Beck, Mammoth, and Ajax mines.

Borickite from the Ajax is described by Dana. It is a compact massive mineral, without cleavage; luster, waxy; color, reddish brown. It is a hydrous phosphate of iron and lime.

Hematite and limonite.—These minerals are common to the oxide zone of all the deposits, whether in the limestone or the igneous rocks. They result from the oxidation of pyrite, and to a very small extent from the decomposition of those copper minerals which contain iron. It is not thought that any hematite or limonite was originally deposited as such except in the contact deposits, such as the Tintic iron mine.

The hematite and limonite occur in irregular masses and in minute particles in all portions of the oxidized zone. In the Ajax mine they occur in cavities in the ore chambers, in rods and stalactites, some of which are several feet in length. These have formed around crystals of selenite, which must have crossed the open spaces in the chambers at various angles, for we find angular rod-like cavities in the hematite, from which the stalactites are suspended. Since these stalactites are always vertical, it follows that the crystals of selenite along which the chalybeate waters passed must have been inclined at various angles to have produced the effects recorded. The selenite is seen but rarely in these rhombic cavities in the stalactites, having been removed by subsequent oxidizing solutions, so that its original presence is inferred from the cast which it has left in the hematite and limonite.

Sphalerite is not a common mineral to this district. It was found in the Swansea mines in association with pyrite and galena. It is commonly without crystal outline, is resinous in color, and shows the characteristic dodecahedral cleavage. It is an original mineral and, where seen, had suffered but little alteration.

Bismuth was found in two mines, the Emerald and the Boss Tweed. In the Emerald a fragment of limestone from the 500-foot level was found coated with very delicate crystals of native bismuth. It was impossible to identify the crystal form on account of its small size, and the determination rests upon analysis. It occurs in perfectly fresh limestone, apart from any known body of ore or even vein matter.

Bismutite.—In the Boss Tweed very considerable bodies of ore occur which assay from 5 to 40 per cent metallic bismuth. This is associated almost exclusively with quartz and barite. Studies of the thin sections show a grayish, straw-colored mineral, which is isotropic and amorphous, inclosing hexagonal plates of quartz which contain radial intergrowths of an unrecognizable mineral. Upon the application of hydrochloric acid the straw-colored mineral effervesces freely. It is undoubtedly bismutite.

There is no market in the United States for this ore, and the quantity is not sufficient to warrant its exportation.

Native sulphur was found in crystals, coating cavities in massive galena ore. In the Eureka Hill mine some of these crystals were nearly perfect and as much as an eighth of an inch in diameter. They were attached to anglesite, which in turn was attached to galena. Its mode of occurrence, coating cavities and attached to known oxide products, indicates its origin as a part of the general process of oxidation.

ORDER OF DEPOSITION.

Microscopic studies show that quartz has formed almost continuously from the beginning to the end of the mineralization; that much of it is subsequent to the oxidation and that it frequently replaces limestone; that barite is earlier than the metallic minerals; that the metallic minerals were all deposited at about the same time, but subsequent to the earliest quartz and the barite.

In the Boss Tweed mine quartz was found in distinct crystals containing many hexagonal skeletons of a finely divided, dark mineral; in irregular masses inclosing malachite and chrysocolla; and lining druses in soft, decomposed vein and country rock.

In the Eureka Hill mine in one case quartz was discovered both coated with and coating sulphides and oxidation products; in another, fine-grained quartz was discovered lined with coarsely crystalline quartz containing crystals of barite, and upon this latter quartz metallic minerals formed subsequently, some of which were highly altered and coated with still more recent quartz. In the Mammoth, Centennial Eureka, and Bullion-Beck quartz pseudomorphic after calcite was discovered, but for the most part the siliceous replacements of limestone show a very fine-grained structure with only an occasional recognizable quartz crystal.

Specimens from the Boss Tweed show tabular crystals of barite forming a honeycomb, the pits of which are filled with enargite and quartz. One specimen from the Mammoth showed a number of barite crystals arranged parallel to one another and entirely inclosed in galena, while another specimen in this mine showed the barite crystals coated with quartz crystals, the remaining spaces between the barite crystals being unfilled. One specimen from the Ajax mine showed, attached to quartz, crystals of barite which were broken along the cleavage and the cracks filled with additional quartz.

Specimens from nearly all of the mines showed galena and enargite riddled with quartz and in some cases residual calcite, which latter mineral is sometimes corroded by quartz.

CHAPTER III.

CHANGES IN ROCKS DUE TO FISSURE AND VEIN FORMATION.

IN THE SEDIMENTARY ROCKS.

In the sedimentary rocks the changes which have been effected by fissuring and vein formation are the sheeting and brecciation of strata, the formation of open spaces, followed by the filling of some of these open spaces along certain well-defined zones and the removal of carbonate of lime and magnesia, together with much substitution of lime-magnesia carbonates by silica and galena. These processes are either mechanical or chemical in their nature.

Mechanical alteration.—Mechanical alteration has produced sheeting in the more resistant beds, which is often so profound as to entirely conceal the bedding planes. In the limestone and dolomite the beds are often brecciated instead of sheeted, and large zones composed of broken angular fragments of limestone are produced. "The Dike," in the Mammoth is such a breccia, which is of so recent origin that the fragments are loosely compacted and without cement, either of calcite or secondary vein minerals. In most cases, however, the brecciation has been more ancient, for the limestone fragments are generally cemented by calcite and by either original or secondary vein minerals. Pl. LXXXV, *B*, is the reproduction of a photograph of a breccia found in the Northern Spy mine, which has been cemented with secondary copper minerals.

Microscopic studies do not show structures which are the result of dynamic action, except that in some cases there is crystallization of calcite and dolomite. Shear zones and irregular or wavy extinctions in the rock minerals are not found, and indeed would hardly be expected, because of the brittle nature of limestone and dolomite. Those spaces which are not of the most recent origin and which have not been filled with vein matter have been either coated or filled with white crystalline calcite.

Chemical alteration.—The commonest form of chemical alteration of the wall rocks is their replacement by silica, galena, and by some, possibly by all, of the other minerals of these vein deposits. In deposits such as these, where the mineralizing solutions have both deposited in open spaces and replaced the wall rocks, and where oxidation has been so extensive, it is extremely difficult to discriminate those changes in the wall rocks which were brought about only by the mineralizing agents. The most common form of chemical alteration is the substitution of silica for lime. In this change the structure, texture, and color of the original rock are usually retained, and microscopic studies show that the silica rarely has crystal outlines, but generally forms a fine-grained mass with microgranular structure. Chemical tests of rocks which the microscopic studies showed to be silicified limestone gave the following results:

Chemical tests of silicified limestones.

	North Star mine.	Mammoth mine.	Eureka Hill mine.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	15.6	84.9	59.28
$CaCO_3$	57.93	5.04	1.06
$MgCO_3$	18.50	3.84	....
PbO	....	....	32.32

Another notable phenomenon of the wall rocks which has arisen from the vein formation is the cave deposits which overlie the ore bodies in the dolomitic limestone. These consist of finely banded, soft, clayey material horizontally bedded at right angles to the stratification. A partial analysis made by Mr. Steiger of a specimen of one of the lighter-colored bands from the 500 foot level of the Bullion-Beck mine gives the following composition:

Partial analysis of a specimen from a cave deposit in the Bullion-Beck mine.

	Per cent.
SiO_2	47.78
Al_2O_3 (P_2O_5 TiO_2)	31.67
Fe_2O_3	.45
CaO	.86
MgO	1.20
Loss on ignition	12.21

Pl. XCVII is a reproduction of a photograph of the deposit from which the specimen analyzed came. The mode of occurrence of these deposits suggests a deposition from water in the nature of a sediment. It is thought that they may be the filling of cavities formed in part by the contraction ensuing upon the substitution of limestone by ore and in part by the settling of the ore body, from which a certain amount of material is doubtless removed during oxidation, leaving it in a somewhat incoherent condition. Into such cavities descending surface waters would bring, mostly in suspension, the fine material resulting from the disintegration of partly replaced limestone, which would be mainly silica and alumina.

In some cases there are also found around the ore bodies ocherous materials rich in lead, which are probably the basic ferric sulphates that often result from the leaching of such deposits as these. Concerning similar deposits at Leadville, Emmons says:[1]

Basic ferric sulphates.—In the following table are given the analyses of three specimens, contributed by Mr. L. D. Ricketts, from material observed by him to frequently constitute a persistent bed under the rich ore bodies, especially on Carbonate Hill. This material is of ocherous-yellow color, somewhat like a dry clay, and easily recognized by its external appearance, though, as will be seen, of very variable composition:

Basic sulphates.

	Maid of Erin.	Morning Star.	Lower Waterloo.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	None.	0.30	0.36
Fe_2O_3	46.70	42.98	44.40
Al_2O_3	None.	0.20	0.28
CaO	0.06	0.64	None.
MgO	0.06	None.	None.
K_2O	5.33	6.31	0.15
Na_2O	1.68	0.83	0.37
H_2O	10.54	10.12	8.99
PbO	4.27	8.27	19.50
Bi_2O_3	0.08	None.	None.
As_2O_5	0.46	0.42	0.39
P_2O_5	0.08	1.58	0.11
SO_3	30.53	27.81	25.07
Cl	0.02	0.26	0.04
Ag	0.0048	0.0036	0.075
Au	Trace.	None.	None.
Totals	99.8148	99.7236	99.685

These substances are somewhat complex basic sulphates, and might be considered to be a mixture of jarosite with varying proportions of basic ferric sulphate. They are evidently an alteration product of pyrite and galena, although, while nodules of galena rich in silver are occasionally found in them, pyrite has not yet been detected. The absence of zinc in the specimens analyzed is noteworthy and is in accordance with the observation already made, that it has been further removed from the original ore bodies than the other metals, presumably on account of the ready solubility of its sulphate. The persistent percentage of the alkalies, which were found in sensibly the same proportions in three other specimens tested, would suggest that the waters which produced this alteration reached the ore bodies after passing through decomposed porphyry. Their chief interest lies in the definite evidence they afford that they result from the oxidation of sulphides. Similar products have frequently been observed in old mine openings where large bodies of pyrite have been long leached by surface waters. Copperas first formed gradually loses a portion of its water on exposure to the air, and the protoxide of iron becomes sesquioxide. Further exposure leads to the formation of limonite.

[1] Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 549.

Finally, argentiferous galena has been found in the wall rocks without accompanying silica. The best examples of this phenomenon come from the Mammoth.

IN THE IGNEOUS ROCKS.

Mechanical alteration.—In the igneous rocks the fissures have been developed almost entirely in the more compact and granular rocks. They are very numerous, though small and short. On the hill between the Swansea and the Iron Duke mines only are they sufficiently strong and close to produce sheeting. Shearing and granulation of the individual minerals of these rocks are absent.

Chemical alteration.—The amount of chemical alteration of the igneous rocks is only slight in the vicinity of the veins, but along the contact deposits it often extends several hundred feet into the monzonite, rhyolite, and andesite.

In the deposits entirely in the igneous rocks quartz, pyrite, and sericite have formed in the wall rocks next the veins for a few inches, but in many cases the wall rocks are perfectly fresh. The pyrite forms along cracks in the rocks and rock minerals, and in some cases the iron appears to have been derived from magnetite which has been sulphidized. Sericite results, in part at least, from the decomposition of the potash feldspars, but there is more potash in the altered than in the original wall rocks, so that it would seem that potash has been a component of the mineralizing solutions. Quartz replaces the lime, magnesia, and soda feldspars, but not the potash feldspars. These changes are more extensive in the vicinity of the veins, but the amount is never so great as to obscure the character of the country rock.

The alteration of the monzonite adjoining the contact deposits is much more extensive, though not essentially different from the alteration produced by the vein solutions. This has been treated fully in Chapter V of Part I.

CHAPTER IV.

STRUCTURE AND PERMANENCE OF THE ORE BODIES; EXPLORATION.

DEPOSITS IN THE SEDIMENTARY ROCKS.

General features.—The ore bodies of the sedimentary rocks form along nearly vertical fractures and extend into country rock on both sides for from a few inches to more than 50 feet. These bodies are extremely irregular and are seldom bounded by definite walls, so that the change from ore to country rock is vague and must be determined either by assay or by the hardness of the rock, the silicified limestone being invariably harder than the unaltered limestone.

The ore bodies follow for the most part N.–S. fissures, but they have also been found on fissures of all other observed directions. The deposits on other than N.–S. fissures usually serve only to connect ore bodies on adjoining N.–S. fissures.

It is rare that an ore body splits or sends off shoots, so that when a body passes from one fissure to another the first fissure is barren beyond the point of departure. At the junction of two fissures, only one of which is ore bearing, the vein is usually wider than when the ore body departs on the intersecting fissure.

In the Gemini mine (Pl. XCII), 600-foot level, an ore body passes from a N.–S. fissure at its south end to an E.–W. fissure, which it follows eastward 30 feet and then turns northward on another N.–S. fissure, thus forming a distinct U. In the surface workings of the Mammoth mine (Pl. XCIII) a great body of ore is seen to turn from a N. 35° E. to a N. 10° E. fissure.

In the Eureka Hill and Bullion-Beck mines there are two nearly parallel ore bodies 250 feet apart. At the south end these trend north and south, but going north they turn gradually to the west until, at a point midway between the Eureka Hill and Bullion-Beck shafts, their course is N. 35° W., and they are much larger than elsewhere; in places even uniting to form a single ore body. Northward from this point they turn again sharply and maintain a N.–S. course as far as they have been traced.

At the south end of the Eureka Hill is an ore body striking east and west which connects the two ore bodies just mentioned, though they extend across the ends of the E.–W. ore body.

The vertical range of the ore bodies is variable. In the Eureka Hill and the Bullion-Beck some of the larger ore bodies have a vertical range of 200 to 600 feet, and in the Mammoth there is a large body which extends from the surface to a depth of over 1,600 feet. In both the Bullion-Beck and the Mammoth there are, however, many bodies of ore which form small horizontal pipes only a few feet in diameter. The accompanying longitudinal section of the north end of the Bullion-Beck mine (fig. 82) gives a very clear idea of the variation in the vertical range of the ore bodies.

The longitudinal variation in the ore bodies is nearly as great as that in a vertical direction. Those bodies which occupy strong fractures at a distinct angle with the planes of stratification are more often continu-

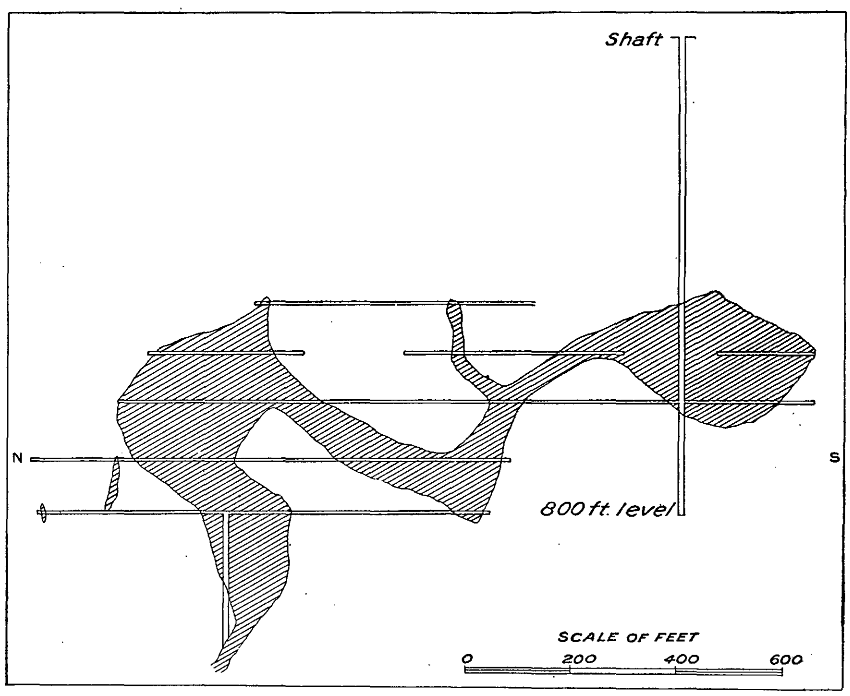
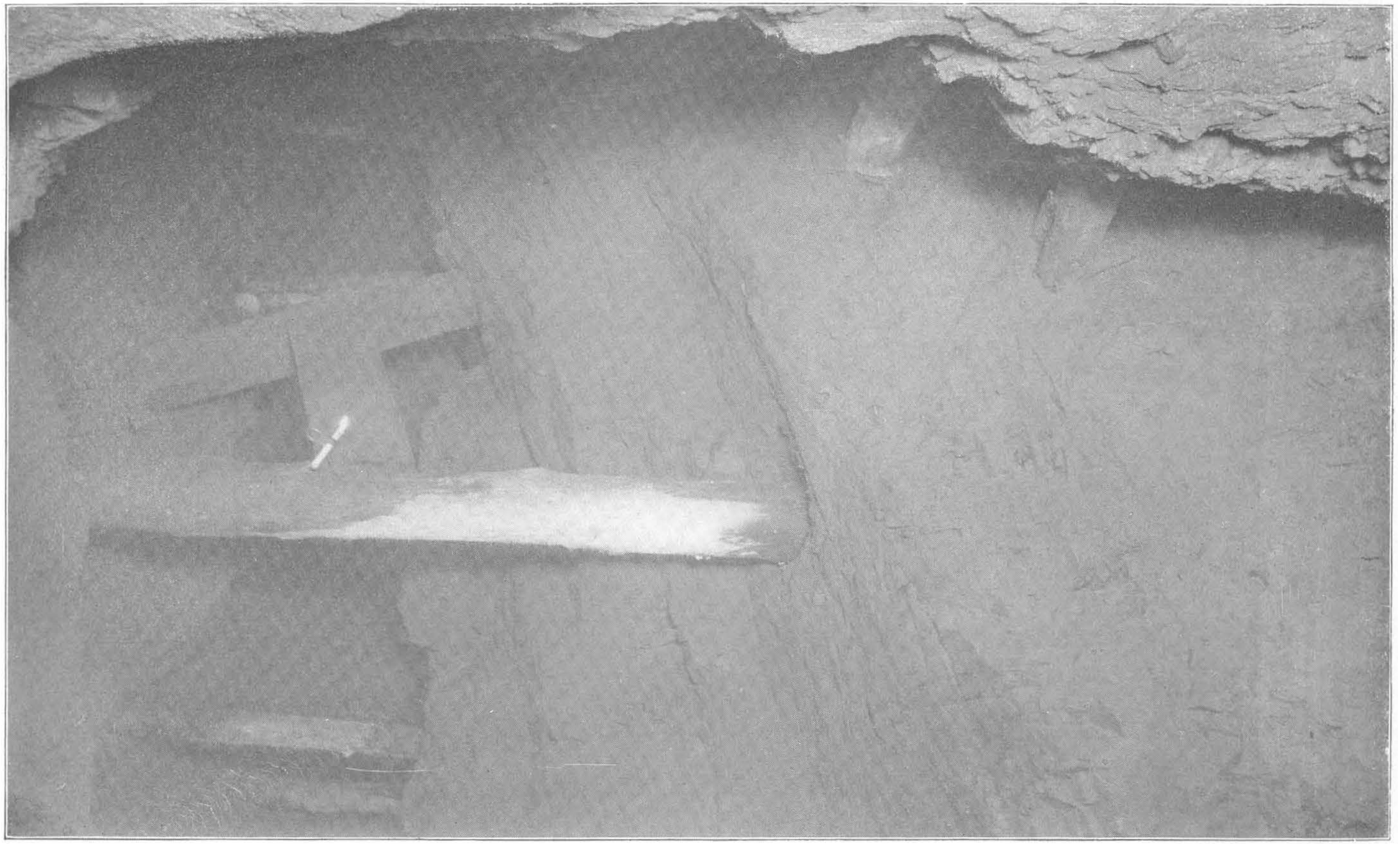


FIG. 82.—Longitudinal section of Silver Gem ore body north of Bullion-Beck shaft.

ous than the ones which occur in openings that result from slipping of individual beds on each other. The longest observed ore body extends from the Utah to the Carissa mine, a distance of 5,000 feet, while in the Bullion-Beck and Gemini there are many ore bodies not more than 25 feet long.

Rich ore shoots.—Nearly all of the vein matter of the sedimentary rocks is ore bearing, though it is not all pay ore. There appears to be no definite law which governs the distribution of the richer portions of the ores. In general, however, the smaller ore bodies are the richest, and where two or more fractures intersect and the ore bodies widen, it is common for the ores to be somewhat richer.



ORE BODY TURNING FROM A NORTH-SOUTH TO AN EAST-WEST FRACTURE, GEMINI MINE, 300-FOOT LEVEL.

In the North Star mine there are four parallel shoots of rich ore which pitch north at an angle of 30° within the general mass of vein material; they do not correspond to any known system of fracture planes. In the Boss Tweed, to the northeast, there are three similar shoots of ore which also pitch to the north at a low angle. The great ore body in the Mammoth, which is an irregular, elliptical-shaped chimney 200 feet long, 50 to 150 feet wide, and extending from the surface to the lowest workings, is situated at the intersection of several fissures and pitches north-northeast at an angle of 70°. At the southern end of the Centennial Eureka, where the ore body pitches to the south at an angle of 30° in a very irregular course, the rich shoot follows the center of the ore body. In other mines, noticeably the Bullion-Beck and the Carissa, the richer ores occur next the limestone, while the heart of the ore bodies is siliceous and of lower grade.

The greatest depth at which ore has been found is in the Bullion-Beck, where it is 1,200 feet below the collar of the shaft, or 5,150 feet above sea level. In the Centennial Eureka and the Mammoth ore has been mined at a depth of over 1,600 feet, but this does not represent so great an absolute depth because of the much greater elevation of the shaft collars of these mines.

In the bottom of the Bullion-Beck mine are two northward pitching chimneys of ore rich in copper, lead, silver, and gold, but there is also a great deal of vein matter in other portions of the lower levels which carries but little value.

The outcrops of the ore bodies are inconsiderable, and not at all commensurate with the size of the ore bodies. Only the Ajax, Mammoth, and Eureka Hill ore bodies show conspicuous outcrops. In the Bullion-Beck the ore, according to Mr. John Kirby, does not extend above the 80-foot level. In the Gemini it is not found above the 200-foot level and not in paying quantities above the 400-foot level.

It is generally conceded that fissures are a phenomenon of the surface rocks and that only the strongest fractures have great depth. It would seem, therefore, that in the deeper workings the ore bodies are likely to become fewer in number but that they will decrease in value is not indicated by the present development at least.

It can not be denied that the average value of the ore per ton is decreasing, but this is due more to the passing from the totally oxidized to the less oxidized ores than to the lesser value of the original ore.

Exploration.—The ore bodies are so irregular in outline and direction that crosscutting to the east or west, followed by drifting on N.-S. fissures, is the best way for opening a new mine. When an ore body is found the safest method is to follow it with levels, winzes, or upraises, and subsequently to extend workings from the mine shaft to the ore bodies thus developed.

When an ore-bearing fissure ceases to carry ore it is safest to look for a cross fissure for the continuation of the ore before following the barren fissure, or, if this method fails, crosscuts should be extended frequently to find other fissures. It is important to bear in mind that these rocks are extensively sheeted, and that comparatively few of the planes of sheeting or fractures carry ore.

Great loss of time and money has resulted frequently from a failure to realize that within the zone of oxidation the tendency has been for the secondary products to be carried downward by leaching, and that hence the original body from which rich oxidized ores have been derived is more likely to be found above than below.

DEPOSITS IN THE IGNEOUS ROCKS.

General features.—In the igneous rocks the ore bodies are well defined and moderately regular in form. They vary from a mere seam to 10 feet in width, and average nearly 2 feet. The limits of the ore are always well defined, though the country rock and the ore are rarely separated by clay seams or friction breccias. The most continuous body of ore is the Sunbeam vein, which is 2,000 feet long. The majority of the veins are not more than a few hundred feet long.

As in the deposits of the sedimentary rocks, the ore follows N. or NNE. fissures principally, and NE. and other fissures for but short distances. The veins of parallel fractures do not, as a rule, overlap, but are connected by ore on cross fractures, the main, as well as the cross fissures, being barren of value beyond the intersections.

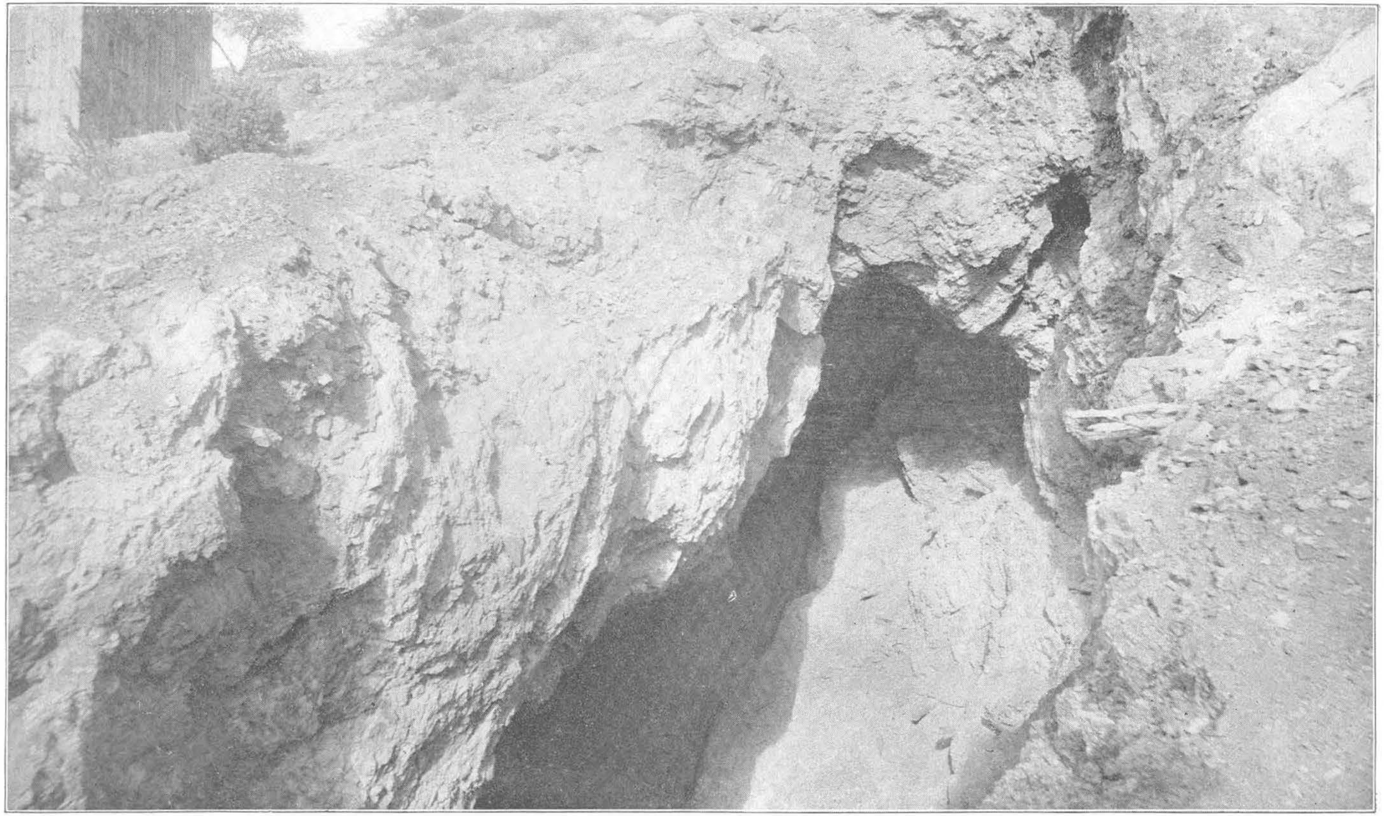
There is a marked banding in the ores, the bands consisting of varying proportions of the three principal minerals—pyrites, quartz, and galena. The individual bands are lens-shaped, being in some cases 2 feet wide, 150 feet long, and 50 feet in vertical extent. They are separated occasionally by clay seams.

Ore shoots.—The portions of the vein to which the term "pay shoots" may be applied are the individual bands of galena ore. These are lens-shaped and without definite pitch, though the longest axis is usually horizontal.

In a majority of the mines work has ceased at the water level because the ore diminished in value greatly and because of the additional expense entailed by the handling of water. Such of the mines, however, as have extended their workings below the zone of oxidation have found argentiferous galena in considerable quantities. In the Swanseas, for instance, the vein varies from 1 to 10 feet in width, and of this nearly one-half can be mined profitably.

While there is a marked decrease in value from the oxide to the sulphide ores and the veins are never large, still there is no good reason for believing that they will not persist to a much greater depth than they are now worked.

Prospecting.—The surface indications of veins of this character form a fairly accurate basis for determining the size and persistence of the



ORE BODY CHANGING FROM N. 35° E. FISSURE TO N. 10° E. FISSURE, MAMMOTH MINE.

veins in depth. It does not seem probable that veins of any considerable size exist where there are no surface indications; on the other hand, outcrops merely indicate the existence of a vein which may or may not prove valuable.

In underground exploration the veins are best prospected by raises or winzes on the veins, for the ore shoots are usually lens-shaped, with the longest axis horizontal, and by simply drifting on the vein one might run parallel to the shoot or between two shoots and in barren vein material.

RÉSUMÉ.

From the foregoing it will be seen that the ore bodies of the sedimentary rocks are strongly contrasted with those of the igneous rocks. In the sedimentary rocks they are very irregular and form chambers, chimneys, pipes, and pockets, often of great size, which extend on both sides of the fracture planes and which are not separated from the country rock by walls or selvages, whereas in the igneous rocks the veins are narrow and regular and are contained within well-defined walls.

The features which they have in common are their mineral composition, their frequent change of direction, and their failure to overlap.

The greater size and persistence of the fracture planes along which the ore has been deposited in the sedimentary rocks may indicate that these deposits will have a greater permanence than the deposits in the igneous rocks, but this is by no means certain.

CHAPTER V.

GENESIS OF THE ORE DEPOSITS.

INTRODUCTION.

Ore deposition in the Tintic district may be divided, according to mode of occurrence, into three distinct classes: First, those in the sedimentary rocks; second, those in the igneous rocks, and third, those along the contact of sedimentary and igneous rocks. Of these the deposits in the sedimentary rocks are the oldest, while as between the others the evidence is less decisive, the contact deposits are thought to be younger than those in fissure veins.

DEPOSITS IN SEDIMENTARY AND IN IGNEOUS ROCKS.

INTRODUCTION.

Notwithstanding the difference in age of these deposits and their occurrence in strongly contrasted rocks, their original mineralogic composition is identical. The deposits of the sedimentary rocks are either cavity fillings or metasomatic replacement of limestone, whereas the deposits in igneous rocks are fissure fillings.

AQUEOUS DEPOSITION.

The first two classes of deposits were probably formed by similar agencies, inasmuch as they were originally of similar mineral composition. It is thought that only a deposition from aqueous solutions could account for the deposits in the sedimentary rocks. At the time of their deposition there was, so far as known, no body of igneous rocks near them. If such a body existed in depth it must have been at such a distance that its influence would not have been immediate, but only through the agency of aqueous solutions. Furthermore, the mineralogic character of both these deposits, their content in barite, and the extensive silicification of the adjoining country-rocks could only have been produced by the agency of aqueous solutions.

CHARACTER OF ORE-BEARING SOLUTIONS.

The character of the solutions is best indicated by the nature of the deposits which have been formed from them. The quartz in the deposits in the igneous rocks and the quartz and jasperoid in the deposits in the sedimentary rocks indicates that silica must have been the predominating constituent of these solutions. Barium was also present in them and has been precipitated in the form of sulphate of barium (heavy spar). The metals were precipitated as sulphides and sulpharsenides; hence the solutions were probably mainly alkaline sulphide solutions. Original carbonates are wanting; hence there is no direct evidence that the solutions were carbonated.

The solutions which made the original deposits, both in the sedimentary rocks and in the igneous rocks, were probably heated. The mineralization of the sedimentary beds occurred before the volcanic activity, and apparently soon after the deformation of the strata, or at a time when the deposits now worked must have been covered by nearly 12,000 feet of strata, since at least that amount was removed prior to the beginning of the volcanic activity. At such a depth ore deposition would have occurred at a temperature approaching 200° F.

The mineralization of the igneous rocks followed their injection closely, and for this reason alone would probably have been at an elevated temperature. What evidence there is goes to show that the solutions were ascending. Throughout the mines there is but little alteration of the wall-rocks at any distance from the ore bodies except such as results from surface waters. These surface waters have produced open spaces in the sedimentary rocks by dissolving the limestone and vein materials, which have been redeposited in bodies of an entirely different character from the original deposits.

ORIGIN OF THE METALS AND GANGUE.

These deposits were probably made by ascending waters at an elevated temperature, for the leaching of the wall-rocks has not been adequate or of a nature to produce vein deposits of this kind. In the igneous rocks the alteration due to mineralizing solutions has added silica and potash to the rock and removed almost completely the iron, lime, magnesia, and soda. On the one hand, the solutions have removed, except in the case of the iron, substances which do not appear in the ore bodies, and, on the other, they have added silica, which is abundant in the ore bodies.

In the sedimentary rocks at the time of mineralization no igneous rocks were present, on the surface at least, and the sedimentary rocks, as shown by the analyses in Chapter II, were totally unlike the ore deposits in composition. Since, therefore, the substances deposited by the mineralizing solutions of both the sedimentary and the igneous rocks were independent of the composition of these rocks, and since the two ore deposits are similar in chemical composition, it would seem as if they must have had a common source which was not the present rocks of the district. Such a supposition does not preclude the occurrence, however, of deep-seated bodies of igneous rocks that have not yet been exposed by erosion, and it is only possible to say that while the deposits may have been formed by leaching of large bodies of igneous rock, the known rocks were not the sources of the elements which make up these deposits. They are the result of chemical processes which occurred at a much greater depth below the earth's surface.

As to the methods by which the ore-bearing solutions may have taken up their various constituents and have redeposited them in the various mineral combinations that are found in these deposits, the following extracts taken from Mr. Lindgren's exhaustive report on The Gold-quartz veins of Nevada City and Grass Valley districts, California,[1] seem so pertinent that they will be quoted here with some fullness:

According to Fuchs,[2] amorphous freshly prepared silica is soluble in water to the extent of 130 grams per ton. The natural siliceous waters show, however, a far greater solubility; the Iceland geysers contain up to 606 grams per ton; Steamboat Springs, Nevada, 306, and the Yellowstone Park geysers up to 580. The silica in the latter is not precipitated by cooling, even to freezing point, when not exceeding 400 grams per ton, and, according to F. A. Gooch,[3] it is probable that the compound is not contained as alkaline silicates, but as free hydrated silica. Saturating the waters with H_2S or CO_2 did not produce precipitation. . . . .

Doelter found that pyrite, galena, antimonite, sphalerite, chalcopyrite (in part), arsenopyrite, and bournonite are to some extent soluble in pure water when heated for almost four weeks in glass tubes to a temperature of 80° C. About one-eighth or one-tenth of the remaining undissolved, finely powdered mineral was in addition usually found to be recrystallized. Pyrite was soluble at the rate of 1,000 grams per ton of solution, or 0.10 per cent. The solution of galena contained 270 grams of PbS per ton.[4]

According to the same authority galena and pyrite are also to some extent attacked by water containing carbon dioxide.

Becker[5] found that pyrite is soluble in cold solutions of sodium sulphide. Ten cubic cm. of solution containing 1.0955 grams of sodium sulphide dissolved 0.6 gram of pyrite, the solution thus containing about 60 grams of pyrite per ton, or 0.006 per cent. Pyrite is also soluble in hot sodic sulphydrate, but not in cold, and is relatively easily soluble in cold and hot solutions of sodium carbonate partly saturated with hydrogen sulphide.

Similar results were obtained with the sulphides of mercury, copper, zinc, and, of course, arsenic and antimony. The sulphides of lead and silver could not be brought in solution, the former not even when heated to 100° C. in closed tube.

Doelter's[6] later experiments show that pyrite, galena, zincblende, arsenopyrite, chalcopyrite, and bournonite are all soluble in sodic sulphide by treating the finely powdered minerals for twenty-four days of twelve hours at a temperature of 80° C. in glass tubes. Quantity of mineral used, about 1 gram; quantity of liquid, about 40 to 50 c. c. Of the pyrite, 10.6 per cent was dissolved, corresponding to an approximate content of 0.2 per cent of pyrite in the solution. Galena is even more soluble. In comparing these large amounts with Becker's results it would thus seem that time is a very important factor in the solution of these minerals. In regard to the solubility of tellurium compounds, which evidently have a close relationship with the gold, there are no data available. . . .

[1] Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, pp. 176-181.
[2] Doelter, Chemische Mineralogie, Leipzig. 1890, p. 189.
[3] Formation of travertine, etc., W. H. Weed: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 655.
[4] Tschermaks mineral. Mittheil., 1889, Vol. II, p. 319.
[5] Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 432.
[6] Tschermaks Mineral. Mittheil., 1889, Vol. II, p. 323.

RELATION OF SOLUBILITY TO INCREASED PRESSURE AND TEMPERATURE.

It is a widely accepted view that in general the decrease of pressure and temperature forms an important factor in the formation of mineral deposits by ascending hot springs. In view of this it may be profitable to inquire how, as far as we know, the solutions of different substances are influenced by the increase of pressure and temperature.

It is proper to draw attention at the outset to the fact that the question is extremely complicated, for the presence of other substances, as a rule, affects the solubility of any given salt; so that the rules obtained from simple solutions of certain compounds may not be applicable at all for solutions of the same in mineral waters.

Pressure certainly affects the solubility of many substances, but the result may be either an increase or a decrease. The investigation of Braun[1] shows that the rate of increase (positive or negative) is a function of the pressure, temperature, heat of solution, and change of volume taking place in the solution. If contraction takes place, which is the less common case, there is in general a decrease of solubility.

Regarding silica, there are apparently no data available; deposition taking place from highly saturated solutions may be due to loss either of heat or of pressure. . . .

The influence of temperature has been more extensively studied. It may be said that up to about 100° C. there is in general an increase in solubility, but recent experiments seem to prove that for many substances there is, in fact, after a certain point has been passed, a distinct decrease. . . .

Assuming a mineral water emerging at the surface with a temperature near the boiling point and a gradually rising pressure and temperature down to a depth of several thousand feet, it becomes clear that we are not in the least justified in assuming a gradual and indefinitely extended increased solubility in depth, or, reversed, that conditions for deposition will gradually become more favorable as upper levels are reached. It is in fact more probable that for temperatures rising high above 100° C. and under increasing pressures there will be a decrease in the dissolving power of the waters, at least as far as the principal constituents of the water are concerned. In all probability the quartz veins here described were deposited from solutions at great depth below the surface, under strong pressure and at temperatures ranging perhaps from 100° C. up to 250° C. It is true, and the fact agrees with results previously stated, that at the mouth of the crevice deposits of many substances are formed by suddenly diminishing temperature, but it does not at all follow that a diminution from 200° to 100° C. will produce a result similar to that of cooling from 100° to 0°. Besides, the precipitation at the surface is very largely caused by the oxidizing influence of the air, escape of carbon dioxide, evaporation, reduction by organic matter, and algous growth. . . .

In regard to the influence of heat and pressure upon the solubility of gold and sulphides, there are but few definite data available, and, in fact, the problem is much more difficult than that offered by the ordinarily easily soluble salts. The experiments by Becker and Doelter indicate that heat, and perhaps also pressure, increases the solubility, but how far this increase extends is almost entirely unknown. It is not unreasonable to suppose that, as with other salts, this increase is not indefinite, but reaches a maximum and then again declines.

SYNTHESIS OF GANGUE MINERALS.

Quartz has been reproduced by Chroustchoff, Doelter, Senarmont, and others from alkaline solutions of silica or by recrystallizing gelatinous silica. According to Doelter,[2] quartz can not be reproduced from aqueous solutions at a temperature below 250° C. The facts hardly appear to bear out this assertion. At Steamboat Springs there are vast masses of siliceous sinter which are distinct surface accumu-

[1] Ostwald, Allgemeine Chemie, p. 1046.

[2] Ostwald, Ibid. p. 154.

lations and scarcely can have been formed at a temperature above 100° C., more probably below. Yet this sinter consists of a mixture of prevailing opal and chalcedonite, with smaller masses of finely granular quartz, often with crystallographic outlines. Small quartz crystals are found in the silicified wood of the auriferous gravels, where the temperature can hardly have been very high at any time.

Opal or cryptocrystalline silica may be deposited at considerable depths, as its occurrence in several deep mines of Grass Valley indicates. Doelter's experiment on the solubility of gold, recorded below, indicates the same fact. . . .

In discussing the solubility of the metallic minerals, especially the sulphides, it has been tacitly assumed that they might have been formed simply by separating out from their solvents by changes affecting the latter. This is certainly not the only way in which they could have been formed in the veins, as is proved by the relative ease with which most of them can be formed synthetically in the wet way, chiefly by the action of sodic or hydric sulphides on different salts. Pyrite, galena, chalcopyrite, argentite, tetrahedrite, bournonite, and arsenopyrite have been obtained by Senarmont and Doelter in this manner. . . .

The reaction by which the oxides of iron or other iron salts are converted to pyrite by the action of hydric sulphide or sodic sulphide is evidently of great importance. This reaction was shown by Dr. G. F. Becker to have taken place to great extent in the altered country rocks of the Comstock lode, the pyrite being principally, apparently, derived from the ferrous silicates; it was experimentally verified by Doelter[1] in case of oxides and carbonate of iron. It is clear that the ferromagnesian silicates and the magnetite in the wall rocks have furnished the greater part if not all of the iron for the pyrite in the altered rocks, while it is equally certain that comparatively little iron has been carried from the country rock in the vein.

The facts brought out by the studies at Tintic, together with those established by the experiments which Lindgren has reviewed, go to show that the deposits in the sedimentary and in the igneous rocks at Tintic were, in their original form, made from ascending heated waters bearing hydrogen sulphide, alkaline sulphides, and arsenical sulphide, and some form of silica, barium, lead, copper, silver, and gold.

The metasomatic nature of many of the deposits in the sedimentary rocks indicates that precipitation from the vein solutions in this case was caused by chemical reactions between the components of the vein solutions and the carbonates of lime and magnesia of the wall rocks. On the other hand, those deposits that fill preexisting spaces, some of which occur in the sedimentary rocks, but which mainly characterize the deposits of the igneous rocks, may be the result of chemical precipitation due to loss of temperature or pressure or of changes brought about in the solutions through the meeting of waters coming directly from the surface and which may contain oxygen, carbonic acid, or even organic matter.

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[1] Chemische Mineralogie, p. 148.

SECONDARY DEPOSITS IN THE SEDIMENTARY AND IGNEOUS ROCKS.

GENERAL FEATURES.

In both the sedimentary and igneous rocks, but principally in the former, surface or vadose waters have altered the original deposits formed in these rocks above the level of permanent water. They have leached the deposits, decomposed the various minerals, and formed them into other chemical combinations. Their most striking action has been the fact that in reprecipitation they have deposited each metal in its various mineral combinations in great measure in separate and distinct bodies.

RELATIONS TO PRIMARY DEPOSITS.

These secondary deposits in the igneous rocks are confined to the vein proper, but in the sedimentary rocks they have formed not only in the vein proper but also as a cement to brecciated vein and country rock and in open spaces in the country rock adjoining the vein and of later formation than the original deposits.

MODE OF ALTERATION.

The metallic minerals of the original deposits were sulphides and sulpharsenides, forming principally pyrite, galena, enargite, and silver sulphide.

Above the level of permanent water these minerals have been largely oxidized and have formed oxide of iron, sulphate and carbonate of lead, hydrous arsenates and arseniates of copper, oxides of copper and native copper, and chloride of silver and native silver.

The original sulphide minerals have, as a first stage in the process of change, taken up oxygen and formed sulphates, which have by further changes passed into the other compounds. Concerning similar changes in the ores of Leadville, Emmons[1] says:

According to J. Roth,[2] of such sulphates 100 parts of water dissolve, respectively:

At 11° C., 0.004383 parts }
At 13° C., 0.003155 parts } sulphate of lead.
At 12° C., 21.300 parts sulphate of iron.

The sulphate of silver is less soluble than that of iron, but probably more so than the sulphate of lead, and at 100° C. it is said to be soluble in 88 parts of water.

Sulphide of silver may be reduced to native silver by the action of water at 100° C., during which, according to Moesta, the water itself is decomposed and SO_3 and H_2S are formed. Native silver is slowly converted into chloride in waters containing alkaline chlorides.[3]

Sulphide of silver is converted directly into chloride of silver at ordinary temperatures when exposed to the action of sulphate of sesquioxide of iron, chloride of sodium, and water.[3] The presence of air is not necessary for this reaction, but if

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[1] Mon. U. S. Geol. Survey, Vol. XII, Part II, p. 551.
[2] Allgemeine Geologie, Berlin, 1879, p. 59.
[3] Percy's Metallurgy of Silver and Gold, Part I, London, 1880.

the sulphate of protoxide of iron is substituted for the basic sulphate, chloride of silver is not produced without the presence of air. This indicates that a salt of sesquioxide of iron must be formed before the sulphide of silver is decomposed.

Moesta's[1] experiments show that this reaction may take place with a solution of NaCl alone at 100° C., and even at 20° C., but that it is quickened by the presence of chloride of magnesium, and still more by powdered pyrite; also that the combination with iodine is more rapid than with chlorine.

Sulphate of lead is transformed at the ordinary temperature into carbonate by solutions of fixed alkaline carbonates, and also by those containing bicarbonate of lime and atmospheric air. Carbonate of lead (cerussite) is soluble in 7,144 parts of water saturated with carbonic acid.[2] In conversion 100 parts, by weight, of sulphide of lead became 126.78 of sulphate, and this in turn 111.71 parts of carbonate of lead.[3] The increase in volume from sulphide to carbonate is 28.13 per cent. Such changes of weight and volume might account for the prevailing sandy condition of the carbonate ores. It may be assumed that they were once comparatively solid masses of galena, and during these transformations occupied, first, a larger, then a smaller, space, thus leaving interstices between the minute crystals of cerusite of which the sand carbonate consists. . . . .

Sulphate of protoxide of iron may become carbonate in the presence of earthy carbonates. Carbonate of protoxide, by oxidation and hydration, becomes hydrated sesquioxide or limonite, which on loss of its water becomes hematite; . . . .

The sulphate of the protoxide may, by oxidation, change directly to sulphate of sesquioxide or basic ferric sulphate, which in turn becomes limonite and hematite.

The fact that carbonate of iron is so rarely found in the Leadville deposits would suggest that their limonite might have been formed in the latter way, and that the basic ferric sulphates, of which analyses are given above, may have been formed directly from the sulphide.

This would account for the changing of pyrite, galena, and silver sulphide at Tintic to limonite, cerussite, and cerargyrite, respectively.

The original sulpharsenide mineral, enargite, has passed through a number of changes, the most important of which are the hydrous arsenates and arseniates, which in turn have been altered to the oxides of copper and finally to native copper.

The alteration has been effected through the agency of surface waters. Such waters usually carry atmospheric oxygen, organic matter, chloride of sodium, and phosphoric and carbonic acids.

In the processes of oxidation the various metals of these deposits have been segregated and form bodies valuable principally for only one of the metals, so that there are great bodies of ore containing principally lead, or copper, or silver. In the sedimentary rocks large bodies of secondary copper minerals were found in the Ajax, where they either completely filled caves in the vein or formed a crust of stalactites and stalagmites on the walls of caves. Similar bodies were found in the Eureka Hill and the Mammoth mines.

Large bodies of secondary lead minerals, principally cerussite, were found in the Eureka Hill, Bullion-Beck, and Sioux-Utah mines, while considerable bodies of horn-silver ore occurred in nearly all of the

[1] Chlor-, Brom-, und Jodverbindungen des Silbers in der Natur, Dr. Fr. A. Moesta, Marburg, 1870, p. 40.

[2] Percy's Metallurgy of Lead, London, 1870, p. 40.

[3] J. Roth, op. cit., p. 243.

mines, but especially in the mines of the Eureka zone. In the Gemini, crusts of horn silver were found coating fragments of vein and country rock which were in some cases a quarter of an inch thick.

In the igneous rocks, owing to the slight alteration and comparative solidity of the wall rocks and the narrow limits of the ore bodies, the products of alteration are not greatly separated. The oxide ores carry about twice as much silver and lead as the sulphide ores, there being a nearly corresponding decrease in iron and silica, but principally in iron.

These separations are greatest in the zones of greatest dynamic activity and ore deposition, as in the Eureka and Mammoth ore zones. In the Godiva-Sioux Mountain ore zone, where the dynamic action has been less and the ore bodies are smaller, the separations are not so clear.

That the separations result from differences in the solubilities and stabilities of the various metallic minerals there can be no doubt. Leaving out of the question the Godiva-Sioux Mountain zone, where dynamic action has been small and opportunity for oxidation poor, it appears that enargite, the original copper mineral, is but rarely found, except in the deepest workings, while its secondary products are abundant throughout the vertical range of the workings; galena, the original lead mineral, is much more common and has been found frequently near the surface; the original silver, which occurs in part as argentite and in part combined with enargite and galena, has been altered to horn silver throughout the mines. Hence it seems probable that enargite and argentite are less stable than galena.

Concerning the secondary changes in the argentiferous galena ores at Leadville, Emmons has written:[1]

> The greater richness in silver of galena over cerussite in this region is very noteworthy. Mr. L. D. Ricketts,[2] who made a detailed study of the ores of Carbonate Hill, states that the average tenor of cerussite in that locality is less than 40 ounces of silver to the ton, while galena averages 145 ounces of silver to the ton. He also states that assays of five galena nodules, and of the carbonate crusts on each, showed that in proportion to the amount of lead present there was six times as much silver in the galena as in the cerussite. * * * Assays of various specimens of ores, vein materials, and adjoining country rocks collected during the investigation show a similar relation in the silver contents of galena and of its cerussite crust, 420 ounces and 28.6 ounces, which are in even greater contrast than in the cases cited above.
>
> The fact that silver is found disseminated throughout the vein materials and adjoining country rocks, even where little or no lead is found, shows that during secondary alteration silver has been further removed from its original locus and more widely disseminated than lead. In fact, it may be assumed that the outlines of the present bodies of lead ore vary but little from those of the original deposits, but it would hardly be safe to make such an assumption in regard to silver ores. It is apparent that this relative distribution of the two metals was brought about by surface waters, and is therefore dependent on the relative solubility of the combinations of the respective metals formed during alteration.

[1] Mon. U. S. Geol. Survey, Vol. XII, p. 553.

[2] Ores of Leadville. Princeton, 1883, p. 87.

There are no experimental data available concerning the order and exact manner of such changes in minerals as these. It is probable that the changes are a direct result of the differences in stabilities and solubilities of the original minerals, but the changes through which these original minerals have gone have probably also been an important factor in the final separation. Moreover, it is certain that by the decomposition of enargite and galena much silver has been liberated which was precipitated either before or after the copper and lead, so that in either case the changes in the chemical composition of the oxidizing solutions must have been an important factor.

THE CONTACT DEPOSITS.

Distribution.—The contact deposits occur in the sedimentary rocks near or along the contact of the sedimentary with all the igneous rocks, but are largest along the contact of monzonite with limestone. The Tintic iron mine is located on such a contact.

Composition.—These deposits consist of jasperoid, hematite, limonite, a very small amount of gold, and, in the Tintic iron mine, a few fragments of the deposits in the sedimentary rocks. The jasperoid replaces the limestone; the iron oxides occur either in considerable cavernous masses, or in dust-like particles through the jasperoid.

These deposits differ from the deposits already described in that they contain no lead or copper, that the iron is deposited in the form of hydrous oxide, and that the silica is always as a replacement of the country rock and does not form vein quartz.

The alteration of the wall rocks has been more extensive than in the other deposits and frequently extends into the igneous rocks several hundred feet from the contact; its chemical nature is not essentially different. It is more fully discussed in Chapter V of Part I.

The universal removal of iron from the igneous rocks in the vicinity of these deposits indicates a possible source of their iron. The structure of the iron mineral, together with the fact that it is mainly limonite, shows that the deposit was made comparatively near the surface by thermal springs. It is, however, possible that the iron was originally formed at greater depth as pyrite, and that its present condition is the result of secondary alteration. The presence of the sulphur, as shown by the analysis on page 690, Chapter II of Part II, would seem to indicate such a possibility.

TIME OF DEPOSITION.

Of the three different classes of deposits of the Tintic district, those which are entirely inclosed by sedimentary rocks are the oldest, having been formed before the eruption of the igneous rocks. Proof of the greater age of these deposits is found in the facts, first, that the fissures along which they were deposited do not extend into the igneous rock, but are abruptly cut off by them; second, that fragments of these deposits are found in the talus along the flanks of the limestone uplift that has been since covered by igneous rock, as in the Godiva mine; third, that portions of the older deposits are found included within the more recent deposits, as in the Tintic iron mine. Of their absolute age it can only be said that they must have been formed since the folding and fracturing of the Paleozoic sediments in which they are now found, which probably took place in Jurassic time and earlier than the igneous eruptions, which occurred in late Tertiary, possibly Miocene, time.

The deposits entirely inclosed in igneous rocks, and those along the contact of sedimentary and igneous rocks, have been formed later than the intrusion of the latter, hence necessarily as late as Tertiary time. No evidence was found which would serve to fix this date more closely.

As to the relative age of these two classes of deposits, those in fissure veins and those along contacts, there is likewise no direct evidence. The fact that the former deposits in their original form contained the metals as sulphides and sulpharsenides, and that the latter were probably deposited from their solutions as oxides, and thus closely resemble modern spring deposits, and further that their metallic contents may have been derived, in part at least, from secondary sulphides in neighboring masses of eruptive rock, indicates a later age for the contact deposits.

CHAPTER VI.

DETAILED DESCRIPTIONS.

MINES OF THE EUREKA ZONE.

INTRODUCTION.

The mines of this zone extend continuously from the southwest side of Eureka Peak for over 8,000 feet to the north, having an average direction of about N. 10° W. The Centennial Eureka is the most southerly mine, while the Eureka Hill, Bullion-Beck, and the Gemini are the other mines to the north in the order named.

There are two nearly parallel ore bodies in this zone 250 feet apart. These trend about N. 10° W., except between the Eureka Hill and Bullion-Beck shafts, where they turn to the northwest for a few hundred feet. The more easterly of these has been called the Eureka, and the more westerly the Silver Gem. The Eureka ore body is nearly continuous throughout the workings of the Eureka Hill and Bullion-Beck mines, and may be represented in the Gemini, but the mine workings do not show this relation. It has not been found thus far in the Centennial Eureka mine.

The Silver Gem ore body is continuous from the north workings of the Centennial Eureka mine through the Eureka Hill to the northern end of the Bullion-Beck mine, and it is probable that the large ore body of the southern end of the Centennial Eureka mine is also a part of this ore body, but this can not be absolutely asserted because of recent faulting.

These ore bodies are irregular in course and vary greatly in the three dimensions. They are, however, more nearly continuous in the Centennial Eureka, Eureka Hill, and Bullion-Beck as far as the Bullion-Beck shaft, but north of this in the Bullion-Beck and Gemini mines the ore is in short, lens-shaped bodies which are generally parallel to the strike of the strata, though not necessarily parallel to the dip.

CENTENNIAL EUREKA MINE.

This mine is situated on the northwest flank of Eureka Peak, the shaft collar being at an elevation of 6,893 feet. It is the southernmost of the four mines of the Eureka zone and has been worked to a depth of 1,660 feet (5,233 feet above sea level). The country rock is Eureka limestone, and consists of an alternating series of blue limestones and blue and gray dolomitic limestones, with occasional chert seams. The strata strike N. 15° W., and are either vertical or dip east at a high angle. In a few places near the surface local dips west were noted.

The most important fractures trend N.-S. Others trend NW., N. 25° E., NE., and E.-W. They are nearly vertical, except those of the E.-W. ones which fault the ore bodies. These dip south at an angle of 45° to 55°.

There are two ore bodies, one south of the shaft the other north of it. The south ore body was discovered about 20 feet below the surface just south of the shaft, and has been followed southward 1,200 feet. It pitches S. at angles varying from 30° to 60° and has been traced downward to the 500-foot level. This ore body trends irregularly S., follow-

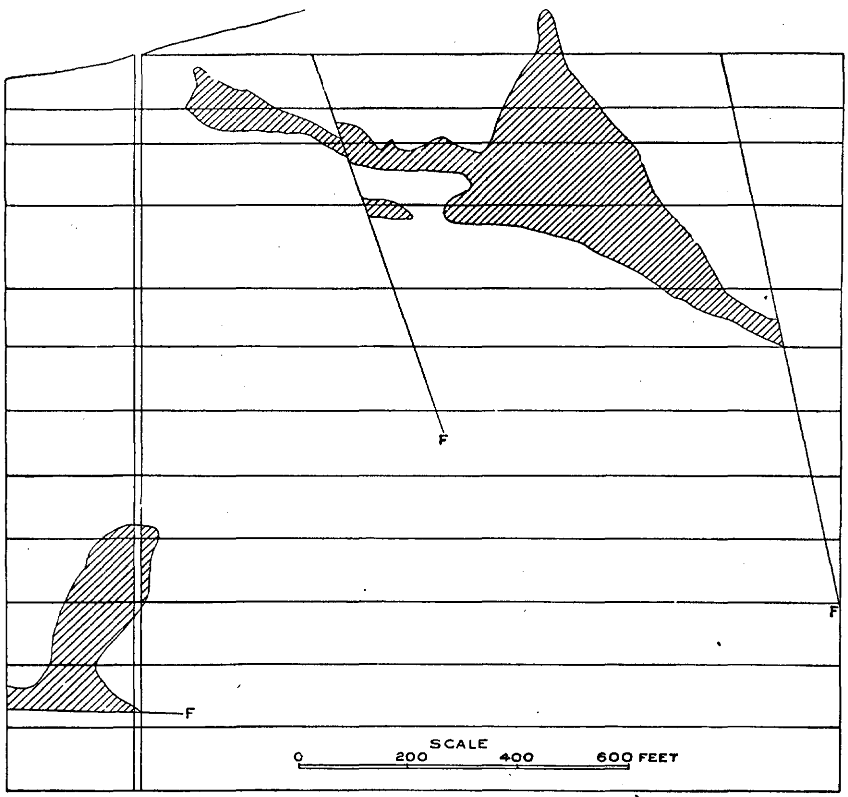


FIG. 83.—Longitudinal section, Centennial Eureka mine.

ing N.-S., NW., NE., and E.-W. fracture planes. An arm extending upward from the main ore body was found 500 feet from the mouth of a tunnel 80 feet above and 300 feet south of the collar of the main shaft.

The north ore body, which is slightly west of the south ore body, extends from the 800-foot to the 1,100-foot levels north of the shaft and into the southwest workings of the Eureka Hill mine, where it forms the Silver Gem ore body.

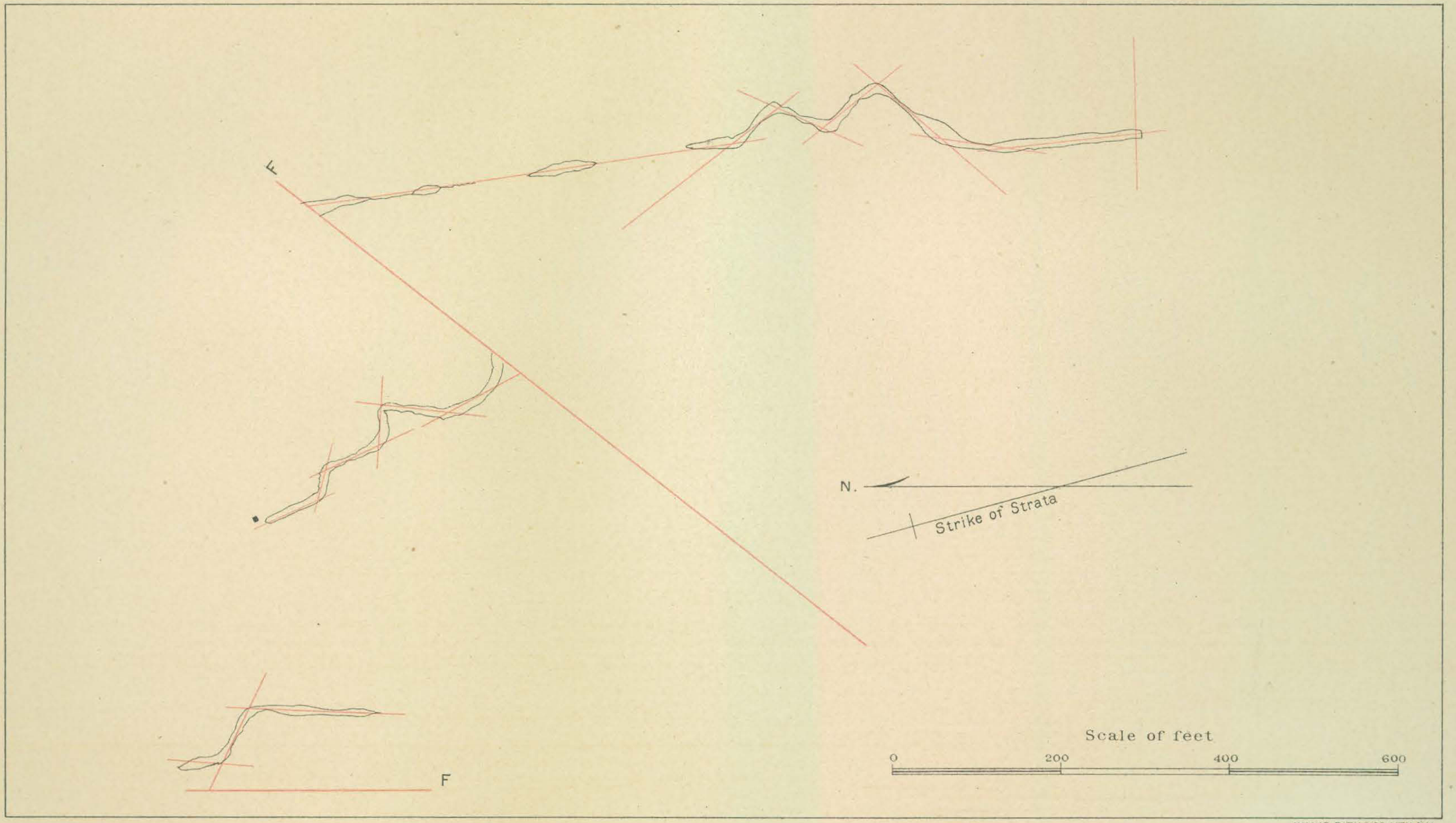
These ore bodies are represented somewhat diagrammatically in the accompanying plan and longitudinal section (Pl. XCIV and fig. 83.)

The south ore body is faulted on the 200-foot level about 350 feet south of the shaft, the southward continuation being thrown to the east nearly 250 feet. It is also faulted 1,200 feet south of the shaft in the 500-foot level, where the ore terminates. Its southern continuation has not been found, but is thought to be thrown to the west.

From the shaft to the first fault the south ore body trends successively above the 100-foot level, N. 15° W., N. 75° W., N. 15° W., N. 75° W., E.-W., NE., and E.-W. in all for 150 feet south; on the 100-foot level, N.-S., N. 25° W., N. 75° W., NW., N. 75° W., and NE., in all for 100 feet; and on the 200-foot level, N. 20° W., in a small body at the fault. South of the fault on the 200-foot level it is in several small bodies in a N.-S. fracture plane, and at the south end forms a Z-shaped body of ore, which is caused by the passing of the ore from one N. 30° W. fracture to another along a N. 30° E. fracture. From this irregular portion at the south end an arm extends to the tunnel above the shaft. On the 300-foot level the ore body forms three distinct lenses, two at the south end and one at the north end. These are connected by a barren fissure. On the 350-foot level the ore body which is at the south end of the mine is in two shoots running from a common point, one N. 20° W., and the other N. 15° E. for 50 feet and pitching S. at angles of 35° to 50°.

On the 400-foot and 500-foot levels but one very small ore body was found. The country rock is greatly altered and brecciated, and there are many small open caves lined with calcite and copper carbonates. There are many well-defined slips, the most prominent of which strike NE. and dip E. at an angle of 45°. This ore body has not been found below or south of the 500-foot level, and has undoubtedly been faulted. The only clue to the direction and amount of displacement is in a small prospect hole in the cliffs 800 feet south of the shaft, where an E.-W. fault was observed, on the south side of which is a 2-foot seam of quartz. From projections made of this ore and of the main ore body in the upper tunnel, it is probable that the movement has been westward on the south side, the amount of displacement being more than 200 feet.

The ore body of the north workings first appears on the 800-foot level. It follows a N.-S. vertical fracture for 100 feet and is 10 to 20 feet wide. It ends 40 feet above the level. Below it pitches north, and on the 900-foot level is over 150 feet long. At the north end it turns into a N. 75° W. fracture. On the 1,000-foot level the course as shown in the stopes is N. 75° W. Below it is more to the west, and pitches S. at an angle of 35°. Northward, just below the 1,000-foot level, it enters the Eureka Hill mine on a N.-S. fissure. This ore body on the 800-foot and 1,000-foot levels follows N.-S. fractures, is vertical, and pitches N. Between the 900-foot and 1,000-foot levels it follows a N. 75° W. fracture westward some 75 feet, only to turn on to another N.-S. fracture and extend to the north and the south with a flat southerly pitch.



JULIUS BIEN & CO. LITH. N.Y.

IDEAL PLAN, CENTENNIAL EUREKA MINE

West of this is a well-defined fault which strikes N.-S. and stands nearly vertical. This has been followed from the 1,000-foot to the 1,600-foot levels. It contains fragments of limestone and ore, principally galena, some of the fragments being a foot in diameter. The width of the breccia on the 1,600-foot level is more than 20 feet.

The minerals of the ore bodies do not differ from those in the other mines. Quartz forms fully half of the bulk of rich ores and probably three-fourths of the bulk of the lower grade ores. Barite occurs sparingly in tabular crystals, some of which are 2 inches long and one-fourth or one-half of an inch wide, usually in aggregates crossing in such a way as to form honeycomb structures. They are embedded in quartz. Calcite forms from one-tenth to one-twentieth of the gangue, and is found through microscopic studies to be unreplaced portions of the original country rock. The ore minerals are enargite, galena, and their oxidation products. These occur in about equal proportions, though the greater part of the galena has been found in the lower workings at the south end of the mine. The ratio of copper to lead is 1 to 1 in this mine, but in the Eureka Hill mine it is about 1 to 15 or 20. These ores contain high values in silver and gold, the rich shoots averaging nearly 100 ounces of silver and 1 ounce of gold to the ton.

These ores are not extensively altered, though malachite, azurite, olivenite, cerusite, and horn silver, or cerargyrite, are common. They rarely occur in pockets or large caves, which are manifestly of secondary origin, as in the Ajax and the Mammoth, and for this reason they show a greater uniformity, having a constant silver-gold content which varies with the amount of lead and copper. They form a striking contrast to many of the other mines where the ores are more oxidized and the amount of silver and gold is in inverse proportion to the amount of lead or copper.

EUREKA HILL AND BULLION-BECK MINES.

West of Eureka are the Eureka Hill and Bullion-Beck mines, whose workings, connected in many places, extend under the hill slopes on both sides of Eureka Gulch in a direction about N. 10° W. or S. 10° E., and explore a portion of the Eureka zone 3,500 feet in length by 1,000 feet in width. Their workings also connect the Gemini mine on the north and the Centennial Eureka on the south.

The Bullion-Beck mine, through the main shaft and winzes, has reached a depth of 1,200 feet (5,150 feet above sea level). The Eureka Hill mine has cut to a depth of 1,150 feet (5,340 feet above sea level). The latter shaft is 100 feet higher than the Bullion-Beck, so that, level for level, there is a difference of 100 feet.

The country rock of these mines belongs to the Eureka series, and consists of a number of beds of pure limestone and dolomitic and cherty limestone, for the most part lower in the stratigraphic sequence than those of the Centennial Eureka to the south and the Gemini to the north. All efforts to follow individual beds proved futile, for two reasons: First, because much of the surface is covered with talus and alluvium, and, second, because the beds change lithologically along the strike. Eureka Gulch is covered with a wash which the mine workings show to be, in places, 200 feet deep. The prevailing strike of the strata is N. 15° W., and the dip either vertical or E. at a high angle. Just where the limestone disappears under the wash on the south side of the gulch a sharp bend to the westward was found in the beds.

This was first observed near the contact of the limestone with the underlying quartzite at a point 3,500 feet southwest of the Bullion-Beck shaft, where the strike was N. 75° W. and the dip 80° SW. It was also noted at several localities between this point and the Bullion-Beck shaft, and finally just east of the Beck shaft. On the north side of the gulch the beds corresponding to those of the south side appear to be from 500 to 1,000 feet west of the normal projection of the strike from the south side. Going northward, therefore, there is a sharp westward flexure of the strata in the vicinity of the gulch, which may have produced some E.-W. faulting, but the only evidence of this is one or two parallel E.-W. fissure planes exposed in the bed rock along the north side of the gulch. Below the surface the limestone is so profoundly altered in the zone of the fold that stratigraphic features are obliterated.

The country rock is profoundly fractured throughout the workings, and in directions which correspond closely to those of the other mines. The principal fractures trend N.-S. and N. 35° W. The other fractures trend N. 10° W., N. 10° E., N. 25° E., NE., and E.-W. The N.-S. fractures are found throughout the entire area compassed by the workings of the mines, while the N. 35° W. fractures occur mostly in the area between the shafts. A comparatively small number noted south of the Eureka Hill shaft were adjacent to this intermediate area, while none were observed north of the Bullion-Beck shaft. The N. 10° W. and N. 10° E. fractures are found throughout the mines, as are also the N. 25° E. and the NE. fractures, while the E.-W. fractures occur at both extremities, but not to any great extent in the intermediate area.

The ore bodies follow these fractures and also occur in open spaces made by the slipping of the strata along their bedding planes. There are two principal ore bodies, about 250 feet apart, which have been traced, except for small intervals, from one end to the other of these mines. The eastern one is called the Eureka and the western the Silver Gem. At the south end the ore bodies trend N.-S., but northward they turn gradually to the west until at a point between the two shafts their main course is N. 35° W., whereas at the north end the course varies from N. 5° W. to N. 15° E., still following for the most part N.-S. fractures.

The greatest amount of mineralization and the largest ore bodies occur between the two shafts. In this area bodies of ore having a

A. PLAN OF ORE BODIES, 500 AND 400 FOOT LEVELS, EUREKA HILL AND BULLION-BECK MINES, RESPECTIVELY.
B. PLAN OF ORE BODIES, 600 AND 500 FOOT LEVELS, EUREKA HILL AND BULLION-BECK MINES, RESPECTIVELY.

vertical extent of 500 or 600 feet, a length of from 200 to 500 feet and a width of 100 feet have been found. The two ore bodies unite in many places, so that it is difficult to distinguish between them. Between the two shafts N.–S., N. 25° E., and N. 35° W. ore-bearing fractures are common, the ore which they carry being in the form of spurs from the main mass. At the south end of the mines these two ore bodies are connected by ore branches which trend E.–W. and NE., but they are never as large as in the intermediate area, and the individuality of each ore body is always recognizable. At the north end the ore has been found to be less persistent, and occurs in isolated lenses and pockets along the fracture planes. It can not be stated with certainty that all of the ore found at this end of the mine belongs to one or the other of the two ore bodies before mentioned.

The only known croppings of these ore bodies occur on the hill slopes just south of the Eureka Hill shaft, where there are two ore bodies, the more easterly of which strikes N. 15° W. and has a small parallel spur on its east side, which is connected with the main body by an ore-bearing fissure striking N. 25° E. The second large body trends N.–S., and west of it there is a small parallel spur connecting with the main ore body by an ore-bearing cross fissure, which strikes N W. Between the two fissures at their south end are two smaller ore-bearing fissures which strike a few degrees E. of N.

On the 300-foot level, which corresponds to the 200-foot level of the Bullion-Beck mine, the ore bodies are from 200 to 300 feet west of the croppings. The opportunities afforded for studying the intermediate region were not such as to make it possible to decide the relation of these two ore bodies. It is presumed, however, that they are not directly connected, because the outcrops are far to the east, while below this level the ore bodies are directly under the bodies of ore on this level.

The relations of these two ore bodies can be best understood by reference to Pl. XCV, which shows reproductions of these ore bodies on the 500-foot and 600 foot levels of the Eureka Hill (400 and 500 Bullion-Beck), respectively.

The accompanying sections (figs. 84, 85, 86, and 87) represent somewhat ideally the relations of the Eureka and the Silver Gem ore bodies, and serve to show the relations of the ore bodies to the country rock as well as their width and vertical range.

Fig. 84 is near the south end; fig. 85 is between the Eureka Hill and the Bullion-Beck shafts, and figs. 86 and 87 are north of the Bullion-Beck shaft. The sections face north.

The two ore bodies on the Eureka Hill 300-foot level are 200 feet apart. The Eureka, 1,200 feet south of the Eureka Hill shaft, forms a small body perhaps 50 feet in length. For 650 feet northward the fissure is barren, but at a distance of 550 feet south of the shaft a narrow body of ore was observed which follows a N. 10° W. fissure for 170 feet, then trends N. 20° W. for 50 feet, then N. 10° W. for 250 feet. North of this is an ore body 50 feet long, and just west of it is a considerable body of ore which follows a N. 30° W. fissure for 150 feet and then turns into a N.-S. fissure for 100 feet. North of these are two ore bodies, one on the west and one on the east, which converge to the north. The more westerly follows a N. 10° W. fracture, which may be a part of the Silver Gem ore body; the more easterly begins as a number of narrow bands of quartz which are from a half inch to 2 inches in width and from 1 to 4 inches apart. Pl. XCVI is a reproduction of a photograph of these quartz bands. The ore follows the bedding planes of the limestone for 200 feet, having a course N. 20° W., and then turns into a N. 30° W. fissure, which it follows for at least 100 feet. Immediately north of this are two small bodies of ore which strike N.-S. and probably form the north extension of the two bodies There are two considerable bodies of ore immediately north of the Bullion-Beck shaft which have been followed for a distance of 500 feet northward. These are 100 feet west of the Eureka ore body and form the only known northward continuation of this.

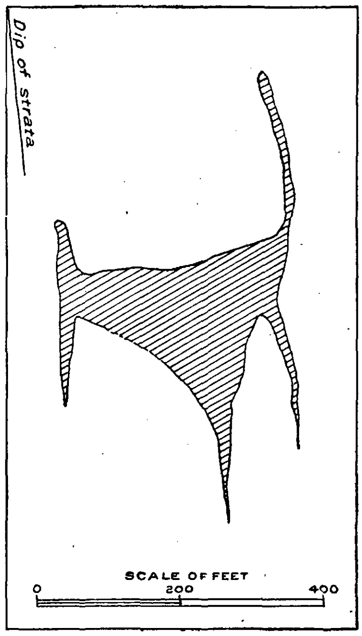


FIG. 84.—Section at south end of Eureka Hill mine, showing. Silver Gem and Eureka ore bodies and an E.-W. connecting ore body.

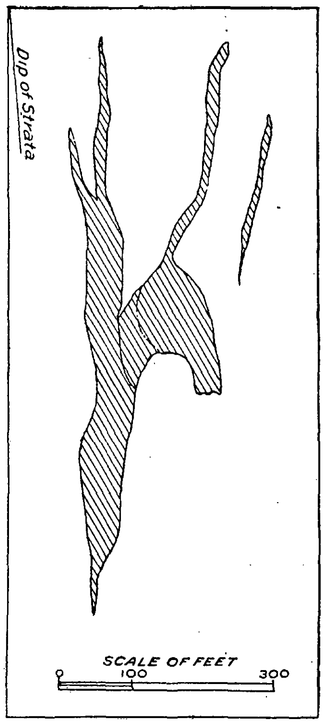
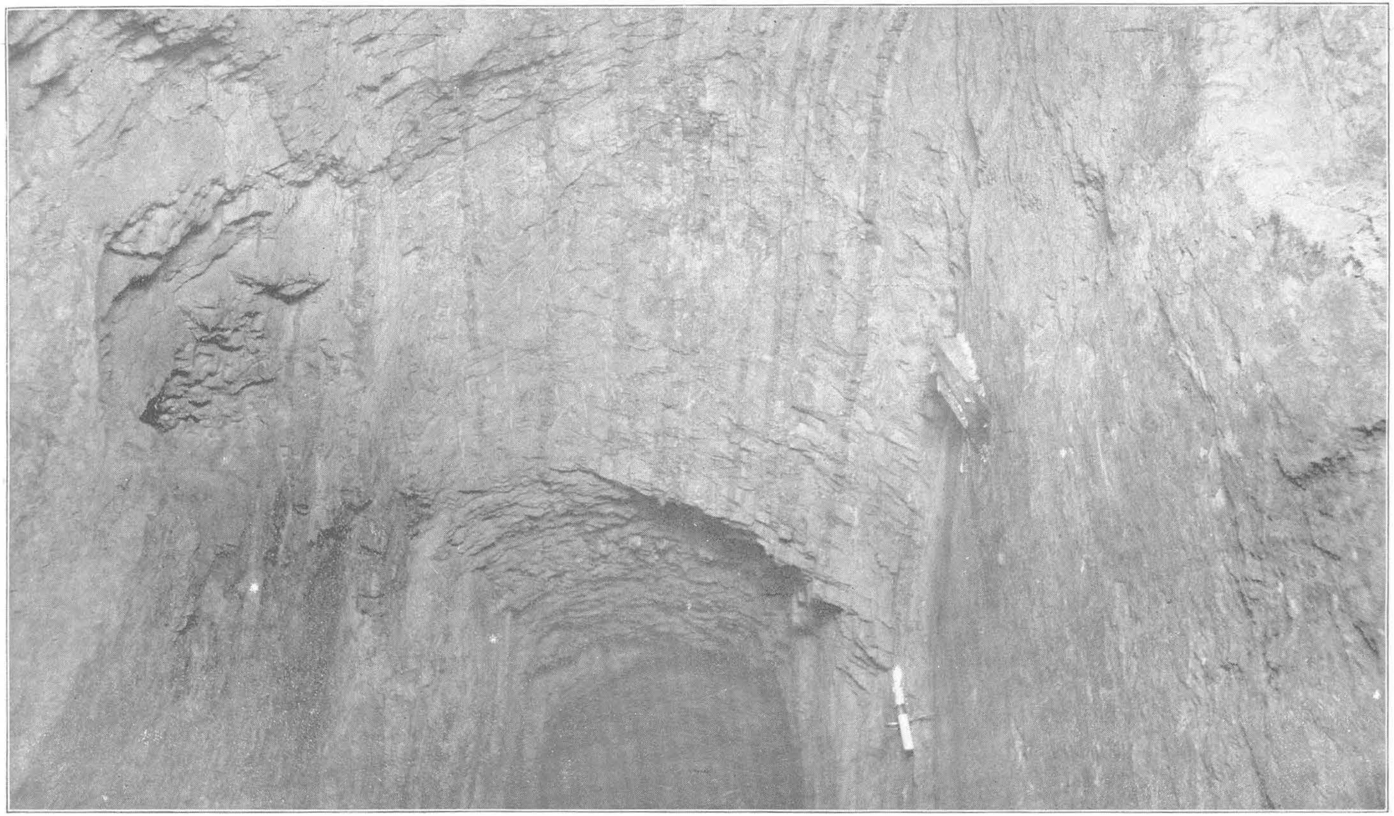


FIG. 85.—Section between Eureka Hill and Bullion-Beck mines, showing Silver Gem and Eureka ore bodies joining.

The Silver Gem ore body, from a point 600 feet south of the Eureka Hill shaft, follows a N. 15° W. fissure for 500 feet and then turns into a N. 30° W. fissure, which it follows for 300 feet, and continues northward intermittently for a distance of 600 feet along N. 20° W. fissures. The most northerly point is 100 feet west of the Bullion-Beck shaft.

On the 400-foot level of the Eureka Hill the Eureka ore body, from



NARROW BANDS OF QUARTZ IN LIMESTONE, THE BEGINNING OF AN ORE BODY, EUREKA HILL MINE.

1,200 feet south of the Eureka Hill shaft to immediately west of the Eureka Hill shaft, is identical with its occurrence on the 300-foot level, except that the ore at the southern end is more continuous than on the level above. North of the Eureka Hill shaft this ore body consists of small intermittent bodies of ore.

The Silver Gem ore body has the same limitations on this level as

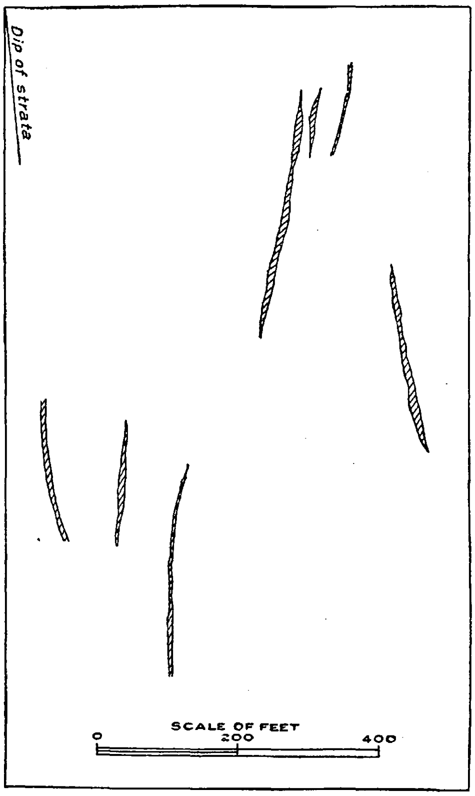


FIG. 86.—Section north of the Bullion-Beck shaft, showing dissemination of the Silver Gem and Eureka ore bodies.

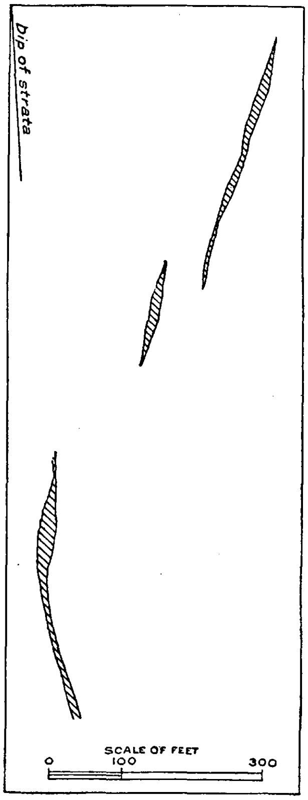


FIG. 87.—Section at north end of Bullion-Beck mine, showing Silver Gem ore body.

on the level above, except that at its northern end it follows a N.–S. fracture.

On the Eureka Hill 500-foot level the Eureka ore body is productive almost continuously, and follows the same fracture plane as on the level above from the south end to a point 300 feet southeast of the Bullion-Beck shaft. North of the shaft two small bodies of ore having the characteristic N.–S. course were noted.

The greatest development of the Silver Gem ore body on this level is between the Bullion-Beck and Eureka Hill shafts. Here there is a great mass of ore and mineralization which follows N. 35° W. fractures, and a number of fractures varying between N. 25° E. and N. 35° W., so that the entire zone between the two ore bodies, the Eureka and the Silver Gem, forms one great ore body. On this level the Silver Gem ore body north of the Bullion-Beck shaft forms three distinct bodies of ore, the most northerly of which is 800 feet from the shaft.

On the Eureka Hill 600-foot level, as shown by the accompanying plan (Pl. XCV, B), the Eureka ore body has two large ore bodies, the first extending from the southern end to a point 450 feet south of the shaft, and the second midway between the Bullion-Beck and Eureka Hill shafts, where it forms a large body of ore 250 feet long, 100 feet wide, and about 100 feet in vertical extent. The country between these two ore shoots is, as far as known, barren.

The Silver Gem ore body has its greatest development on this level and forms continuous bodies of ore, varying locally in width from 1 to 100 feet and extending from the southernmost workings to the Bullion-Beck shaft. South of the Eureka Hill shaft it follows for the most part a N.–S. fissure. There is one well-defined spur extending southeast from the main ore body along a N. 25° W. fissure. From a point west of the Eureka Hill shaft the ore follows a N. 35° W. fissure, which is intersected by a number of N.–S. fissures along which ore extends from the main mass both to the north and to the south. North of the Bullion-Beck shaft two small lenses of ore have been found which follow N. 5° W. and N. 10° W. fissures.

On the 700-foot level the Eureka ore body has not the continuity that has obtained heretofore, whereas the Silver Gem ore body presents the same phenomena as on the level above, and in addition sends off a spur to the west along a N. 25° W. fracture and forms an additional ore body connecting the southern end of the main ore body with the central portion. Just at the Bullion-Beck shaft there is an ore body which follows a N. 25° E. fissure in both directions for a distance of 300 feet. This may be a branch of the Silver Gem ore body which crosses to the vicinity of the Eureka, though there has been no connection on ore. The main ore body of the Silver Gem continues almost without interruption to a point 250 feet west of the Bullion-Beck shaft. Two hundred feet from the north end of this ore body there is a spur which follows almost continuously N. 10° E., N.–S., N. 10° W., N. 25° W., N. 5° E., and N. 10° W. fractures northward in the order given.

On the Eureka Hill 800-foot level the Eureka ore body has not thus far shown any considerable amount of mineralization. The Silver Gem, on this level, at its southern end has two parallel ore bodies which follow N. 15° W. fractures and are connected by a N. 25° E. fracture which, barring a short barren interval, connects these parallel fractures with the main ore body. The ore follows northward from this point along N. 10° W. and N. 20° W. fractures, sending off several shoots to the east on the east side, in one case to the north and in the other cases to the southwest. West of the Bullion-Beck shaft the ore occurs in pipe-like form which follows a N. 10° E. fracture, then an E.-W. fracture westward, then a N.-S. fracture southward, then an E.-W. fracture westward, where it makes a large body of ore and finally connects with the great ore bodies to the north through a small pipe which follows a N.-S. fracture. The northern ore body follows N.-S. and N. 15° E. fractures with but slight interruptions until at its northern end it dies out on a N. 15° W. fracture.

In the levels below this point the ore is localized in chimneys of greater or less dimensions, the country between the various chimneys being practically barren of both ore and mineralization. At the northern end of the Bullion-Beck is such a chimney, which has been followed to a depth of 1,200 feet. The chimney appears to be about 30 feet in diameter and pitches to the south at an angle of 70°.

The Eureka ore body has been found to be the most persistent, the richest, and to contain the largest ore bodies above the 600-foot level. On the 300-foot level is its greatest N.-S. extension, while below this point it narrows rapidly, until on the 800-foot level it forms but two small bodies of ore.

The Silver Gem ore body does not appear at the surface, but from the 300-foot to the 800-foot levels of the Eureka Hill mine forms continuous bodies of ore from the southernmost workings to the Beck shaft. North of the Beck shaft it is first seen definitely on the 500-foot level. From this level it forms nearly continuous but small bodies down to the 900-foot level, but below this, at the northern end at least, its forms only a chimney. The Eureka and the Silver Gem ore bodies appear to merge more or less completely on the 400, 500, and 600 foot levels between the two shafts, but above and below these points they are distinct.

At the southern end of the workings there is an E.-W. ore-bearing fissure which has yielded considerable ore. This fissure connects the two main ore bodies; it is vertical, is ore-bearing on the 400, 500, and 600 foot levels, and is only a connecting link between the two.

On the 700-foot level there was observed a fracture which, from the fact that it carried fragments of ore and country rock, is thought to be of recent origin, but no displacement of the vein could be made out. On the 1,000-foot level were two fractures showing similar phenomena, one south of the Eureka Hill shaft, striking N. 60° E., the other north of the Bullion-Beck shaft, striking N. 30° W. The latter is about 5 feet wide and shows much rounded fine-grained detritus, which is so even in size that it resembles sifted gravel. The only other faults noted were on the 300-foot and the 900-foot levels.

The ores of these mines present all the varied phenomena observed in any of the precious-metal mines of the district. Quartz is the most abundant of the vein minerals. The only other gangue mineral is barite, but original, or unreplaced, calcite forms about 2 per cent of all the ores shipped, and a much higher percentage of the vein matter.

The copper minerals are for the most part oxidation products, such as olivenite, clinoclasite, malachite, azurite, cuprite, and others, all of which are derived from either enargite or tennantite. Galena is abundant, as is also cerussite, while anglesite is found occasionally.

The richest silver ores are very siliceous, the silver forming as a coating on the quartz surfaces and filling the cracks of the rock. The galena and enargite ores carry a moderate amount of silver, but more than the cerussite or secondary copper ores.

Gold is nearly always present, but the proportion is very variable. The ore in the Eureka ore body is essentially silver-lead, while in the Silver Gem copper is nearly as abundant as lead, and at the south end gold has frequently formed a very important factor. The richest ores have been the small shoots extending from the greater masses, while the great bodies have been essentially low grade and very siliceous.

The valuable metals almost invariably occur near the walls of the ore bodies, and as a result the heart of the shoots is very siliceous; especially is this true of the large shoots. Galena is more persistently abundant along the walls than enargite.

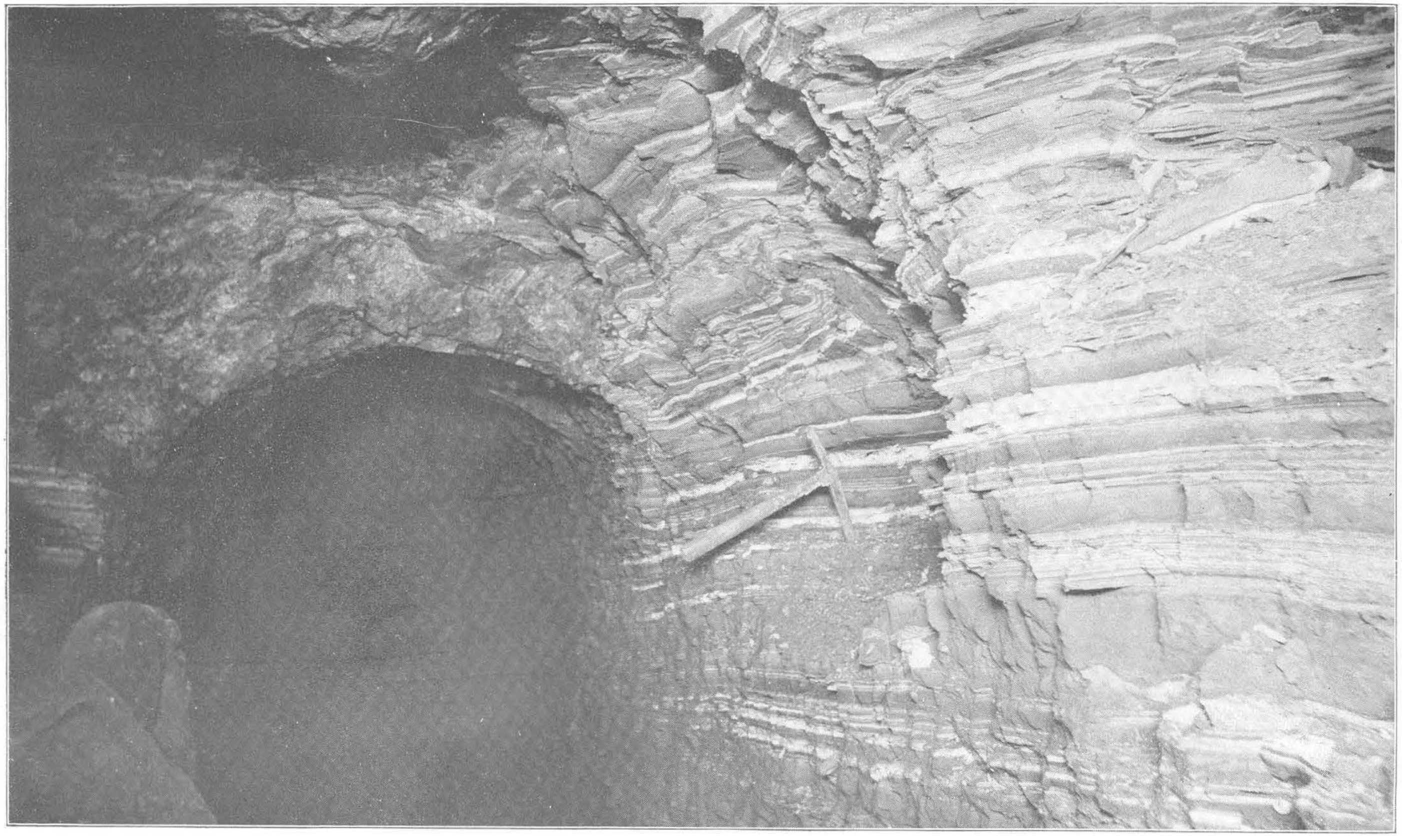
There are in these mines many cave deposits. On the 300-foot level of the Eureka Hill is one composed of finely banded quartz and cerussite, stratified horizontally and at right angles to the bedding planes of the limestone. This material carries about 20 per cent lead carbonate and 15 ounces in silver. Pl. LXXXIV is a reproduction of a photograph of this deposit, which appears to represent an open space filled by mineralizing solutions, passing horizontally along a fracture plane.

On the Bullion-Beck 500 level is a cave deposit composed of soft, clayey material, which appears to be the decomposition product of silicified limestone, and overlies an ore deposit. It is thin bedded, and, like the deposit just described, stratified at right angles to the bedding plane of the limestone. Pl. XCVII is from a photograph of this deposit. This thin-bedded deposit fills a cavity in the limestone which is, in all probability, a space made in the country rock by metasomatosis. Pl. LXXXVI, Fig. B, is a reproduction of a photograph of a specimen of metamorphosed limestone which has been attacked by mineralizing solutions, and the attendant loss in bulk is compensated by well-defined shrinkage cracks. There are many such beds of clay which are so constantly over ore deposits that they are taken by the miners as a very certain indication of ore.

GEMINI MINE.

The Gemini mine joins the Bullion-Beck on the north and east. Its workings have attained a depth of 1,100 feet and extend a few degrees east of north or west of south for over 4,000 feet. The country rock is a fine-grained, bluish-gray limestone belonging to the Eureka formation and striking N. 5° E., with dip E. at an angle of 85°.

The limestone is cut by a series of fractures which correspond closely



SOFT, DECOMPOSED, SILICIFIED LIMESTONE, SHOWING BEDDING AT RIGHT ANGLES TO THE ORIGINAL STRATIFICATION AND FILLING A CAVE IN THE LIMESTONE, BULLION-BECK MINE, 500-FOOT LEVEL.

to those observed in the other mines of the district, the most pronounced trend N. 1° to 10° W., forming a very small angle with the bedding planes of the limestone. They are either vertical or dip E. at a high angle. The other fractures strike N. 80° W., NW., N. 15° E., and E.-W., and are nearly vertical.

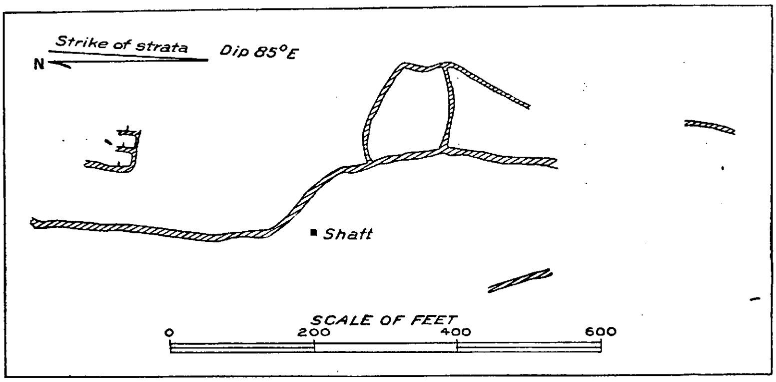


FIG. 88.—Plan of 600-foot level, Gemini mine, showing ore bodies.

The principal ore-bearing fissures are those having courses nearly N.-S. In exceptional cases ore is found in the NW. and the E.-W. fractures.

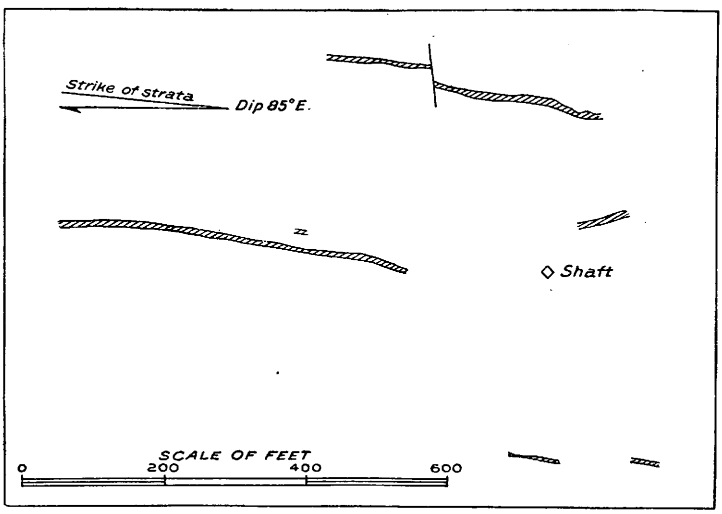


FIG. 89.—Plan of 800-foot level, Gemini mine, showing ore bodies.

The relations of the ore bodies to one another and to the country rock are shown by the accompanying plans (figs. 88 and 89) of the 600-foot and 800-foot levels and the cross section (fig. 90) which is just south of the shaft.

The only ore found above the 400-foot level was in small bunches following N. 5° to 10° W. fractures. On the 500-foot level one important body was found just east of the main shaft. At its southern end it follows a N. 10° W. fracture, then a NW. fracture, and finally was lost in a N.-S. fracture. Its total length was 600 feet. On the 600-foot level the ore body of the 500 is seen, together with at least three parallel ore bodies, and three E.-W. shoots. As shown by the plan, 300 feet north of the shaft is a barren fracture which 85 feet east carried valuable ore for 60 feet. North of this ore body are three N.-S. ore bodies, 30 feet apart, which have yielded ore for 50 feet or more north of the E.-W. ore body. Neither the fractures nor the ore bodies extend south of the E.-W. ore body. The vertical range of these ore bodies is about 100 feet. Pl. XCII is a photograph of the western end of this E.-W. ore body, showing the sharp turn into one of the N.-S. ore bodies. Southeast of the main shaft on this level is a large mineralized zone known as the Packard stope. This was not well seen, owing to the caved condition of the workings, but seems to be characterized by two E.-W. ore-bearing fractures, 100 feet apart, which extend eastward from the main shoot heretofore mentioned and join a second N.-S. ore fracture, the intermediate rocks being greatly broken and the interspaces filled with secondary minerals. The Packard stope has a vertical range of about 200 feet and is for the most part below this level. On the 700 the main shoot has been productive only at the north end, while the N.-S. ore fracture, which on the level above formed the east boundary of the Packard stope, has been ore bearing for several hundred feet north of the main shaft. Two hundred and fifty feet east of the main shaft is a body of ore first discovered in the Bullion-Beck. This trends N.-S. and is vertical for 400 feet, or so far as it is developed. On the 900-foot level the main ore body is represented by a barren clay seam trending N.-S.,

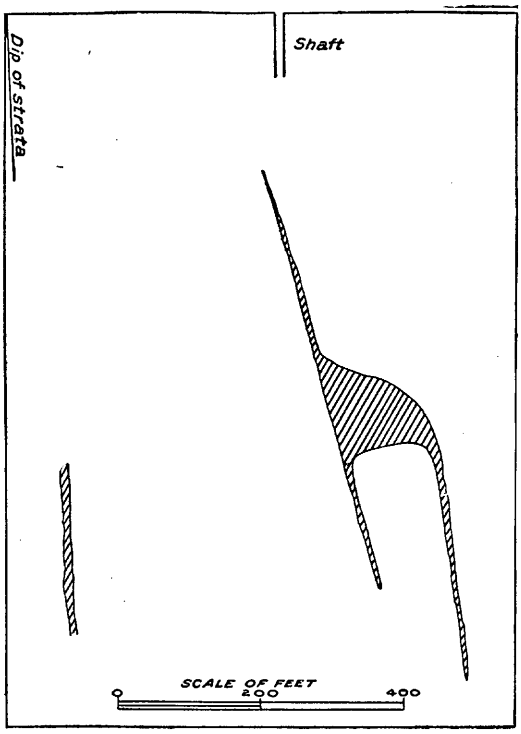


FIG. 90.—Cross-section, Gemini mine, showing form of ore bodies.

while the east ore body is well developed for nearly 600 feet and follows N.-S. and N. 15° E. fractures.

The ore then occurs in fractures parallel to and crossing the bedding of the limestone. They have a vertical range of 100 to 400 feet, rarely exceeding 600 feet in length. They do not appear on the surface. The mineralization extends on both sides of the fracture into the country rock in an irregular way, so that the ore bodies vary from a few inches to several feet in width.

On the 300-foot level, a little more than 2,000 feet north of the main shaft, is an E.-W. fracture, 10 or more feet wide, which contains angular fragments of limestone and rhyolite, some of which were a foot or more in diameter. On the 600-foot level, about 1,000 feet south of the main shaft, is a 10-foot dike of rhyolite which strikes NE. and dips SE. at an angle of 85°. Three hundred feet north of the shaft, on the 1,100-foot level, is an E.-W. fracture of considerable width which shows bowlders of limestone and rhyolite. In the most easterly workings of the 600, 700, and 800 foot levels is a definite contact between rhyolite and limestone which strikes nearly N.-S. The two rocks are separated by a zone of broken material 10 to 20 feet wide, which appears to be a surface talus and is composed of limestone and vein matter partially cemented with rhyolite. It is approximately 300 feet east of the shaft and nearly vertical. It is comparable with the prerhyolite talus observed in the Tetro, Godiva, and Uncle Sam mines.

Faults were noted at the north end of the 600-foot level and near the contact of the rhyolite and limestone on the 800-foot level. These invariably trend nearly E.-W. Other recent movements have been at an angle of only a few degrees with the bedding planes; hence it is not unusual to find open spaces with polished and slickenslided bedding surfaces parallel to the bedding planes.

The mineralization occurred previous to the rhyolite flows, for, along the contact of rhyolite and limestone, fragments of vein matter are found in the talus separating them.

That a limited amount of movement has taken place subsequent to the rhyolite flows is shown by the rhyolite fragments in some of the E.-W. fractures.

The principal gangue mineral is quartz. This is usually black and porous and imitates occasionally the structure of the limestone. Barite is present in limited amount. The metals of commercial value are lead, silver, and gold. Copper is in extremely small quantity.

The Packard stope affords the best example of the separation and secondary concentration of silver in the district. In this stope were great masses of ore valuable only for horn silver. This filled cracks and crevices in the vein and the country rock adjacent to the vein, whereas when the vein has been but little altered it shows a relatively small amount of silver, and this associated for the most part with galena. The processes of oxidation have extended so as to alter the ores completely to a depth of 700 feet and in part to the lowest level.

OTHER MINES IN OR NEAR THE EUREKA ZONE.

WEST CABLE MINE.

This mine is located near the mouth of Cole Canyon, west of Eureka. The shaft, which is 500 feet deep, is in the cherty limestones of the Eureka formation. These strike N. 35° W. and dip E. at a high angle.

The limestone is intersected by fractures, the most common of which trend N. 25° E., N. 75° E., and N. 10° W.

Beyond considerable silicification of the limestone there seems to be no mineralization at this point.

HERKIMER MINE.

This mine is on the southwestern slope of Eureka Peak, north of Robinson. The workings have been extended to a depth of 500 feet. The country rock is Eureka limestone. On the 500-foot level a crosscut extended to the west shows thin beds of dark and light limestone, which has been called "ribbon lime." The strata trend N. 10° W., and are either vertical or dip E. at an angle of 85°. There is also a crosscut to the east, which shows a dark, compact, dolomitic limestone. This limestone has been fractured extensively, the fractures striking N. 15° E. Many of these form large open fissures several hundred feet long. These fissures are stained with iron oxide and occasionally bear quartz.

SOUTHERN EUREKA MINE.

Just east of the Herkimer is the Southern Eureka. It is 500 feet deep. The country rock is gray and bluish dolomitic limestone of the Eureka formation. At the time of the examination crosscutting had not begun. The rock at the bottom of the shaft, however, showed numerous nearly vertical fracture planes, the course of which was N.-S. In sinking the shaft these fractures were encountered constantly, and showed at times a large amount of soft material, which appears to be altered limestone more or less worked over by surface waters. Secondary calcite is abundant in these fissures, but as yet no distinctly vein mineral has been found.

ANNANDALE MINE.

This mine is southeast of the Southern Eureka, and at the time of examination was but 200 feet deep. The country rock is blue dolomite of the Eureka formation and strikes N. 10° W. Its dip is nearly vertical. It is fractured much as in the Southern Eureka and the fracture planes have been filled by calcite in some cases.

TENNESSEE REBEL MINE.

The Tennessee Rebel is on the lower slopes of Eureka Peak, northeast of Robinson. It is 500 feet deep. There has been a limited amount of crosscutting in an east and a west direction from the shaft. These workings show blue-gray impure limestone of the Eureka formation, trending somewhat W. of N. This is cut by numerous N.–S. and N. 15° E. fractures.

OPEX MINE.

Immediately east of the Tennessee Rebel is the Opex. It is 500 feet deep, and, like the Tennessee Rebel, is in a blue-gray limestone or dolomite of the Eureka formation. The crosscut to the west at the bottom of the shaft shows the strike of the country rock to be N. 30° E. and its dip NW., at an angle of 60°. This is intersected by the same series of fissures that are found in the Tennessee Rebel, many of which are very pronounced and form large open spaces. There has been considerable alteration along these fissures, and the deposition of secondary calcite is common.

MINES OF THE MAMMOTH ZONE.

This zone has not been traced as continuously as either the Eureka or the Godiva–Sioux Mountain zones. It is highly probable, however, that it extends from the Eagle mine, which is on the north side of Eureka Peak, near Eagle Canyon, southward through the Grand Central, Mammoth, and Ajax mines to the contact of the limestone and monzonite, or a little more than 8,000 feet. The general trend of the zone is N. 10° W. The ore forms irregular bodies of very variable dimensions. In the Eagle it forms a large vertical mass parallel to the strike of the strata, which crosses their dip planes at an angle of about 15°. In the Grand Central it forms two nearly parallel ore bodies which dip steeply W., crossing the strata at a slight angle; the more westerly one is parallel to the strike of the strata, but the other trends more to the east and at an angle of about 25°.

In the Mammoth the ore forms a large, irregular elliptical-shaped chimney, which pitches northeast at an angle of 70°, and from which in the upper and intermediate workings long branches extend northward.

In the Ajax the ore follows a N.–S. fissure, which splits to the south and forms two nearly parallel ore bodies, the more westerly of which may extend to the Lower Mammoth. The more easterly forms the main dependence of the Ajax mine, and where it is cut by cross fissures very large bodies of ore have been found.

The exploration in Gardiner Canyon, next east from Eagle Canyon, was in search of the northern continuation of the ore bodies of the Mammoth mine, but the large bodies of ore recently found in the Grand Central indicate that the Mammoth ore body passes to the west of Gardiner Gulch. But this does not prove that there has not been mineralization in the vicinity of the canyon.

EAGLE MINE.

This mine, formerly known as the Wyoming, is situated just east of the town of Eureka, near the mouth of Eagle Canyon. The workings have attained a total depth of 400 feet. The ore occurs in the upper beds of the Eureka limestone, which here strike N. 15° W. and dip E. at an angle of 75°.

The fracture planes trend N.-S., N. 25° E. and E.-W. There seems also to have been much movement parallel to the stratification planes of the limestone.

A large body of vein matter has been developed in these workings, which seems to follow for the most part openings parallel to the bedding planes of the limestone, though in several cases it has been found to cross them for short distances. The greater part of the ore has been taken from a pipe-like shoot within the vein zone, which has been followed from the surface to a depth of 400 feet; it is vertical for the first 300 feet, then pitches to the south at an angle of 30° for 60 feet, and where last seen is again vertical.

The vein minerals differ from those found in the majority of the mines, in that there is a great deal more of siliceous, and less of metallic, material. Copper seems to be wanting. While in rare cases ore has been found carrying as much as 15 per cent lead, the great bulk of the ore is valuable for its silver and gold only, the proportion between these two metals being about equal.

GRAND CENTRAL MINE.

This mine is situated southeast of Eureka Peak and between it and the Mammoth mine. The workings, which are 850 feet in depth, are for the most part in Eureka limestone, but it is probable that the extreme easterly workings are in the Godiva limestone. The country rock is so extensively fractured that it is difficult to determine the true bedding; it seems probable, however, that its average strike is N. 25° W. In the upper levels the dip of the beds is SW. at an angle of 45°, and in the lower levels NE. at an angle of 70° to 80°.

The fractures, which are nearly vertical, trend N.-S., N. 25° E., N. 60° E., N. 15° W., and N. 30° W.

There are two bodies of vein matter in the workings of this mine, which where best developed are about 75 feet apart. The more westerly body carries a variable proportion of all of the minerals common to this district. These are distributed, however, in small bunches and pockets so irregularly that they are difficult to follow. The ore seems to have been deposited for the most part along N. 15° W. and N. 30° W. fracture planes, which dip W. at angles varying between 45° and 70°. The more easterly body, which has been the main producer thus far, is siliceous, and carries high values in gold, a little silver, and almost no lead or copper. It follows for the most part a N. 10° E. fracture plane, which dips W. at an angle of 75° or is vertical.

EMERALD MINE.

This mine is located on a southerly spur of Eureka Peak, between the towns of Mammoth and Robinson. The workings have attained a depth of 700 feet. They are all in Eureka limestone, which strikes about N. 55° W. and dips NE. at an angle of 65°. Both gray and cherty dolomitic beds and beds of pure blue limestone have been met in the workings.

The principal fracture planes strike N. 20° W., N. 30° E., and E.-W.

Along the N. 30° E. fractures there has been a great amount of silicification. The silicified rock, or jasperoid, however, preserves the color and structure of the limestone, and in places even shows the bedding. This jasperoid carries a considerable amount of iron oxide, and occasionally small values of gold. It resembles in many ways the deposits found in the limestone near the contact with the igneous rocks, and may have a similar origin. To the east there has been found a small amount of copper ore, but this is always in small masses, greatly shattered, and partially cemented by oxidized minerals.

White crystalline calcite is found throughout the mine, filling fractures and small caves. Pl. XCI is a reproduction of a photograph of a filled fracture, showing not only the pure white calcite, but also angular fragments of unaltered limestone within the calcite.

MAMMOTH MINE.

This mine is at the head of Mammoth Basin. It has been productive from the first, the location having been made on a large, irregular, elliptical-shaped body of ore, which has been followed continuously from the surface to the bottom of the mine, a vertical distance of 1,600 feet.

The country rock is Eureka limestone, which trends somewhat irregularly NW. and SE. and dips NE. at angles varying between 30° and 60°. The following variations in strike were noted on the several levels: 400, N. 55° W.; 600, N. 55° W.; 700, N. 25° W.; 800, E.-W. and N. 70° W.; 1,200, N. 60° W.; Plummer tunnel, NW.

The country rock is a bluish-gray dolomitic limestone having frequent shaly alternations which correspond to the upper beds of this formation; the contact between it and the Godiva limestone is on the hill slope about 200 feet east of the shaft house.

The limestone is profoundly fractured throughout the mine. The most pronounced fractures trend almost due N.-S., and are both ore bearing and non-ore bearing.

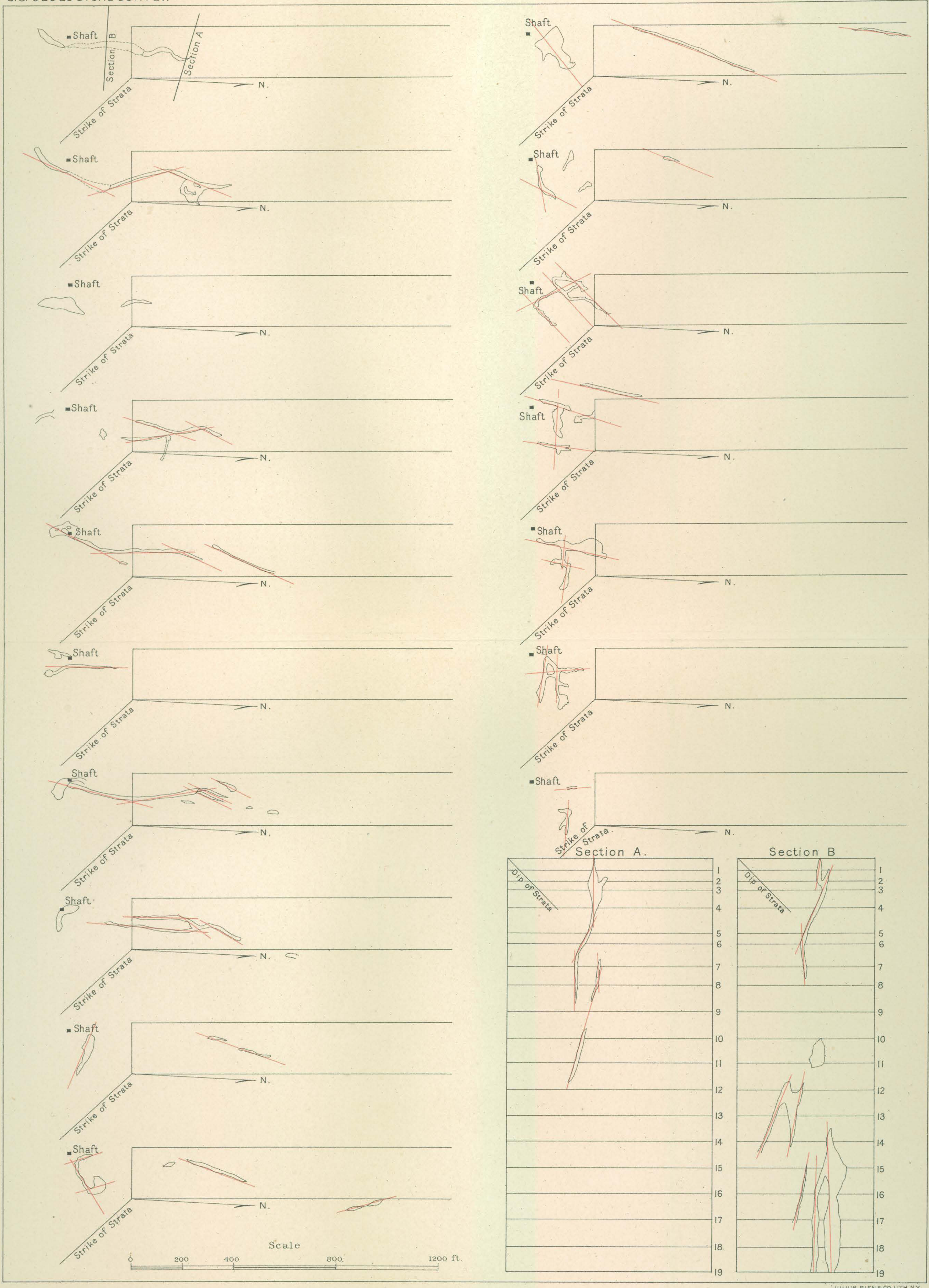
Other fractures trend N. 20° W., N. 15° E., NE., and E.-W. These fractures are numerous, are represented by smooth walls, and carry both solid and broken vein material and secondary calcite. They appear to have both preceded and followed the deposition of the ore.

The vein material follows the fractures in the limestone always at an angle with the bedding. Starting at the surface just south of the shaft is a large, irregular, chimney-like mass, the longer diameter of which trends N. 15° E.; it continues to the bottom of the mine, or to a depth of 1,600 feet, pitching NE. at an angle of 70°. The variation in the form of this chimney in depth can best be judged from the accompanying plate (Pl. XCVIII), which gives horizontal sections of the ore bodies on successive levels. At the surface it is over 100 feet long and 50 feet wide. On the 600-foot level it is 170 feet long and from 5 to 50 feet wide, and follows an E.-W. fracture, dipping N. at an angle of 50°. On the 700-foot level it seems to resemble a C in form, while on the 800-foot level it is 160 feet long and 110 feet wide at the south end. On the 1,000-foot level the whole mass of vein material is 400 by 250 feet. On the 1,100-foot level the vein material follows three N.-S. fractures 150 feet apart, the middle showing an E.-W. cross fracture filled with quartz for a distance of 100 feet eastward. On the 1,200-foot level the form of the vein material is much the same as on the level above, except that the eastern N.-S. body does not appear, or at least has not been developed by the mine workings. On the 1,300-foot level and below the E.-W. ore bodies are more prominent than the N.-S. It is not improbable, however, that additional development may reveal the N.-S. ore bodies.

From this chimney vein matter extends several hundred feet northward along fracture planes, striking N. 15° E., N.-S., and N. 20° W. Section A (Pl. XCVIII) is a cross section of this. One branch extends continuously from the 500-foot level upward to the surface. The others form detached lens-shaped bodies, which show no direct connection with the main chimney. They all follow the same fracture planes as the greater bodies, though barren locally. Pl. XCIII is a view showing the north end of the great chimney at the surface, in which its upper portion is seen to narrow to a small, barren fissure. Section B (Pl. XCVIII), which is near the shaft, shows the main chimney below the 1,000-foot level and the shoots northward from this in the upper levels. It will be seen at once that these shoots are extremely irregular, for the ore bodies do not cut the section continuously—that is, that both the upper and the lower edges of these shoots have a wide vertical range and that the fracture planes are often barren for great distances. Section A (Pl. XCVIII) is near the Finn tunnel, and shows well the two principal shoots from the main chimney, so far as developed.

The minerals of these deposits are quartz, barite, pyrite, galena, enargite, and their oxidation products, together with silver and gold, which give the principal value to the ores. The galena ores carry the greater part of the silver and the siliceous ores the gold. Barite is common to the siliceous ores, and it is in association with the more finely crystalline barite that much of the gold is found. The copper mineral is enargite, which has been pretty generally altered to hydrous-arsenical minerals and copper carbonates. The alteration products carry less silver or gold than the original minerals.

Quartz and jasperoid greatly predominate over the other vein materials. They occur both as a cement to brecciated limestone and replacing the limestone. On the 1,200-foot level, as already described, the vein matter is 300 by 200 feet, much of which is an iron-stained jas-peroid that retains the structure, and at times the color, of the



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MAMMOTH MINE. PLAN OF ORE BODIES BY LEVELS AND CROSS SECTIONS limestone. The crystalline quartz, which is stained with iron, passes by almost insensible degrees into jasperoid. From the 1,200-foot level down the heavy metals occur in two rich shoots near the east side of the great mineralized mass. These shoots differ in that the east one often carries high values in gold and is very siliceous, while the one to the west carries less gold and, besides being less siliceous, contains considerable lead.

The processes of oxidation have acted extensively throughout the mine and conceal to a great extent the original structure of these deposits.

At the north end of the 800-foot level is a narrow body of ore which carries but little silica and in color and texture resembles the limestone closely. This is apparently a direct replacement of the limestone country rock by finely divided or unaltered sulphides. The greatest amount of copper has been found in a large isolated body on the west side of the 400-foot level north, which has no traceable connection with other ore, but is immediately under large ore bodies. This is undoubtedly a secondary deposit, and, like them, carried but little silver, lead, or gold.

There is considerable brecciation of the ore bodies, which rarely extends far into the country rock, and on the 1,350-foot level is a large, open cave, 50 feet long, 25 feet wide, and 30 feet high, the floor of which is composed of broken fragments of vein and country rock. Such fracturing and open spaces appear to result from a loss in bulk of the country rock through the substitution of vein for country rock, followed by slight surficial movements which have caused the vein matter to break and settle. In the westerly workings is a mass of breccia popularly known as "The Dike." This consists of a zone of limestone 20 to 100 feet across, composed of angular fragments varying in size from the smallest possible up to a foot or more. In this there is no secondary alteration, but little, if any, subsequent calcite, and no ore cement. The boundaries are irregular, and the vertical distribution shows that it is not continuous throughout the mine, though found in all the westerly workings. It is the most recent of all the phenomena noted, and represents an earth movement of considerable intensity and short duration.

SIOUX-AJAX TUNNEL.

This tunnel is located at the head of Mammoth Basin, north of the Ajax mine. It is being driven eastward into Mammoth Mountain, and, at the time of this writing, is somewhat over 3,000 feet in length. The tunnel is for the most part in the beds of the Eureka formation, but the last few hundred feet are in Godiva limestone. The strata are extensively cut up by fractures, so that the strike and dip are hard to determine. At the mouth of the tunnel the strike seems to be about N.-S. and the dip about 20° E. The strike of the beds throughout the tunnel is probably about the same as that noted for the mouth, whereas the dip probably varies between 20° and 70° E., averaging 45°.

The principal fractures trend N.-S., N. 15° E., N. 25° E., NE., N. 15° W., and E.-W. These fractures usually appear in groups of three or more and are nearly vertical. They have been the seat of much alteration in the limestone and the channels for waters bearing both carbonate of lime and silica. As a result of these various processes we find many caves in the limestone, or the limestone replaced by silica, forming jasperoid, or finally crystalline calcite filling the fracture planes and solidifying the rock mass.

There are three more important zones of silicification, one near the mouth of the tunnel, under the croppings of the Ajax vein; a second about 1,300 feet from the mouth of the tunnel, which has been called the Cleveland, and a third about 2,500 feet from the mouth of the tunnel, to which no name has been given.

On the Ajax fissure much ore has been found in the Ajax mine; on the Cleveland and other fissures no ore has been found, probably because of the lack of development.

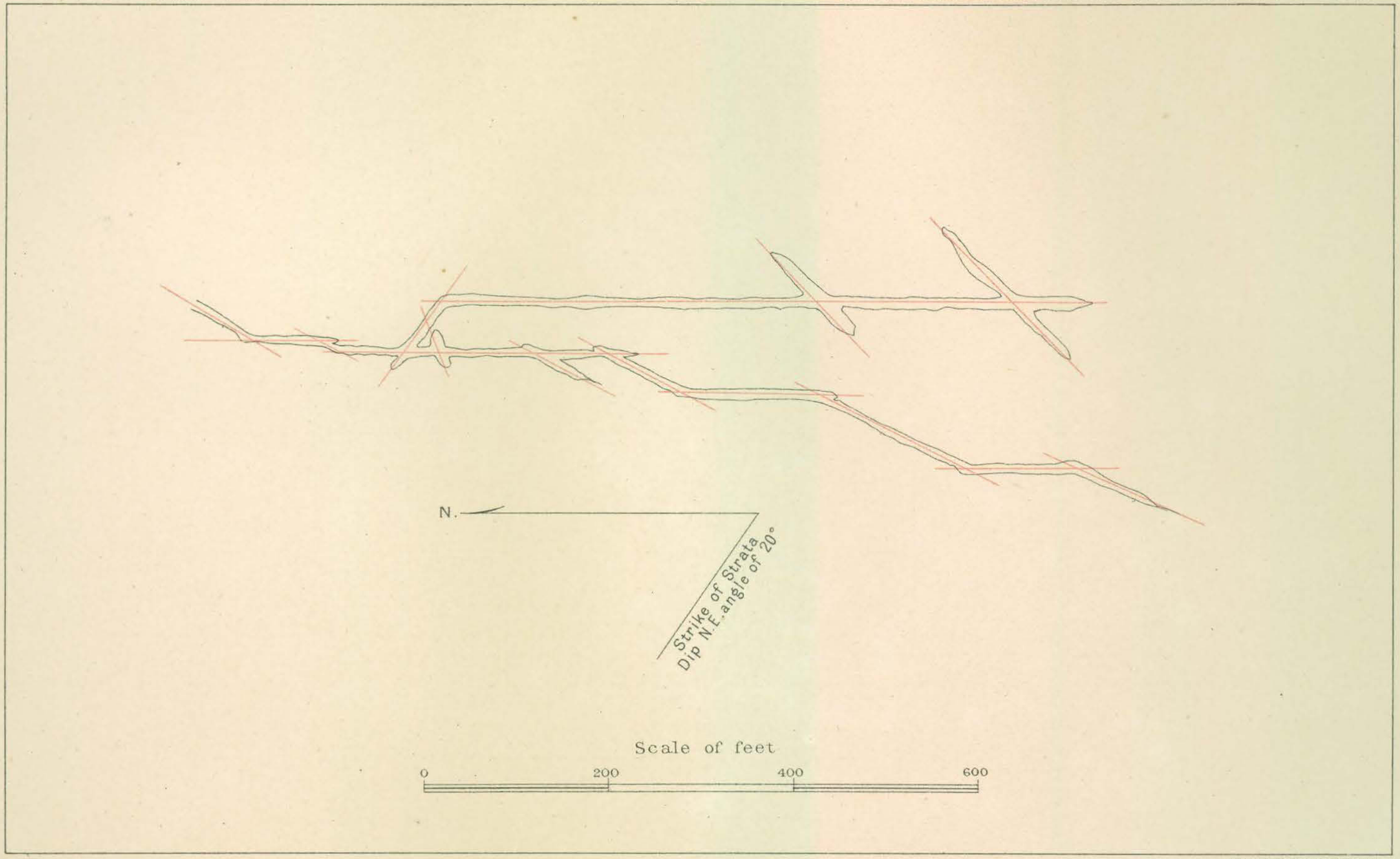
In the more easterly workings of this tunnel the limestone is occasionally coated with native sulphur, thus indicating probable fumarolic action connected with the volcanic activity, though it may result from the decomposition of pyrite, which has been seen occasionally in this limestone. In either case it would seem unwise to consider this an indication of precious-metal deposits.

AJAX MINE.

The Ajax, formerly the Copperopolis and the American Eagle, is situated south of the Mammoth mine and at the head of Mammoth Basin. A tunnel extends southeast into the hillside, and at its end, a point 187 feet below the surface, a shaft has been sunk 400 feet. North and south of the tunnel entrance are many open workings in the hill slopes. The country rock is Eureka limestone, thin bedded as a rule, and metamorphosed locally. On the 400-foot level these beds strike N. 55° W. and dip NE. at an angle of 20°, this being the average strike and dip of the strata in this mine.

The rocks are intersected by many fractures, most of which are ore bearing, though most of the ore is secondary or oxide ore. The most persistent fractures strike N.-S. and dip W. at angles varying between 70° and 90°. Other fractures trend N. 25° E., N. 35° E., N. 65° E., and N. 55° W.

Just west of the U. S. L. M. No. 1, at the north end of the workings, vein matter is first noted, that can be traced continuously to the southern extremity of the mine. The accompanying diagram (Pl. XCIX) shows the relation of the fissures to each other and of the mineralization to the fissures. The first vein matter is found in a fissure striking N. 35° E. A short distance southwest it intersects a N.-S. fracture,



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AJAX MINE. DIAGRAMMATIC PLAN OF ORE BODIES and following this south 75 feet turns into a N. 25° E. fracture, which it follows south 25 feet, only to return to a N.–S. fracture. Continuing in a southerly direction along this fissure for 70 feet, it splits, one part following a N. 55° W. fissure to the southeast for 100 feet, where it turns into a N.–S. fracture and connects southward with the main workings of the mine; the second part continuing southward along N.–S. and N. 25° E. fissures until it finally ceases to carry any valuable vein matter, though it is thought to extend as a barren fissure to the contact of the limestone and the monzonite.

In the surface workings the greater portion of the mineralization extends along the main N.–S. fractures. Where other fractures intersect these main fractures the mineralization usually follows the former for a short distance and then returns to another of the main fissures. There appear to be but two important exceptions to this mode of occurrence, which are where NE. fissures intersect the main fracture. The vein matter does not leave the main fracture, but sends off shoots to the northeast and southwest for distances of 100 feet or more. It is along these NE. fractures that the bulk of the ore has been found in the lower workings of this mine. Two such fractures were seen on the surface which are identical with the east and the west fissures developed in the mine. They are 200 feet apart at the surface, but owing to the shallow easterly dip in the upper portion of the easterly one, they are 400 feet apart on the lowest level. Midway between is a persistent N.–S. fissure, which has been productive throughout the mine.

Where the westerly of the NE. fissures appears at the surface, N.–S. and N. 15° E. fissures were noted, both of which stand nearly vertical, while the NE. fissure dips E. at angles varying from 45° to 60°. Where the easterly NE. fissure appears at the surface, not only was a N.–S. fissure plainly visible, but also a N. 25° E., and, as in the previous case, the NE. fissure had a shallow E. dip. In the lower workings, however, these two NE. fissures stand vertical, or dip W. at an angle of not less than 70°.

The ore extends but a few feet beyond any intersection, except in the main ore channel. Mineralization at the intersection of the NE., N.–S., and N. 25° E. fractures has formed large bodies of ore with irregular boundaries extending in many horizontal shoots for considerable distances beyond the main mass of the ore.

The vein minerals are those common to all the mines of the district, especially the Mammoth, but the proportion of copper to other minerals is much greater than in the Mammoth.

The separation and concentration of the different metals—lead, silver, copper, iron, and gold—has been even more complete than in the Mammoth. These metals are found so intimately associated in the veins in the lower levels, as to leave no room for doubt as to their common origin. The numberless open spaces adjacent to the veins have been formed largely by dissolution of the country rock, and have furnished ample space for the redeposition of the decomposition products of the original deposits. Several such caves were found only partially filled which afforded excellent opportunities for study. In one of these, stalactites of hydrous oxide of iron are suspended from rods of similar material which often attain a diameter of several inches and a length of 2 or 3 feet. These rods being inclined at various angles, the stalactites, which are necessarily vertical, hang from the rods at various angles. The rods are hollow, but have the cast of selenite crystals; moreover, several remnants of selenite were found in them. They are also frequently coated with crystals of calcite. It seems certain that selenite crystallized in long, slender, prismatic crystals in the open caves, which it crossed at various angles, and that subsequently these crystals formed paths for waters charged with iron, which precipitated in the open space of the caves, and that at some period after this deposit was well advanced the gypsum was removed. Last of all, calcite was deposited to a limited extent on all exposed surfaces. Fig. 91 is a

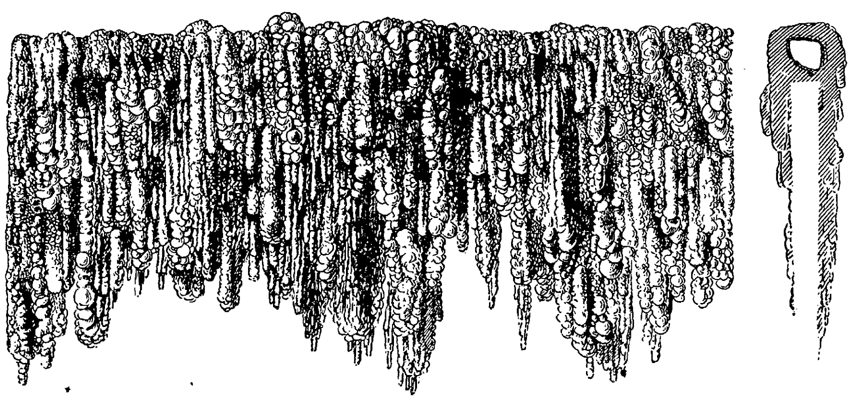

FIG. 91.—Stalactites of hematite and limonite suspended from rods of the same materials, Ajax mine. The hollow space in the section was originally filled with a slender prismatic crystal of selenite.

reproduction of one of these stalactites of iron, and shows the inclination of the stalactite to the rod. The separate diagram on the right of fig. 91 is a cross section of this rod, and shows the cast of the selenite crystal.

In other caves incrustations of small stalactites and stalagmites of olivenite, machacite, and other products of decomposition from enargite were found, which were in many cases coated with calcite.

It is but a step from the cave lined with the products of oxidation to the caves filled with these products. It seems obvious that those deposits which contain principally one metal and occur in places which can not be truly said to belong to the fissure systems are subsequent separations due to oxidation, a process which goes on unequally, owing to differences of stability and solubility of the various metallic compounds. This process is exceptionally well made out for the changes in the copper minerals, because of the distinct colors which these minerals have and the fact that they are the first to decompose. The silver-lead minerals follow the same law, but the discrimination is much harder, because of the stability of galena and the lack of vivid colors. The gold content of the vein deposits at best is small, and since gold is not easily attacked by chemicals, its rearrangement in or near the vein is extremely limited.

LOWER MAMMOTH MINE.

The Lower Mammoth is just south of Mammoth, at the foot of the mountain of the same name. A tunnel has been run into the mountain almost due east for a distance of about 675 feet. For the first 300 feet this tunnel is in Eureka limestone. At this point a dike of monzonite 25 feet wide was cut. The rest of the workings are in Eureka limestone, all of which has been extensively metamorphosed. At a distance of 600 feet from the mouth is a zone of finely broken, angular limestone, about 20 feet across, which is locally called "The Dike." Such a phenomenon was seen in the Mammoth, but that there is any similarity between these two, other than a genetic relation, is not at all proved. At a distance of 650 feet from the mouth of the tunnel a pronounced fissure was found in the solid limestone, upon which a shaft has been sunk. This appears to have been a seat of ore deposition, for in it are found quartz, barite, galena, and copper carbonates, carrying marketable values of silver and gold. This vein has not been developed extensively as yet. Its course is N.-S., and it stands nearly vertical. The vein matter varies in width from a mere seam to several feet and is greatly oxidized.

GARDINER CANYON.

Considerable exploration of the Godiva limestone has been carried on in the gulch, notably by the Medea, the Plutus, and the Marion. The limestone is cut by many fissures, the principal ones of which trend N. 15° E., NE., and NW. Occasionally the limestone is cut by small seams of quartz, and in other cases by small clay seams.

Selected fragments from the talus have been found to carry from 0.1 to 0.17 ounce in gold per ton, but the limestone in place, as far as tested, is barren, except possibly some early shipments of silver ore reported to have been made from near the Marion.

MINES OF THE GODIVA-SIOUX MOUNTAIN ZONE.

INTRODUCTION.

The mines of this ore zone form an almost continuous chain of openings from the northern end of Godiva Mountain to the southern end of Mammoth Mountain, where the monzonite breaks across the beds of stratified rocks. It follows the east flanks of Godiva and Sioux mountains. The Godiva and the Uncle Sam are probably on the same ore body, which, however, is not connected with that of the Humbug, though both are on the same fracture zone. From the Humbug to the Utah mine the ore, from surface indications, appears to be continuous, but it has not been traced by mine workings. From the Utah through the Sioux and Northern Spy mines to the Carissa the ore extends unbrokenly. From this point southwest there are several ore bodies in parallel fissures within the general fracture zone, but as far as known they are not connected with one another. It is doubtful, moreover, if there is any connection between the ore bodies in this portion of the zone and those to the north.

TETRO MINE.

The Tetro mine is on the northwest slope of Godiva Mountain. It is worked through a tunnel having a general southeasterly course, the first 275 feet of which are in rhyolite, the rest of the workings, which are in the nature of crosscut exploration to the northeast and southwest, being in Godiva limestone. The rhyolite is greatly altered, apparently by the action of surface waters, and rests against a talus of limestone fragments 65 feet thick, under which is a narrow zone of comparatively solid limestone, then 50 feet of shattered rock, which overlies limestone heavily sheeted parallel to the general contact of limestone and rhyolite. The talus is similar in every respect to that seen at the base of any steep limestone slope. Many of the fragments are brecciated limestone cemented with calcite and quartz. They also present rounded surfaces, such as result from weathering. This contact is marked on the present surface by a change of slope; the limestone has steep, sharp slopes, covered with a great amount of talus, whereas the rhyolite forms a smooth, slightly inclined surface, composed of coarse rhyolitic sand and scattering bowlders that have rolled down from the limestone cliffs. The contact on the surface trends N. 10° E., but where seen underground strikes N. 50° E. (See Pl. LXXXII).

Near the rhyolite in the tunnel and to the southwest the limestone strikes N. 75° E., differing from the normal strike, which, in the northeast workings, is N. 25° W. The dip is always E. or S., at an angle of 65° to 70°.

This limestone, which belongs to the Godiva series, is dark blue or black, and somewhat silicified in places, so that it resembles jasperoid. Some of the beds contain thin lenses of interbedded chert.

The fractures in the limestone strike N.-S., N. 35° W., and N. 75° E. They are nearly vertical, and in some cases a foot or two in width, the spaces between the walls being in some cases open, and in others filled with fragments of limestone. The N. 75° E. fissures are mostly near the contact with the rhyolite.

Secondary calcite is abundant in all these fissures, but at the time of examination no ore had been found in place.

GODIVA MINE.

This mine is situated at the extreme north end of the mountain of the same name. It is worked through a shaft and tunnel, the greatest depth of the workings being 350 feet. The tunnel, which runs southward, intersects the shaft at a distance of 560 feet from the mouth and 200 feet below the collar of the shaft. For the first 250 feet the tunnel is in highly altered rhyolite. The rest of the workings are in Godiva limestone, which apparently strikes N. 15° W. and dips E. at an angle of 70°.

There are numberless fractures in the limestone, the most important of which strike N.-S. and N. 30° W. From the contact of the rhyolite to a point somewhat south of the shaft is a zone of profoundly fractured and altered rock, much of which has been silicified.

The ore follows fractures parallel to the bedding planes of the limestone, and also fractures having a course nearly N.-S., but ends abruptly where it meets the rhyolite. It is separated from the rhyolite by sharp, well-defined walls, or by a talus composed of both country-rock and ore.

The abrupt termination of the ore at the contact with the rhyolite, either in talus or sharp walls, indicates clearly that it is older than the rhyolite.

The ore body is composed essentially of silicified limestone, cerargyrite, and cerussite, and has been valuable principally for its silver-lead content, though small bod'es of gold ore have been found in it. Copper seems to be entirely wanting.

The limestone along the contact with the rhyolite has been silicified, and as this resembles the silicification produced by the vein action, it is oftentimes difficult to distinguish between vein matter and limestone that has been altered by hydrothermal processes consequent on the extrusion of the rhyoli e.

UNCLE SAM MINE.

This mine is located on the north slope of Godiva Mountain, near the Godiva mine. It is worked through a shaft and two tunnels which extend to the south. The main tunnel was in blue limestone of the Godiva series, and at the time of examination was extended to the south 325 feet. The workings of the tunnel level have followed fractures in the country-rock, which trend N. 30° W., N. 15° W., N. 20° E., NE., and E.-W.

The lower tunnel is 175 feet below the upper one, its mouth being 400 feet north. Rhyolite was found for 425 feet. The next 230 feet is an altered mass which seems to be made up of limestone, vein material, and rhyolite, and beyond this is solid siliceous limestone. This mixed zone, which is in the nature of a talus, partially cemented with rhyolite, indicates that the ore deposition occurred in the limestone prior to the extrusion of the rhyolite. Similar proofs were found in the Godiva mine.

At the end of the upper tunnel a small streak of galena ore was cut, striking E.-W. This is followed westward to the side line, and shows a strong shoot of galena in the face of the drift. To the east this shoot was lost a short distance above the level and east of the tunnel.

The principal ore body occurs in a chimney which is cut in the drift 76 feet east of the main tunnel. It is very irregular. Its greatest length is not more than 100 feet and its width from 4 to 6 feet. Its course varies from N.–S. to N. 25° W. and N. 55° W., and it pitches SE. at an angle of 50°. At the time of examination it had been followed for a depth of 150 feet below the tunnel.

The ore shoot is essentially pure galena, averaging for over 2,000 tons 65.5 per cent lead, 2 per cent iron, 4 per cent zinc, the rest of the vein material being carbonate of lime and sulphur. The demarcation of the ore shoot is strong; the wall rocks are comparatively unaltered. There is but little oxidation.

HUMBUG MINE.

This mine is located on the east slopes of Godiva Mountain, near its northern end, at an elevation of 7,458 feet. The mine is in rocks of the Godiva and Humbug formations. It is worked through two tunnels, and at the time of examination a winze had been sunk 100 feet below the lower tunnel, which is 100 feet below the upper tunnel. The contact between the two formations is 160 feet from the mouth of the upper tunnel and 300 feet from the mouth of the lower tunnel. The strike of this contact is N.–S. and the dip vertical or slightly E. The section of the Humbug series exposed in these two tunnels shows it to consist of a very compact, siliceous, black limestone, without beds of distinct sandstone. The limestone of the Godiva series is coarsely crystalline and of a light-blue color, which resembles the limestone seen in the Sioux-Utah, but the base of the Humbug series is materially different in the latter mine.

The country rock is fractured extensively, the principal fractures trending N.–S., E.–W. and NE. These correspond closely with the fractures observed in the Sioux-Utah.

There is but one vein in these workings. This was first found on the surface about 200 feet above the upper tunnel. The vein as a whole trends N.–S. It has not the great length of the Sioux-Utah vein, but, so far as developed, seems to be a chimney-like shoot pitching sharply S., and is largest at the intersection of two or more fissures.

The ore is composed of quartz, barite, argentiferous galena, and their oxidation products, freely stained with iron. There is so little copper in the vein that no allowance is made for this in the ore market. The ore is usually rich in silver and gold, the content in silver being highest in the presence of galena. Cerargyrite is also found. The gold is more abundant in the lower workings, and is associated with quartz.

SIOUX AND UTAH MINES.

These two mines, which are worked in common, are situated on the east slope of Mammoth and Godiva mountains. Their ore body is connected on the north with that of the Humbug and on the south with that of the Northern Spy mine. They are worked through the Sioux tunnel at the south and the Utah tunnel at the north end, respectively, each of which is driven westward from the eastern face of the mountain. The sedimentary beds here strike N.–S., and their average dip along the ore zone is 45° E.; to the westward the dip steepens to 90°, and to the eastward it shallows to 25°, or even to horizontality.

The best section is afforded by the Sioux tunnel, which cuts talus, then 50 feet of sandstone, next 250 of limestone and 20 feet of sandstone, all belonging to the Humbug series; beneath these it enters coarsely crystalline light-blue limestone of the Godiva formation, reaching the ore body at about 550 feet from the mouth of the tunnel.

The principal fractures are N.–S., N. 15° E., N. 30° W., and E.–W. These fractures are, for the most part, vertical.

The ore body thus far developed is in the nature of a nearly horizontal shoot, which rises gradually from the level of the Sioux and the Utah tunnels to a height of nearly 200 feet above this level between them. South of the Sioux tunnel it keeps the same level. It follows generally a N.–S. direction, but is set off on the other fracture courses common to these mines from one to another, but prevailingly to N.–S. planes. When it follows N.–S. planes it has generally a rather shallow dip to the eastward, but on the cross fissure it is nearly vertical. Where the dip is shallow the ore solutions probably followed stratification planes or planes of movement making but a slight angle with the bedding of the limestone.

To reach the position of this ore shoot, however, the ore solutions appear to have ascended along vertical fractures also parallel to the bedding and to the east. Such is shown to be the case in the Northern Spy mine, next south, but where these ore-bearing fissures are in the Sioux and the Utah remains yet to be determined.

The fact that the ore is always shallow on all planes parallel in strike to the stratification, and always steep on the intersecting planes, seems to indicate that the relation of fissures and bedding planes is important.

Certain vertical cracks immediately under the ore bodies that are filled either with oxidation products, such as cerussite and iron oxide, or with fragments of limestone, are not, as has been sometimes supposed, planes of deposition or channels for original vein solutions, and do not form, in the strict sense, feeders to the main rich ore body.

The ore body varies from 2 to 50 feet in width, and forms great chambers and irregular-shaped ore bodies nearly parallel to the planes of stratification or of fissuring.

There appears to have been in the Utah a little faulting. The amount of displacement is not known. Judging from surface contact of the Godiva and the Humbug series, however, it can not be great. Before admitting the presence of a fault on a vein of this character, it is necessary, first, to show that the vein has not turned into an intersecting fissure, and, second, to discriminate between original and secondary minerals.

In a region so subject to oxidation the vein is thoroughly oxidized; the material taken up by the surface waters is, at least in part, reprecipitated before these waters find their permanent level, so that secondary deposits, such as limonite, cerussite, malachite, etc., are common, and usually die out slowly in such a way as to suggest faulting.

The minerals of this vein are similar in every respect to those of the northern end of the Northern Spy and the Humbug mines. The gangue minerals are quartz and barite. The metallic minerals are hematite and limonite, cerussite, galena, argentite, cerargyrite, some form of gold, and a small amount of enargite or its oxidation products. The quartz is most abundant in the center of the vein, the metallic minerals forming next the wall rocks. Barite is more often associated with quartz than with the other minerals. These minerals are frequently banded parallel to the wall rocks.

Several specimens were found consisting of pipe-like masses of quartz and barite about 8 by 10 inches in diameter. These have a concentric structure and are made up of spongy layers of quartz and barite, the top rounding out and overlapping the lower portions, so that they resemble the mouths of geysers.

NORTHERN SPY MINE.

This mine, which is southwest of the Sioux mine, on the east slope of Mammoth Mountain, establishes the continuity of this ore body from the Carissa on the south to the Sioux on the north. It is worked by a tunnel and two shafts. The tunnel is at the south end and is driven southward in the ore body. The main shaft, which is 700 feet deep, is about midway between the Sioux and the Carissa, while the other shaft is at the north end. Like the tunnel, the shafts are on the ore body.

The country rock is Godiva limestone, whose bedding planes can not be recognized. It probably has a N.-S. strike at the north end and a NW.-SE. strike at the south end, the change in strike at the south end being due in part to the fact that the south end of the mine is near where the beds turn around the end of the synclinal axis and in part to the fact that the Spy-Ajax fault, which has displaced the southern end of the syncline to the east 1,000 feet, crosses the strata near the main shaft.

The fractures observed in the workings are principally N. 15° E., N. 35° E., E.-W., and N. 20° W. fractures.

The ore trends mostly N. 15° E., but locally bends and parallels the other fracture directions. At the northern end it follows vertical planes or parallels the bedding of the limestone, as in the Sioux and the Utah mines. At the southern end, however, it follows fissures which are either vertical or dip W. at a high angle. Moreover, in several places the ore body, where parallel to the bedding, bends over and is vertical, crossing the beds at a high angle. In other places it continues in a vertical fracture to the surface, but sends off spurs parallel, or nearly so, to the bedding planes (fig. 92). The ore body is rarely more than 10 feet wide, and averages possibly 2 feet.

At the northern end the ores are siliceous, containing cerargyrite and cerusite, valuable minerals. At the southern end and in the lower workings the ore is not so siliceous and contains more copper than lead. It is always completely oxidized. There has been some recent disturbance, for in the tunnel at the southern end the ore body is brecciated and recemented with malachite and chrysocolla, and at a point about 100 feet below the surface the skull of a small rodent of recent age was found.

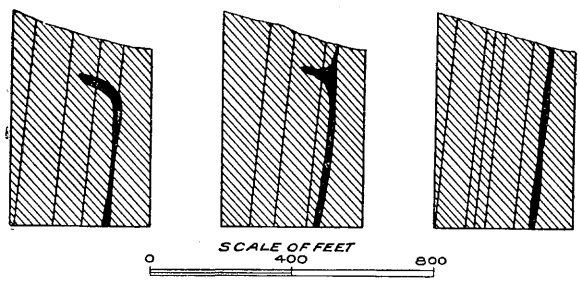

FIG. 92.—Cross-sections, Northern Spy mine, showing relation of ore to limestone and fissures.

In the lowest level there is a large open cave, extending 150 feet below the 700-foot level, which seems to have resulted from disturbances of the country rock, the whole mass having settled into the spaces produced either by the fractures or by loss of bulk in the rock mass due to the substitution of vein matter for limestone. There is in the vicinity of this cave a very considerable amount of iron oxide, metallic copper, and malachite, which has undoubtedly been brought thither from the original ore body.

CARISSA MINE.

The Carissa, which adjoins the Northern Spy, is just north of Sioux Pass, on the southeast slopes of Mammoth Mountain. It is opened by a single shaft 250 feet deep and by several short tunnels. It is in Godiva limestone, which strikes N. 25° W. and dips E. at an angle of 25°.

The fractures are N. 15° E., N. 65° E., and N.-S. The ore follows generally the N. 15° E. fissure, but vein matter is found also at the other places, and at the southern end passes out of the mine on a N. 65° E. fissure. Just north of the shaft a spur extends from the main ore body to the south, but this has not proved profitable.

The ore body is vertical for the first 75 feet from the surface, and below this dips W. at an angle of 60°.

The normal width of the vein is about 3 feet. Just south of the shaft, at the crossing of a N. 15° E. and a N. 65° E. fissure, it widens to 30 feet for a distance along the vein of 55 feet. The outer portions of this abnormal ore body are composed of rich copper ore, and the center is a solid mass of almost pure barite, about 20 feet thick. While there is some argentiferous galena locally, copper is the predominating metal, and makes up from 5 to 50 per cent of the ore. The copper is in the form of sulphide and sulpharsenide, which by oxidation have given rise to a great number of rare hydrous-arsenical copper minerals. Silver and gold are found principally in streaks around large masses of barite, rarely within them. Oxidation is by no means complete, though all of the ores are extensively oxidized, and completely so to a depth of 100 feet.

RED ROSE MINE.

This mine is situated on the southern slopes of Mammoth Peak, a short distance west of Sioux Pass. The main workings are a tunnel running northeast and having a shaft 500 feet deep at the end. The ore bodies have also been prospected by short tunnels below the main tunnel and by a number of prospect shafts of slight depth. The country rock is metamorphosed limestone of the Eureka series, which here strikes NW.-SE. and dips NE. at an angle of 45°.

Owing to a temporary suspension of operations, this mine was examined only on the surface. There appears to be one large body of ore striking N. 15° E., which extends northward from the gulch below the main tunnel for 700 feet; thence its course is northeast for 600 feet, then N. 15° E. for 150 feet to a point where it forks, part of the ore body continuing to the north and dying out, and the rest, which is the main body, trending successively N. 35° E., N. 15° E., and N. 35° E. for a distance of 500 feet. At the main tunnel there is a small spur which extends southwest on a N. 25° E. fissure for 300 feet, and finally a parallel ore body on the east side, also below the main tunnel.

The croppings at the main tunnel stand above the general surface of the ground 10 or 15 feet, and are composed of silicified limestone and vein material. The silicified limestone extends to the north and northwest, or at a right angle with the ore body, following a certain definite bed from 50 to 100 feet thick in the limestone series.

The ore, which is highly oxidized, is siliceous and contains lead, silver, and copper, the copper being more abundant than either lead or silver.

BOSS TWEED MINE.

The Boss Tweed is situated in the gulch between the Carissa and the North Star mines. The country rock is metamorphosed limestone, the bedding of which is entirely obliterated. The mine has been worked through a tunnel running N. 35° E. and by several winzes cut to a depth of 150 feet below the tunnel level.

There are two systems of fracture in the limestone, the principal of which runs N. 35° E. The other trends N.-S.

The ore follows these fissures, extending perhaps 50 feet on a NE. fissure, then 10 feet on a N.-S. fissure, then turning into a NE. fissure for a similar distance, and so going step by step to the NNE.

At the tunnel level the ore body dips E. at an angle of 85°. Twenty-seven feet below this level it stands vertical for a distance of 50 feet, and below dips W. at an angle of 85°. In this ore body there are three shoots of rich ore, all of which pitch N. at a low angle.

The vein minerals are quartz, barite, enargite, tetrahedrite, bismutite, galena, and some form of silver and gold and their oxidation products. Bismuth is found in the form of carbonate, which yields as much as 42 per cent metallic bismuth, but the payable ore is copper ore. Silver and gold are present sparingly. Silver is most abundant in the galena ores. Barite occurs locally in great masses, at times several feet thick.

The ores in the tunnel are completely oxidized, but at a depth of 100 feet they are only slightly altered.

NORTH STAR MINE.

The North Star mine is on a southern spur of Mammoth Mountain, just south of the Red Rose mine and north of the Tintic iron mine. Its workings are in metamorphosed Eureka limestone, which appears to strike N. 25° W. and to dip 35° N. E. It is a finely crystallized limestone, traversed by numerous narrow black bands, and containing much quartz, garnet, and wollastonite. The metamorphism is a contact phenomenon resulting from the intrusion of the near-by monzonite.

This limestone is intersected by a great number of fissures, the principal ones of which trend N.-S. and N. 25° E. The others trend NW., N. 30° W., NE., and E.-W.

The mine is worked through several tunnels which run southward and by two shafts, the total depth being about 500 feet.

There is one ore body which is nearly vertical and has been traced on the surface from the gulch southward to the crest of the spur, thence to the southwest along the ridge to the mouth of North Star Gulch.

On the crest of the hill is a small spur extending to the east on an E.-W. fissure for 100 feet, while 200 feet southwest is a second spur extending to the north on a N. 35° E. fissure for 400 feet. Near the southern end is an E.-W. ore-bearing cross fissure. The observations underground show a similar series of phenomena, the ore changing from N.-S. at the north end to NE. and SW. at the south end.

The ore body is extremely irregular in width, varying from a narrow seam to a body some 20 or 30 feet across. The points of greatest width are at the intersection of many fractures. On the 250-foot level, where there is a large stope, fractures were observed trending N. 25° E., N. 30° W., and N. 80° W. The ore at such a point usually leaves one fissure and continues a short distance in another fissure, then turns again into a fissure parallel to the original one. The original fissure loses its ore rapidly beyond such a point of intersection.

The vein minerals are quartz, barite, galena, cerussite, iron oxide, enargite and its oxidation products, together with some form of silver and gold. The lower levels show a greater amount of lead and silver and less barite than the upper workings. The copper is found at the southern end of the vein. Two-thirds of the value of the ore is in gold, the rest in silver and lead. The gold is closely associated with the finely crytallized barite. Coarsely crystalline masses of pure barite occur in the upper workings. There are four rich shoots thus far developed in this ore body, all of which dip W. and pitch N. Of these, three are distinctly gold bearing and one carries lead and silver.

The ore body is oxidized to its lowest point of working, some 500 feet below the crest of the hill.

GOVERNOR MINE.

This mine is south of the Boss Tweed, at the head of Dragon Gulch. It is in metamorphosed limestone and its workings have reached a depth of 200 feet. It was not open at time of visit. The strike of the strata is N.–S., and their dip E. at an angle of 30°.

The fissuring of the country rock follows N. 35° E. and N. 15° E. directions. A single ore body can be traced which strikes N. 35° E. It contains much quartz and some barite, with copper and lead minerals. Whether it carries silver and gold is not known.

BLACK DRAGON MINE.

The Black Dragon ore body is the southwest continuation of the Governor ore body. The country rock is metamorphosed limestone, the strike of which on the 315-foot level is N. 15° W. and its dip 25° NE. In this mine the general course of the ore body is N. 35° E., with a dip SE., varying between 80° and 85°. This has been intersected by E.–W. fissures, which carry small amounts of secondary ore. At the breast of the 200-foot level the course of the main ore body is N. 85° E. At the shaft on this level the main ore body is intersected by a fissure trending NW. and is 20 feet wide, forming a large but purely local body of ore, the north wall of which dips at an angle of 45° and the south wall dips at an angle of 80°. On the 315-foot level the ore alternates between fractures running N. 35° E. and those running NE.

The vein material is similar to that found in the Governor. It is a siliceous ore, carrying a great deal of barite locally and some pyrite. The silver and the gold values are unevenly distributed through the vein, the gold seeming to be more abundant in the presence of barite and decreasing with increase of copper. The silver values are for the most part in the lead ores. Oxidation of the vein is not by any means complete, though there is no water in the mine.

WEST DRAGON MINE.

The West Dragon is on the southwestern continuation of the Black Dragon, being in metamorphosed limestone striking N. 15° W. and dipping NE. at an angle of 25°. The ore trends N. 35° E. and dips SE. at an angle of 85°. A small body of secondary minerals was seen in an E.–W. fissure which dipped S. at an angle of 75°. The workings are near the surface, and the principal vein minerals are quartz, limonite, and chrysocolla. The vein extends still farther to the southwest and forms broken fragments in the great iron deposits of the Tintic iron mine.

MINES OF THE IGNEOUS ROCKS.

INTRODUCTION.

These mines are either in quartz-porphyry, monzonite, or monzonite-porphyry.

The quartz-porphyry is west of the monzonite and contains the workings of the large mines—the Swansea and the South Swansea. Their ore zone trends slightly W. of N., and continues southward from the quartz-porphyry into the monzonite, where it forms the ore zone of the Four Aces and Picnic mines.

In the monzonite, which lies east of the quartz-porphyry, and for the most part on the east side of Silver City, there are several long and many small short and widely distributed veins. These trend NNE. or NE., but have a N.-S. course locally.

The veins in monzonite-porphyry are mostly on Treasure Hill, between Silver City and Diamond. Their trend is nearly N.-S.

At the time of our field work the majority of the mines were closed, so that the observations were confined largely to the open cuts and prospect holes.

In only a small number of mines had the workings reached the water level. The visible ore was mostly oxidized, and consisted of quartz stained with iron oxide and cerussite or lead carbonate. Copper minerals occurred only in the southern mines.

Mines in Quartz-Porphyry.

SWANSEA MINE.

The Swansea mine is situated just north of Silver City, in quartz-porphyry. It is now 650 feet deep and has been worked along the vein northward about 1,000 feet. It has been productive from the earliest times up to 1896 in a more or less satisfactory manner, but since 1896 it has yielded a large amount of argentiferous galena. The earliest work was in the oxidized zone, which was rich in silver and carbonate of lead to a depth of 250 feet. The mining was carried on, for the most part, in the tunnels north of the present shaft and through winzes from these tunnels. When, at a depth of 250 feet, barren pyrite was met, practically all work ceased. In the spring of 1896, however, at a depth of 350 feet, argentiferous galena and cerussite, or lead carbonate, were found, which have been traced to a depth of 650 feet.

The great bulk of the ore is found in a vein which trends, for the most part, N. 10° W.

There are one principal and two spur veins in this mine. While the main vein trends N. 10° W., it is somewhat irregular, both longitudinally and vertically. In the tunnels north of the shaft its course is that of the principal fissure. On the 100-foot level it is N.-S. or N. 15° W.; on the 450 it is N. 15° W.; on the 550 it is N. 10° W. or N.-S. The vein dips, as a whole, W. at the surface at an angle of 70°. On the 300-foot level it dips E.; at the 350, W.; on the 450, E., at an angle of 85°, and below this, so far as known, W., at an angle varying between 70° and 90°.

The spur veins are best seen in two places: First, on the 300-foot level, where the subordinate vein is 25 feet west of the main vein and stands vertical. It has no considerable longitudinal or vertical extent, and follows the fracture of the main vein of the level above, the main vein on this level being to the east and dipping E. Second, on the 100-foot level, where it is parallel to and east of the main vein. Like the previous minor vein, it has little persistence.

The main vein varies greatly in width, averaging about 3 feet, though on the 550-foot level it is 10 feet wide and in other places is represented only by a narrow seam of clay. The spur veins are rarely over 2 feet wide.

The line of demarcation between the vein and the wall rocks is always sharp, but on the west side the wall rocks have been somewhat more altered than on the east side, so that the former are lighter and resemble the vein rocks very slightly. They are impregnated with pyrite. Their potash feldspars have been altered to sericite for a few inches from the vein. There has also been a slight addition of quartz to the wall rocks.

The vein minerals are pyrite, galena, quartz, sphalerite, and chalcopyrite. These are distributed throughout the vein, but arrange themselves in bands, of which, in the one case, pyrite is the predominating mineral, and in the other, galena, quartz being more abundant in the bands of pyrite than in the galena bands, but common to both. As a result of this, the rich ore shoots are in the form of lenses having their greatest dimension parallel to the course of the vein. A section across the vein of the 550-foot level from east to west showed 18 inches of pyrite and quartz, 18 inches of galena and quartz, 30 inches of pyrite and quartz, 6.5 inches of galena, 3 inches of pyrite, and, finally, 3 inches of galena. The ore shipped varies greatly and is divided into three classes—the carbonate, the iron sulphide, and the silver-galena ores.

The level of permanent water is just below the 650-foot level. The 250-foot level marks the limit of complete oxidation, though there is great oxidation along the intersecting fracture planes in the wall rocks down to the lowest level. The oxidized vein below the zone of complete oxidation is the pyritiferous portion, richest in quartz.

SOUTH SWANSEA MINE.

The South Swansea adjoins the Swansea mine at its southern end, and, like it, is in quartz-porphyry. It is now 650 feet deep and has been followed lengthwise 300 feet. The history of this mine follows closely that of the Swansea. There was an early period when ores of considerable value were taken from the oxidized zone, then a period of idleness covering many years, and finally the striking of the rich ores below the barren pyrite soon after they were found in the Swansea. Work on this property is done through a single compartment shaft.

The fractures of the quartz-porphyry are the same as in the Swansea, except that there has been some recent faulting. The main fractures run N. 15° E. and N. – S. The N. 10° W. fractures are present, but do not carry ore, as in the Swansea, and are not so well developed. The fractures of recent origin run N. 70° E. and N. 55° W.

The vein follows for the most part a N. – S. fracture, but turns at its northern end slightly to the east and joins the Swansea through a cross fissure, the course of which is N. 55° W. The main vein dips W. at angles of 85° to 90°, while the cross vein dips E. at an angle of not more than 70°. The two veins overlap but little, and die out rapidly beyond the cross fissure, leaving a barren clay seam.

Like the Swansea, the South Swansea vein is tortuous in length and depth. On the 450-foot level its dip is W. at a high angle at the north end, and E. at a similar angle at the south end. On the 550-foot level its dip is W. throughout its developed course, but between the 450 and the 550-foot levels the vein has gained 29 feet to the east, showing that it must have a local dip eastward between these levels.

The recent fractures N. 55° W., and N. 70° E. have faulted the vein on the 400-foot level, the amount of displacement being small. On the 450-foot level there has also been post-vein movement near the shaft. North of the shaft the vein strikes N. 10° W. and dips 85° W., while south of the shaft its course is N.–S. and its dip is E. at an angle of 80°. The intermediate country between the two portions of the vein is occupied by numerous clay seams striking N.–S. and without vein-mineral content.

The minerals and their distribution are the same as in the Swansea.

Oxidation has taken place in the same manner and to approximately the same depth as in the Swansea.

The ores are sorted by the miners into three classes, and are called by the local men, first, lead and iron sulphide; second, iron sulphides; and third, carbonate or oxidized ores. The first-mentioned ores average 50 ounces of silver to the ton, 20 per cent lead, 30 per cent iron, and 15 per cent silica; those of the second class average 25 ounces of silver, 7 per cent lead, 38 per cent iron, and 13 per cent silica; and the third class, 90 ounces of silver, 40 per cent lead, 20 per cent iron, and 12 per cent silica.

Mines in Monzonite.

FOUR ACES MINE.

The Four Aces mine is situated about 650 feet south-southeast of the South Swansea. It is on the same fracture zone as the South Swansea and Swansea mines. At the time of writing this property was not producing extensively. Its workings follow a vein which strikes somewhat W. of N., following apparently a N. 10° W. fissure.

PICNIC MINE.

The Picnic mine is 200 feet south of the Four Aces. The vein trends N.-S. Development has not been carried on extensively, therefore the relations between the Picnic and the Four Aces are not well established. The main fractures, as in the Four Aces, belong to the N. 10° W. system.

PARK MINE.

This mine is 400 feet southeast of the Picnic. It has been worked through a shaft and a tunnel. At the time of examination the mine was idle, the tunnel being the only accessible working. It had been extended into the hill about 400 feet and followed a fracture running N. 50° E. and dipping 35° NW. This appears to carry the ore, which is, however, so completely oxidized that little could be determined as to its character or value. The vein was traced on the surface from the Park mine to the Silver Bow mine. Its course near the Park mine is N. 50° E.; at the crest of the hill it is N. 15° E., and so continues to the Silver Bow shaft.

SILVER BOW MINE.

The Silver Bow mine is north of Silver City and east-southeast of the Swansea mines, at the head of a small southward-opening basin. The fractures belong to the northeast system. The N. 15° E. fractures are the most prominent, and closely associated with them is a N. 50° E. fracture. These two fractures carry the veins. The other fractures are N.-S. and N. 10° W., but these have not been found to be ore bearing.

The veins of the Silver Bow are three in number. The two larger ones trend N. 15° E., the smaller one N. 50° E., between the two major veins. The development has been so slight that further relations between these veins can not be definitely stated. It seems probable that there is a repetition of the relations in the Swansea and South Swansea veins, and that the more easterly of the N. 15° E. veins will prove to be the main vein north of the Silver Bow, while the other one, which extends into the Park mine, is the more important south of this mine.

The ores are oxidized, and, as far as seen, are similar to those of the other mines in this district.

South-southeast of the Silver Bow is a prominent outcrop which has been prospected near the surface for a distance of 400 feet. Its course is N. 10° W. and its dip W. at an angle of 80°.

South of this, and perhaps 100 feet to the east, is another clearly defined vein, which has been worked extensively in times past. This trends N.-S. at its southern end and N. 50° E. at the northern end. The turn in the vein is well shown in an open shaft at the surface. Other fractures common to this rock mass are present, but show no evidence of mineralizing action.

MONTEREY-IRON DUKE MINE.

The mine is situated northeast of Silver City, just west of the road. In times past the southern end of the known vein had been worked extensively, and a considerable amount of valuable ore removed. At the present time work is carried on at the north end and has reached a depth of 370 feet. The country rock is unusually coarse in texture. Just to the east of the shaft are two small patches of quartzite, which are evidently caught-up masses inclosed in the monzonite. The principal ore-bearing fissure trends N. 15° E. to N. 20° E.; at the southern end, N. 20° E., and at the northern end, N. 15° E. So little work has been done on the vein that its continuity is not definitely established. The fracture zone appears to extend longitudinally about 2,500 feet. The vein is vertical for the first 100 feet below the surface, and dips W. at an angle of about 75° below this point. Seven hundred feet north of the shaft is a cross fracture carrying vein matter which strikes N. 75° E. and dips NW. at an angle of 70°. At the extreme northern end of the zone are several small outcrops striking N. 10° W. and N.-S.

The vein minerals are the same as in the Swansea mines, together with a limited amount of chalcopyrite. The values of these ores below water level are in the gold and silver, but thus far they have not been found in paying quantity.

Oxidation has extended to a depth of 100 feet from the surface. Below this there is a constant flow of water, and at the 350-foot level about 4,000 gallons per day must be pumped to keep the mine dry.

CLEVELAND MINE.

The Cleveland mine is north and east of the Iron Duke. What led to the location of the mine at this point was probably the alteration and staining of the country rock along the fractures and the occurrence of more or less vein quartz. There seem to be three parallel croppings of doubtful vein material just south of the Cleveland shaft, which strike N. 25° E., and are approximately 150 feet apart. Of these the more easterly is in the line of strike of a well-defined vein cropping just east of the Iron Duke shaft. Just west of the Cleveland the more westerly turns N. 50° E. North of the Cleveland are also three small croppings, the more westerly of which strikes N. 50° E., and dips NW. at an angle of 80°. The other two strike N.-S.

MURRAY HILL MINE.

There are two veins in this vicinity. The more easterly strikes N. 45° E., and is vertical. The other strikes N. 25° E., and dips W. at an angle of 75°. The veins have not been traced for any considerable distance.

YANKEE GIRL MINE.

Under this head will be described the group of six veins appearing at the surface at this mine and in the immediate southeast country. At the Yankee Girl shaft there is a vein striking N. 25° E., and dipping NW. at an angle of 50°. Just east of this is a second vein, the strike of which is N. 30° E. North and east is a third small vein, having the same strike, and dipping NW. at an angle of 75°. South of this are two veins, which strike N. 35° E. and dip 65° NW. The sixth vein is 1,000 feet southeast of the Yankee Girl, and strikes N. 55° E., dipping NW. at a high angle. They are about 200 feet apart and show, on the surface at least, no connecting links. Little is known concerning their underground development. The Yankee Girl is reputed to have produced considerable oxidized ore.

WHEELER MINE.

The Wheeler mine is 2,300 feet due east of Silver City. It has been developed to a depth of only 225 feet. The vein appears at the surface on the crest of a hill, where its course is N. 55° E. To the north it trends N. 15° E., then N. 60° E., and finally is lost in a N.-S. fissure. Its dip is always west at an angle varying between 75° and 90°.

RABBIT'S FOOT MINE.

The Rabbit's Foot mine is immediately east of the Wheeler. The vein was first discovered on the southern slopes of the hill, where its course is N. 30° E. To the north it trends N. 25° W., and then N. 30° E., its dip being N. and W. at an angle of 75°. Additional vein croppings were noticed in the gulch northeast of this mine; it is probable that these represent the continuation of the vein of the Rabbit's Foot mine. Their strike is N. 35° E. and their dip NW. at an angle of 75°.

PRIMROSE-LUZERNE MINE.

This mine is just south of the Rabbit's Foot. There are two veins, one of which, on the crest of the hill, strikes N. 30° E. and dips NW.; the other, just south of this, strikes N. 75° E. and dips NW. at an angle of 75°. This vein has been followed to a depth of 250 feet.

SUNBEAM MINE.

The Sunbeam mine, the oldest mine in the district, is nearly a mile due east from Silver City. The vein outcrops strongly and has been followed to a depth of 490 feet. Its history is the same as that of the other mines of the igneous-rock area, except that up to the time of writing rich ores have not been found below the water level. The vein on which the Sunbeam is located has been traced almost continuously 4,000 feet from the mouth of the gulch northeast.

At the southern end the strike of the vein is N. 25° E. Three hundred feet north it trends N. 45° E. for a distance of 400 feet, when it appears, on the surface at least, to be offset to the north about 100 feet, then trends NE. for 1,100 feet. At the Sunbeam shaft the course is but a few degrees E. of N.; across the gulch north of the shaft it is N.-S. Skirting the side of the hill to the next gulley it turns N. 35° E., and on the top of the hill trends NE. At the southern end the vein stands vertical. Just north of the Sunbeam shaft it appears to dip west at an angle of about 80°. Where the strike is N.-S. the vein is vertical, but at its northern end the dip is west again at a high angle. In the gulch just below the Sunbeam shaft it branches on the east side, sending off a strongly marked vein to the south.

The vein varies in width from a mere seam to 10 feet.

The Sunbeam vein has been productive throughout its length, yielding ores of unusual values. It is reported that the Sunbeam mine alone, which represents only about one-sixth of the length of the vein, has yielded over $500,000 of oxidized ore.

Water was encountered at a depth of 490 feet in so great a flow that all mining operations below this level were suspended.

MARTHA WASHINGTON MINE.

This mine is northeast of the Sunbeam, and the vein on which it has been located has been followed to a depth of 350 feet. It is traceable, though not continuously, for a distance of nearly 3,000 feet. The southern end, called the "Triumph," strikes NE. Going north, the vein is offset to the northwest 100 feet. For a distance of 300 feet from this point it has not been found on the surface. Halfway up the hillside, however, it crops again somewhat to the northwest, its course being N. 50° E. Where it crosses the crest of the hill the strike is N. 20° E. On the north side of the gulch it trends N. 75° E. for a distance of 400 feet, from which point to its northern limit its trend is N. 25° E.

The Martha Washington shaft is located near the northern end, and in its workings a second vein has been found on the northwest side, the course of which is N. 55° E. This is traceable intermittently to the southwest for a distance of 1,200 feet.

These two veins dip NW. at varying angles, the average dip being about 65°. The ore is oxidized throughout the workings.

UNDINE MINE.

The Undine is immediately east of the Sunbeam and has been cut to a depth of 350 feet. There appears to be but one vein. This can be traced on the surface from the Undine shaft northeast nearly 2,000 feet. Its course is somewhat irregular, but at the southern end averages NE.; its mid portion is N. 30° E., and the northern end is NE.

The vein dips NW. at an angle varying between 50° and 80°. This feature is well illustrated by its curved outline on the surface.

JOE DALY MINE.

The Joe Daly mine is immediately south of the Undine. The vein was first found near the mouth of the gulch leading to the Undine, its course being N. 25° E., except at the northern end, where it is N. 35° E. There is some evidence on the surface that this vein extends to the crest of the hill, but it is by no means certain that there is vein matter in the fissure throughout the entire distance. The workings have not reached the water level.

LUCKY BOY MINE.

The Lucky Boy mine is southeast of the Undine. It shows at the surface but two small vein croppings. The strike of the westerly one is N. 35° E., its dip 50° NW.; of the easterly one, N. 15° E., its dip 45° NW.

Mines in Monzonite-Porphyry.

NEW STATE MINE.

This mine is at the southeastern margin of the special quadrangle. The country rock is altered in these workings to dazzling white, stained here and there with limonite.

Four nearly parallel veins were noted at the surface. The more easterly strikes N. 40° E. at the southern end, and at the northern end trends N. 10° E. and joins the second vein, the course of which is N. 40° E. The other two veins, parallel to each other, are southwest of the second vein, their course being N. 35° E. and their dip W. at an angle of 60°. These veins are never more than 2 feet in width. They are siliceous and contain a little tetrahedrite and chalcopyrite.

ALASKA MINE.

The Alaska mine is immediately north of the New State. Its workings extend to a depth of 200 feet. The vein appears well marked at the surface; at the southern end its course is NE. and at the northern N. 40° E. The dip is 70° NW.

DIAMOND DISTRICT.

TREASURE HILL MINE.

This mine is located on the slopes of Treasure Hill, about a mile and a half north of Diamond. The present shaft is close to the old workings of the Tesora and Golden Treasure, both of which have produced large amounts of ore in the past. The country rock is considerably broken up and jointed. The vein of this mine forms a very prominent capping of siliceous or cherty vein material near the top of Treasure Hill. It trends N. 15° E. For 200 feet from the surface the vein is marked by well-defined parallel walls, which stand nearly vertical.

Below this point the country rock east of the vein, as seen on the upper levels, shows a number of bands, the soft material is water bearing, and in one case carries an iron-stained sulphide band of ore 6 inches wide.

The vein in the upper levels is entirely oxidized, carrying 45 per cent iron, with silver and gold in varying quantities. The sulphide zone was first found 250 feet from the collar of the shaft. This marks the ground-water level, and the further development of the mine has necessitated the handling of a large amount of water.

JOE BOWERS NO. 2 MINE.

This mine is just north of the Blue Bird mine. It is worked through an incline shaft to a depth of 200 feet. The vein strikes N. 10° E. and dips steeply W. The ore occurs in bunches or small shoots in the vein, which is composed of clay and decomposed monzonitic rock. The shoots pitch S. In the upper portions of the workings the ore is principally galena, with pyrite and quartz as gangue minerals, but at the 200-foot level a body of enargite was found in galena.

Water was reached at a depth of 175 feet. The flow is not yet large.

LAST CHANCE MINE.

This mine is situated on the south slope of Treasure Hill, to the east of the Homestake mine. The vein has a N.-S. trend. Its material consists of decomposed country rock, clay, manganese (?), and rusty quartz containing narrow stringers of azurite.

HOMESTAKE MINE.

This mine is on the south side of Treasure Hill, not more than a mile north of Diamond. Like other mines of this part of the district, the Homestake was worked in the early period of Tintic mining and yielded a considerable amount of ore. The shaft is now at a depth of 400 feet.

Its vein trends N.-S. and dips slightly W. The vein material is quartz and decomposed monzonite-porphyry, which is impregnated with pyrite. The ore minerals are enargite and galena, both of which carry silver and gold. The ore is distributed in pay shoots, the principal one of which either pitches to the south or is vertical. Throughout the vein these shoots of rich ore narrow or split and sometimes send off stringers.

The oxidation extends to a depth of about 200 feet, below which point the ore is entirely sulphide or sulph-arsenide and the country rock is thoroughly saturated with water.

BLUE BIRD MINE.

The Blue Bird mine is situated on the east side of Treasure Hill about a half mile north of Diamond. The present shaft is 225 feet deep.

The vein strikes N. 30° W. and dips NE. The width of the vein varies from 2 to 4 or more feet. The vein material is decomposed monzonite-porphyry, which resembles bluish-gray clay. This is often full of pyrite and sometimes runs several per cent in lead. Small veins can sometimes be distinguished traversing the vein material.

MINES OF THE CONTACT DEPOSITS.

INTRODUCTION.

In the limestone along the contact of igneous and sedimentary rocks occur bodies of jasperoid which contain in places a sufficiently large amount of iron oxide to make the deposits valuable for fluxing purposes. The two localities of greatest production are, first, just south of Mammoth Mountain, along the contact of the Eureka limestone with the monzonite, and on which is situated the Tintic iron mine; and, second, on the first ridge east of Mammoth Mountain and just beyond the eastern border of the Tintic mining district map, along the contact of rhyolite and Eureka limestone, and on which is situated the Black Stallion group of mines.

TINTIC IRON MINE.

This mine, which is also known as the Dragon iron mine, is one mile east of Silver City, or due south of the North Star mine. The ore is in Eureka limestone at its contact with monzonite. The limestone, which is highly altered and metamorphosed, strikes about NW. and dips NE. at an angle of 45°. The monzonite is greatly bleached for several hundred feet from this contact. The alteration of both the limestone and the monzonite has been fully treated in Chapter V, Part I.

The workings, which are in the nature of a large open cut, are now 200 feet deep, the ore being loaded on teams and hauled out of the open cut to the surface through large tunnels.

The ore consists of a large irregular mass of jasperoid in which are shoots of limonite and hematite, containing a small amount of gold. The shoots of iron are also irregular in form, but stand nearly vertical. They trend irregularly, but follow either E.-W. or N.-S. courses.

The limonite is either in cavernous masses having horizontally banded botryoidal structures or in dustlike particles through the jasperoid.

These deposits differ from the deposits already described in that they contain no lead or copper, that the iron is deposited in the form of hydrous oxide, and that the silica is always as a replacement of the country rock and does not form vein quartz.

The following analyses show that in composition it is not unlike the direct oxidation of pyrite in the ore bodies of the deposits in limestone. The first analysis is of a specimen from the Tintic iron mine, and the second of a specimen from the Ajax mine.

Analyses of iron ore from the Tintic and Ajax mines, by George Steiger.

	No. 298.	No. 299.
	Per cent.	*Per cent.*
SiO_2	3.25	3.83
CuO	None.	7.51
TiO_2	None.	None.
Al_2O_3	.76	1.37
Fe_2O_3	80.02	72.17
FeO	.24	.09
MnO	Trace.	None.
CaO	.42	None.
BaO	None.	None.
MgO	.30	.10
Water 100°—	1.71	1.95
Water 100°+	12.30	12.36
SO_3	.47	.83
S	.10	.04
P_2O_5	.78	Trace.
Total	100.35	100.25

There are, in addition, occasional isolated masses of ore rich in silver-lead, copper, quartz, and barite, but these appear to be detached portions of the Black Dragon ore body, since they have the composition peculiar to the deposits in the limestone and are almost invariably found in the plane of projection of this ore body.

BLACK STALLION MINE.

This mine is situated about 3 miles east of Robinson. The only essential difference between the Tintic and the Black Stallion iron mines is that at the latter the igneous rock which bounds the deposit is rhyolite, whereas at the Tintic iron mine it is monzonite.

The ore follows the contact closely for several hundred feet, and consists of jasperoid, which replaces the limestone, the mode of occurrence of the iron being, in the jasperoid, similar in every respect to that at the Tintic iron mine.

INDEX.

Numbers in *italic* are those of pages on which illustrations (plates or figures) appear; numbers in **black-faced type** are those of pages on which detailed descriptions of species are given.

B.

G.

H.

Q.

T.

U.

V.