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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, Director

CONTRIBUTIONS

TO

ECONOMIC GEOLOGY

1902

S. F. EMMONS
C. W. HAYES
Geologists in Charge

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., March 9, 1903.

SIR: I have the honor to transmit, for publication as a bulletin of the Survey, a manuscript entitled Contributions to Economic Geology, 1902.

The report contains 61 contributions from 33 members of the Survey who have been engaged more or less continuously throughout the year in economic work, together with a brief statement by the geologists in charge of the section of metalliferous ores and the section of non-metalliferous economic minerals, of the extent and character of the economic work being carried on in the Survey.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1902.

S. F. EMMONS,
C. W. HAYES,
Geologists in Charge.

INTRODUCTION.

By C. W. HAYES, *Geologist in Charge of Geology.*

This bulletin has been prepared primarily with a view to securing prompt publication of the economic results of investigations by the United States Geological Survey. It is designed to meet the wants of the busy man, and is so condensed that he will be able to obtain results and conclusions with a minimum expenditure of time and energy. It also affords a better idea of the work which the Survey as an organization is carrying on for the direct advancement of mining interests throughout the country than can readily be obtained from the more voluminous reports. Should this bulletin be favorably received by those interested in the development of the mineral industries of the United States, it is proposed to publish early in each calendar year a similar bulletin containing the results of the last year's field work in economic geology.

In the preparation of the present volume, promptness of publication has been made secondary only to the economic utility of the material presented. The papers included are such only as have a direct economic bearing, all questions of purely scientific interest being excluded.

The papers represent three classes: (1) Preliminary discussions of the results of extended economic investigations, which will later be published by the Survey in more detailed form; (2) comparatively detailed descriptions of occurrences of economic interest, noted by geologists of the Survey in the course of their field work, but not of sufficient importance to necessitate a later and more extended description; (3) abstracts of certain economic papers which have appeared in Survey publications during the last year, chiefly such as give a general account of the distribution and mode of occurrence of particular mineral deposits throughout the United States.

The papers have been grouped according to the subjects treated. At the end of each section is given a list of previous publications on that subject by this Survey. These lists will be found serviceable by those who wish to ascertain what has been accomplished by the Survey in the investigation of any particular group of mineral products. They are generally confined to Survey publications, though a few titles of important papers published elsewhere by members of the Survey are included.

The results of the Survey work in economic geology have been published in a number of different forms, which are here briefly described:

1. *Papers and reports accompanying the Annual Report of the Director, United States Geological Survey.*—Prior to the present year many economic reports were published in the royal octavo cloth-bound volumes which accompanied the Annual Report of the Director. This form of publication for scientific papers has been discontinued and a new series, termed Professional Papers, substituted.

2. *Bulletins of the United States Geological Survey.*—The bulletins of the Survey comprise a series of paper-covered octavo volumes, each in general containing a single report or paper. These bulletins, formerly sold at nominal prices, are now distributed free of charge to those interested in the special subject discussed in any particular bulletin. This form of publication facilitates promptness of issue for economic results, and most economic reports are therefore published as bulletins. Their small size, however, precludes the use of large maps or plates, and reports containing large illustrations are therefore issued in the series of Professional Papers.

3. *Professional Papers of the United States Geological Survey.*—This series, paper covered, but quarto in size, is intended to include such papers as contain maps or other illustrations requiring the use of a large page. The publication of the series was commenced in 1902, and the papers are distributed in the same manner as bulletins.

4. *Monographs of the United States Geological Survey.*—This series consists of cloth-bound quarto volumes, and is designed to include exhaustive treatises on economic or other geologic subjects. Volumes of this series are sold at cost of publication.

5. *Geologic folios of the United States Geological Survey.*—Under the plan adopted for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and these quadrangles, which number several thousand, are separately surveyed and mapped. The unit of survey is also the unit of publication, and the maps and descriptions of each quadrangle are issued in the form of a folio. When all the folios are completed they will constitute a Geologic Atlas of the United States.

A folio is designated by the name of the principal town or of a prominent natural feature within the quadrangle. It contains topographic, geologic, economic, and structural maps of the quadrangle, and occasionally other illustrations, together with a general description.

Under the law, copies of each folio are sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly.

Circulars containing lists of these folios, showing the locations of the quadrangular areas they describe, their prices, etc., are issued from time to time, and may be obtained on application to the Director of the United States Geological Survey. The tables on the following pages show the folios issued to date, with the economic products discussed in the text of each, the products of greatest importance being printed in italics.

List of geologic folios showing mineral resources described.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
1	Livingston	Mont	3,354	Iddings, J. P.; Weed, W. H.	Gold, copper, clays, lime, stone, *coal*.
2	Ringgold	Ga.-Tenn	980	Hayes, C. W	*Coal*, *iron*, manganese, lime, clays, stone, road metal.
3	Placerville	Cal	932	Lindgren, W.; Turner, H. W.	*Gold*, copper, quicksilver, chromite, stone.
4	Kingston	Tenn	969	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
5	Sacramento	Cal	932	Lindgren, W	*Gold*, copper, chromite, iron, coal, stone, lime, clay.
6	Chattanooga	Tenn	975	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
7	Pikes Peak-Cripple Creek.	Colo	932	Cross, W	*Gold*.
8	Sewanee	Tenn	975	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
9	Anthracite-Crested Butte.	Colo	465	Eldridge, G. H	*Coal*, *silver*, stone, lime, clay.
10	Harpers Ferry	Va.-W. Va.-Md.	925	Keith, A	*Iron*, *ocher*, copper, stone, road metal, lime, cement.
11	Jackson	Cal	938	Turner, H. W	*Gold*, *copper*, chromite, iron, manganese, ocher, coal, stone, lime, clay.
12	Estillville	Va.-Ky.-Tenn.	957	Campbell, M. R	*Coal*, iron, marble, lime, stone.
13	Fredericksburg	Md.-Va	938	Darton, N. H	*Greensand marl*, stone, fuller's earth, clays, sand, gravel, *underground water*.
14	Staunton	Va.-W. Va	938	do	Iron, marble, lime, clay, coal.
15	Lassen Peak	Cal	3,634	Diller, J. S	Gold, infusorial earth, lime, stone, coal.
16	Knoxville	Tenn.-N. C	969	Keith, A	*Marble*, slate, stone, gold, lime, cement, clay, water power.
17	Marysville	Cal	925	Lindgren, W.; Turner, H. W.	*Gold*, coal, gas, clay, lime, stone, water supply.
18	Smartsville	do	925	do	*Gold*, copper, quicksilver, iron, lime, clay, stone.
19	Stevenson	Ga.-Ala.-Tenn.	980	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
20	Cleveland	Tenn	975	do	*Iron*, lead, lime, stone, clay.
21	Pikeville	do	969	do	*Coal*, iron, stone, clay.
22	McMinnville	do	969	do	*Coal*, iron, stone, clay.
23	Nomini	Md.-Va	938	Darton, N. H	*Greensand marl*, fuller's earth, clay, stone, sand, gravel, *underground water*.

List of geologic folios showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
24	Three Forks	Mont	3,354	Peale, A. C	*Gold*, silver, copper, iron, coal, lime, clay, pumice, *mineral springs*.
25	Loudon	Tenn	969	Keith, A	*Coal*, marble, lime, stone, clay, iron, slate, water power.
26	Pocahontas	Va.-W. Va	950	Campbell, M. R	*Coal*, lime, stone, clay, marble.
27	Morristown	Tenn	963	Keith, A	*Marble*, *stone*, lead, zinc, lime, cement, clay, water power.
28	Piedmont	Md.-W. Va	925	Darton, N. H.; Taff, J. A.	*Coal*, iron, lime, stone, road metal, clay.
29	Nevada City special.	Cal	35	Lindgren, W	*Gold*.
30	Yellowstone National Park.	Wyo	3,412	Hague, A.; Weed, W. H.; Iddings, J. P.	National Park; no mining permitted.
31	Pyramid Peak	Cal	932	Lindgren, W	*Gold*.
32	Franklin	Va.-W. Va	932	Darton, N. H	*Iron*, coal, manganese, lime, stone, road metal, clay.
33	Briceville	Tenn	963	Keith, A	*Coal*, *iron*, lead, marble, lime, stone, clay.
34	Buckhannon	W. Va	932	Taff, J. A.; Brooks, A. H.	*Coal*, lime, stone, clay.
35	Gadsden	Ala	986	Hayes, C. W	*Coal*, *iron*, lime, stone.
36	Pueblo	Colo	938	Gilbert, G. K	*Stone*, *gypsum*, clay, iron, *artesian water*.
37	Downieville	Cal	919	Turner, H. W	*Gold*, iron, chromite, lime, marble.
38	Butte special	Mont	23	Emmons. S. F.; Tower, G. W.	*Copper*, *silver*, gold.
39	Truckee	Cal	925	Lindgren, W	*Gold*, silver, coal, stone, mineral springs.
40	Wartburg	Tenn	963	Keith, A	*Coal*, *oil*, iron, lime, clay.
41	Sonora	Cal	944	Turner, H. W.; Ransome, F. L.	*Gold*, quicksilver, copper, chromite, lime, stone.
42	Nueces	Tex	1,035	Hill, R. T.; Vaughan, T. W.	Stone, gravel, *underground water*.
43	Bidwell Bar	Cal	919	Turner, H. W	*Gold*, manganese, iron, chromite, stone.
44	Tazewell	Va.-W. Va	950	Campbell, M. R	*Coal*, iron, barite.
45	Boise	Idaho	864	Lindgren, W	*Gold*, silver, coal, diatomaceous earth, stone, clay, springs, artesian water.
46	Richmond	Ky	944	Campbell, M. R	Coal, fluorite, phosphate. clay, stone, road metal.
47	London	do	950	do	*Coal*, stone.
48	Tenmile district special.	Colo	62	Emmons, S. F	*Silver*.
49	Roseburg	Oreg	871	Diller, J. S	Gold, copper, quicksilver, coal, clay, stone.
50	Holyoke	Mass.-Conn	885	Emerson, B. K	Granite, emery, chromite, quartz, trap, sandstone, clay.
51	Big Trees	Cal	938	Turner, H. W.; Ransome, F. L.	*Gold*, silver.
52	Absaroka	Wyo	1,706	Hague, A	Silver.
53	Standingstone	Tenn	963	Campbell, M. R	*Coal*, oil, lime, clay.
54	Tacoma	Wash	812	Willis, B.; Smith, G. O.	*Coal*, *stone*, clay.
55	Fort Benton	Mont	3,234	Weed, W. H	Gold, *silver*, lead, iron, gypsum, *coal*, stone, artesian water.

List of geologic folios showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
56	Little Belt Mountains.	Mont	3,295	Weed, W. H	*Coal*, *silver*, lead, copper, iron, *sapphires*, mineral water.
57	Telluride	Colo	236	Purington, C. W	*Gold*, *silver*.
58	Elmoro	do	950	Hills, R. C	*Coal*, stone, *artesian water*.
59	Bristol	Va.-Tenn	957	Campbell, M. R	*Coal*, iron, zinc, barite, marble, clay.
60	La Plata	Colo	237	Purington, C. W	*Gold*, *silver*, coal.
61	Monterey	Va.-W. Va	938	Darton, N. H	Iron, stone, clay, road metal.
62	Menominee special.	Mich	125	Van Hise, C. R.; Bayley, W. S.	*Iron*.
63	Mother Lode district.	Cal	428	Ransome, F. L	*Gold*, silver, manganese, quicksilver, stone.
64	Uvalde	Tex	1,040	Vaughan, T. W	*Asphalt*, gold, silver, iron, coal, water supply.
65	Tintic special	Utah	229	Tower, G. W.; Smith, G. O.; Emmons, S. F.	*Gold*, *silver*, *lead*, *copper*.
66	Colfax	Cal	925	Lindgren, W	*Gold*, stone, clay, water supply.
67	Danville	Ill.-Ind	228	Campbell, M. R	*Coal*, clay, gravel, underground water.
68	Walsenburg	Colo	944	Hills, R. C	*Coal*, stone, clay, *artesian water*.
69	Huntington	W. Va-Ohio	938	Campbell, M. R	*Coal*.
70	Washington	D.C.-Va.-Md	465	Darton, N. H.; Keith, A.	Gold, iron, clay, stone, road materials, greensand marls, *underground water*.
71	Spanish Peaks	Colo	950	Hills, R. C	*Coal*, stone, gold, silver, *artesian water*.
72	Charleston	W. Va	938	Campbell, M. R	*Coal*, *salt*, *oil*, *gas*, iron.
73	Coos Bay	Oreg	871	Diller, J. S	*Coal*, gold, stone.
74	Coalgate	Ind. T	980	Taff, J. A	*Coal*, stone, clay.
75	Maynardville	Tenn	963	Keith, A	*Marble*, coal, stone, lead, zinc, lime, road materials, clay, water power.
76	Austin	Tex	1,030	Hill, R. T.; Vaughan, T. W.	Oil, stone, lime, clay, cement, artesian water.
77	Raleigh	W. Va	944	Campbell, M. R	*Coal*.
78	Rome	Ga.-Ala	986	Hayes, C. W	*Bauxite*, *iron*, *slate*, lime.
79	Atoka	Ind. T	986	Taff, J. A	*Coal*, stone, clay.
80	Norfolk	Va.-N. C	1,913	Darton, N. H	Sand, clay, *underground water*.
81	Chicago	Ill.-Ind	892	Alden, W. C	*Stone*, clay, molding sand, water power, water supply.
82	Masontown-Uniontown.	Pa	458	Campbell, M. R	*Coal*, *oil*, *clay*, stone, glass sand, iron.
83	New York City	N. Y.-N. J	906	Merrill, F. J. H.; Hollick, A.; Darton, N. H.	*Trap*, *marble*, granite, *road material*, clay, iron, water power, water supply.
84	Ditney	Ind	938	Fuller, M. L.; Ashley, G. H.	*Coal*, gas, clay, stone, iron.
85	Oelrichs	S. Dak.-Nebr	871	Darton, N. H	Stone, gypsum, lime, volcanic ash, *underground water*.
86	Ellensburg	Wash	820	Smith, G. O	Building stone, road metal, *ground water*, *artesian water*.
87	Scotts Bluff	Nebr	892	Darton, N. H	Volcanic ash.
88	Camp Clarke	do	892	do	Volcanic ash.

6. *Mineral Resources of the United States.*—From 1883 to 1894, inclusive, an octavo cloth-bound volume bearing the above title was issued annually, with only two exceptions, the years 1883-84 and 1889–90 being included by pairs in single volumes. The first of this series was Mineral Resources of the United States, 1882; the last, Mineral Resources of the United States, 1893. In 1894 this form of publication was discontinued, in accordance with an act of Congress, and the material was included in certain parts of the sixteenth, seventeenth, eighteenth, nineteenth, twentieth, and twenty-first annual reports. The separate publication of the series on mineral resources was resumed, however, in 1901, in accordance with an act of Congress, and two volumes of the new series, Mineral Resources of the United States for 1900 and for 1901, have been issued.

This publication contains a systematic statement of the production and value of the mineral products of the United States, a summary of new mineral resources developed, and occasionally short papers on economic geology, when necessary in accounting for the new developments.

INVESTIGATION OF METALLIFEROUS ORES.

By S. F. Emmons, *Geologist in Charge.*

INTRODUCTION.

In the years immediately following the organization of the United States Geological Survey its geological work was classed under two broad divisions, namely, general geology and mining geology. The primary object of the latter work was, by careful scientific studies of the most extensive mines and mining districts of the country, to gather together such an array of accurately determined facts with regard to the phenomena of ore deposition as would serve as a basis for generalizations, or laws governing the formation of metalliferous deposits. Incidentally it was expected that a demonstration of the correct geological structure and relations of the deposits in each individual district would prove of immediate practical value to those engaged in mining in that district, and serve as a guide to them in their explorations. This, however, was regarded as of secondary importance compared to the first object, since general laws are useful to mine owners the world over and are not confined in their application to the mines of a certain district.

The commercial interest of mining industry was more directly subserved by the collection of statistics of the mineral resources of the country, which was at first a branch of mining geology. As time has gone on and, with increasing pecuniary resources, the field of work of the Survey has widened, the above-mentioned classification of its work has been somewhat changed in title, as well as in the scope of the different divisions, but the main underlying principles have remained practically the same.

The collection of mineral statistics is of direct commercial value to mining industry, which was readily recognized by the general public, and, direct and generous appropriations having been made for it, it has become a special division.

GENERAL GEOLOGY.

Whereas in the early days but little could be done toward preparing a geological map of the whole country, which is theoretically the prime object of a geological survey, because of the want of the indispensable topographic basis for such a map, so great progress has now been made in the preparation of the topographic map that geological mapping is in an advanced stage, and what was formerly called "general geology" is now mainly comprised under the term "areal geology."

Under the folio form, in which the separate sheets of the Geological Atlas of the United States are published, there appears, together with the topographic and areal maps of the given fraction of a degree which it represents, a so-called economic map. The topographic map represents the physical relief, or shape of the surface; the areal map indicates by color conventions the area occupied on that surface by the different varieties of rocks which constitute the surface, while on the economic map the different rock varieties are so indicated that emphasis is given to those which carry minerals of economic value. Thus, the areal geologic work affords results of economic value, and is, moreover, an indispensable basis upon which all economic studies must be founded.

ECONOMIC GEOLOGY.

What was formerly called "mining geology" is now designated "economic geology," and in late years the scope of this work has so greatly increased that it has been found advisable to have it conducted under two general heads, with a geologist in charge of each, namely, that of "metalliferous ore deposits," and that of "nonmetalliferous deposits," those of iron being included in the latter class because of their close economic connection with coal deposits.

The investigation of deposits of metalliferous minerals as at present conducted comprises several types of work varying with the conditions under which it is carried on. These are: First, the investigation of important and extensive mining districts, such as Cripplecreek, Leadville, etc., which may be called "special district surveys." These are regions of unusually large concentrations of metalliferous deposits, where within a small area the underground workings of a great many large mines have laid open to scientific observation relatively large portions of the interior of the earth, and whose individual outputs form a comparatively large fraction of the total product of the country. Even in cases where such districts have passed their prime from an industrial standpoint, their investigation is of the utmost value, since it affords a scientific record of critical phenomena which furnish material for the formulating of the general laws spoken of above. Hence, this work must be done with the highest degree of scientific accuracy and detail, and it generally occupies the work of at least two field seasons—one by the topographic corps in preparing the necessary maps, and one by the geologists in making the areal and underground surveys.

To the general public, and especially to those who own mining property in a region, it often seems that the publication of such work is unduly delayed, since they are mainly anxious to learn the facts that directly aid in the development of their own property; but from the point of view of those engaged in the work, and who are responsible for a correct determination of the facts of nature, it is more essential that these facts, upon which future generalizations must be based, should be determined with the greatest possible accuracy than that the public demand for prompt publication should be yielded to.

The second class of economic work may be called economic work incidental to areal work. In regions that are under areal survey it often happens that there are considerable mining developments, though the important mines are not gathered together into one small area or district, but occur at points so widely separated throughout the region that it would be inadvisable to survey the whole area with the amount of detail that is given to the work in special districts. In such cases, after the areal surveys have been completed and published, economic geologists are detailed to study the various mine developments of the area with a view to the determination of facts of structure and genesis of the ore deposits examined rather than of their immediate commercial value. Such are the reports on the Telluride quadrangle by Mr. Purington, and on the Silverton quadrangle by Mr. Ransome.

A third class of economic work is the reconnaissance examinations, in which it is not intended to make a complete or exhaustive examination of a mine or district, but such a characterization as may, in a comparatively short time, bring out its most striking and evident features, both structural and genetic. Here again the primary object, from the point of view of the Survey, is the gathering of facts bearing upon the broader questions of structure and origin. As to the practical bearing of such work in determining the probable value in depth of individual deposits in a region which is still in the prospect stage, mining men are apt to have somewhat exaggerated ideas. While a geologist who has had wide field experience in studying mining districts should be able to draw more valuable conclusions as to the future prospects of a region as a whole than the prospector or miner, as to an individual deposit, until it can be studied underground over a considerable extent, both vertically and longitudinally, he can not, as a rule, obtain such scientific data as will enable him to give an authoritative estimate of its probable value.

It has hitherto not been the policy of the Survey to publish this reconnaissance work in all cases. It has been considered that, inasmuch as the very fact of publication of a report by the Survey gives to its statement a measure of official indorsement by the Government, and as courts of law have accorded to such publications an authority as evidence in mining cases equal to that of a text-book on geology or mining, incomplete material or opinions that are confessedly liable to be changed or modified by more complete studies should not be accorded the dignity of a Survey publication. Certain parts of this work, for instance the rapid examinations of mining districts by heads of divisions for the purpose of determining whether or not they should be the subject of official examination in the immediate future, are primarily not intended for publication. Again, visits are often made to a number of different districts for the purpose of determining certain isolated and special facts that bear upon some important generalizations under consideration, and their immediate publication might defeat the end for which they were made.

Facts of general interest, with regard either to special mines or to mining districts, or generalizations from facts gathered in studies of a great many mines or districts, but which are of a more or less tentative nature, have been published from time to time by members of the Survey, under authorization of the Director, in some scientific publication, such as the Transactions of the American Institute of Mining Engineers, thus reaching directly and without delay the class of persons most immediately interested in them, namely, the mining engineers.

The practical working of this system was well illustrated during the Washington meeting of the American Institute of Mining Engineers in 1900. At this meeting papers were read by different members of the Survey, as the result of their independent observations during a series of years, on the following subjects:

Some Principles Controlling Ore Deposition, by C. R. Van Hise.
Secondary Enrichment of Ore Deposits, by S. F. Emmons.
Enrichment of Gold and Silver Veins, by W. H. Weed.
Metasomatic Processes in Fissure Veins, by W. Lindgren.

These papers presented theoretical views upon the processes involved in the formation of ore deposits which the respective authors had been gradually arriving at during their Survey work. In most cases they represented rather preliminary statements, made for the purpose of stimulating discussion and investigation among mining engineers, than final and completed results, such as would be expected from an official publication. Yet this prompt publication has been of the utmost practical importance to mining industry, for the first three papers give a scientific means of answering a question of the most vital interest to the investor in mines, to which, in spite of all that has been written on it, only vague and contradictory answers had hitherto been presented—the question, namely, whether veins (or ore deposits) become richer or poorer with increasing depth. The answer was not categorical, for such answers are seldom possible in so complicated a science as geology, but it explained the manner of formation of the very rich bonanzas which have made certain mines famous and why they are succeeded by leaner ores in depth.

The stimulation of discussion and investigation, which was the general purpose of such papers, has been so fully accomplished in this case that they have been followed by a series of important contributions from the most eminent authorities on the study of ore deposits in Europe, as well as in this country, and all have been gathered together and published in a special volume by the Institute of Mining Engineers. Such publications are not intended to be final. Already, since the appearance of the above-mentioned volume, important modifications of the views therein presented have been suggested, and further important additions to our knowledge of the subject are to be expected from the constantly increasing amount of accurate work that is being done every year by the Survey.

A brief review will now be given of the published results of this work, together with a statement of that which is in progress but has not yet reached the stage of publication.

Economic Publications on Metalliferous Deposits.

During the year 1901 there was published in the Bulletin series, by F. L. Ransome, a volume (Bulletin No. 182) on the Economic Geology of the Silverton Quadrangle, which belongs to the second class of economic publications mentioned above—that is, economic examinations incidental to areal work. The Silverton quadrangle had already been areally surveyed by a party under the charge of Whitman Cross, who has been engaged for a number of years past in making a geological study of the whole region of the San Juan Mountains in southwestern Colorado. Under the system adopted by the Survey, as each fraction of a degree—in this case one-sixteenth, or fifteen minutes—is surveyed topographically and areally, the results are published in folio form, and when mining interests justify it an economic geologist is detailed to work either with the areal party or following it and to make a special study of the mines and ore deposits of the whole area. Such a study had already been made by C. W. Purington of the mines of the Telluride quadrangle, and his results were published as a special paper in the Eighteenth Annual Report.

The whole San Juan region is rich in ore deposits, occurring to an unusual degree in well-defined fissures and also in more irregular forms, called stocks or chimneys, which carry values in gold, silver, copper, lead, and zinc. The Silverton quadrangle, which lies next east of the Telluride, contains, like the latter, a large number of important mines within its area. In many of these the richer ores or bonanzas have been extracted and they are, for the time being, abandoned; others, such as the Camp Bird, Silver Lake, and Tom Boy, are in active operation. The record obtained from the latter is naturally the most valuable, but the former also afford data of importance.

This report contains not only a statement of the geological relations of each important deposit in the area which must prove of practical value to those engaged in mining there, but some very valuable generalizations which Mr. Ransome was able to make from the lode fissures and stocks or masses, also a statement of their contained minerals and their paragenesis and origin, as well as important contributions to the new theory of enrichment of ores by descending waters.

It is to be noted that under the new system of gratuitous distribution of such papers, recently ordered by Congress, the edition of this report was exhausted within a few weeks of its appearance.

In Bulletin No. 178, W. H. Weed has given the result of a reconnaissance examination of tin deposits in the Franklin Mountains, near El Paso, Tex. The openings upon these deposits were too shallow to afford very satisfactory data as to their probable value or continuity, and the paper is mainly useful as proving the actual occurrence of tin minerals at the locality named, since the existence of such minerals has often been announced without any satisfactory basis of fact.

Bulletin No. 186, on Pyrite and Marcasite, by H. N. Stokes, though more strictly classed as a chemical paper, deserves mention here because it represents the results of experimental observations on the chemical processes which take place during the secondary enrichment of ore deposits.

These investigations were undertaken by the division of chemistry and physics at the request of the geologists who had read papers upon this subject at the Washington meeting of the American Institute of Mining Engineers, and who felt that the theory needed confirmation from the chemical side, since, while their field studies had shown that certain conditions produced certain results, they necessarily could not demonstrate the actual chemical processes by which those results had been brought about.

Part II of the Twenty-Second Annual report, forming a volume of nearly 900 pages, published in 1902, was devoted exclusively to reports upon ore deposits. These were:

(1) The Old Tungsten Mine at Trumbull, Conn., by W. H. Hobbs.

This is a geological description of an abandoned mine in a locality which had long been classic for the fine mineralogical specimens obtained there. While not important from an economic point of view, the paper is valuable as furnishing data with regard to the manner of occurrence of the rare tungsten minerals—hübnerite and scheelite.

(2) Lead and Zinc Deposits of the Ozark Region, by H. F. Bain and C. R. Van Hise.

This report was made in response to a demand for a prompt preliminary statement concerning the lead and zinc ores of the Ozark region. It is both areal and economic in character, and in some respects in the nature of a reconnaissance, since it was not possible under the circumstances to make the study exhaustive, and work is still being carried on in the region. Perhaps its most important result is the practical demonstration and confirmation of Professor Van Hise's theory with regard to the agency of surface waters in redistributing and enriching the lead and zinc deposits of the Mississippi Valley region, and the indication of the practical deductions that may be drawn therefrom to guide the miner in his search for ore.

(3) Ore Deposits of the Rico Mountains, Colorado, by F. L. Ransome.

This area is also situated in the San Juan Mountains, and the economic work followed an areal survey by Mr. Cross and his party, but the conditions there differ from those in the Silverton quadrangle, in that the ore deposits are concentrated within a limited area. It could thus be properly made the object of a special survey, especially as the peculiar nature of the ore deposits renders it unusually worthy of such detailed study. Unfortunately, by the time the Survey was in condition to undertake this examination the principal mines had been practically worked out and a large proportion of their underground workings had become inaccessible. This fact has given rise to some unfavorable criticism of the methods of the Survey on the part of those who consider that the most important result of its work is the immediate aid afforded by it to the miner in the development of the mines of the particular district under survey. In this case geological conditions are such that it would have been impossible to make a satisfactory study of the ore deposits until the peculiarly complicated geology of the whole quadrangle had been worked out. Furthermore, few mining districts present conditions so favorable for a definte determination of some of the underlying principles controlling ore deposition, conditions which the able mining engineers who had at different periods had charge of the principal mines of the district had of necessity been unable to completely understand, because the true geological relations of the deposits were not yet known.

Mr. Ransome's report, in spite of the obstacles he had to contend with in making the examination, gives a remarkably able and satisfactory delineation of the conditions governing ore deposition along bedding planes of limestone under impervious shales, in part replacing a bed of gypsum, and associated with well-defined fissure systems and differential movements along bedding planes, and of the genetic connection of its deposition with the intrusions of igneous rock in the immediate vicinity. It constitutes a most valuable contribution of well-determined facts bearing upon the general theory of ore deposits.

(4) Geology and Ore Deposits of the Elkhorn Mining District, Montana, by W. H. Weed and Joseph Barrell.

This is mainly the study of one great mine; a mine, moreover, that is practically worked out, and to which are applicable the same criticisms that were made of the Rico report. Here, also, the study has been extremely fruitful in presenting facts bearing upon the formation of a rather unusual type of ore body. The deposit is considered by Mr. Weed to be in the nature of a saddle-reef deposit, formed in crushed limestone under a shaly roof within arches of pitching anticlines. He further considers the ore to have been deposited by hot solutions rising from a cooling batholith of eruptive rock. There is also evidence of secondary sulphide enrichment in the ore.

(5) Gold Belt of the Blue Mountains of Oregon, by W. Lindgren.

This report is the result of an elaborate reconnaissance examination made by the author in the summer of 1900 of an area somewhat over 50 by 100 miles in extent. It shows the ability and thoroughness that characterize all of Mr. Lindgren's work, and will no doubt prove a useful source of information to those engaged in mining in that region. In actual scientific results such work is generally less fruitful than would have been the same amount of time and labor devoted to a smaller area containing well-developed mines.

(6) Ore Deposits of Monte Cristo, Washington, by J. E. Spurr.

This, the final report of the volume, is also in the nature of a reconnaissance, since the region had not been previously mapped geologically and the available topography was on so small a scale as to afford a very imperfect base for his geological observations. His time was also limited; nevertheless, as the area was small ($3\frac{1}{2}$ by 4 miles), he was able to make as fairly complete a study of the deposits and map the geology in as much detail as the economic importance of the region demands. His general conclusions are, first, that the ore occurs mainly as replacements of certain igneous rocks and to a less extent as the filling of open spaces; second, that they have been deposited by descending waters, and hence that the best deposits will be found relatively near the surface.

The other economic publications that have appeared during the year 1902 are:

Bulletin No. 193.—Geological Relations and Distribution of Platinum and Associated Metals, by J. F. Kemp.

This is an account of few known occurrences of platinum and associated metals throughout the world, based upon the published literature on the subject and supplemented, in the case of a few occurrences in this country and Canada, by personal observations of the writer. It contains also a discussion on the mineralogical association and probable origin of these metals.

Professional Paper No. 1.—Ketchikan Mining District of Alaska, with an Introductory Sketch of the Geology of Southeastern Alaska, by A. H. Brooks.

This is the first paper of a new series of quarto publications by the United States Geological Survey, authorized by the law of Congress of May, 1902, which confines the report of the Director to a single volume, and directs that these papers, like the bulletins, shall be distributed gratuitously. It is a reconnaissance report on the present mining development of this large district of southeastern Alaska, which includes Prince of Wales Island and the adjoining mainland. It is accompanied by a sketch of the geology of those parts of southeastern Alaska that have been visited by members of the Survey.

Economic Work on Metalliferous Deposits now in Progress.

In enumerating the different pieces of work which have not yet reached the stage of completion, the order followed will be geographic, taking each State and Territory, in which actual work has been done, in alphabetical order.

APPALACHIAN REGION.

Mining in the Appalachian region, except for iron and coal, has been conducted mainly in widely separated localities, and there are few concentrations of metallic deposits which form mining districts comparable to those in the West; hence hitherto no studies of special areas have been made. In the course of journeyings, however, observations have been made in different parts of the region, especially by Mr. Weed, of the copper deposits, many of which have been reopened since the rise in the price of this metal. On later pages he gives an interesting summary of observations on various of these deposits, notably in New Jersey, along the contacts of the trap bodies which break through the Triassic rocks, in the interior of Maryland, and in the southern part of Virginia and North Carolina. Such observations will be continued from time to time as the conditions of Survey work admit.

ARIZONA.

The copper production of Arizona has in recent years assumed an economic importance rivaling that of the Lake Superior region and of Butte, Mont., which up to a comparatively recent date had together furnished more than two-thirds of the entire copper output of the country. Its principal mines had in consequence been developed to such an extent that their study promised to yield valuable data of vital importance in the theory of ore formation, especially in the line of secondary enrichment, a process which is particularly active in warm and arid climates. Since the commencement of the decade, therefore, considerable economic work has been done in this Territory, of whose geology up to this time but little was known. The following areas have been studied:

Bradshaw quadrangle.—This area was geologically surveyed during the summer of 1901 and its economic resources studied, as far as their development permitted, by T. A. Jaggar, jr., and Charles Palache, instructors of geology at Harvard University. Under ordinary circumstances it would have been more logical to have commenced work in this region on the Jerome quadrangle, which adjoins the Bradshaw on the northeast, but work in this area would have necessarily been incomplete because members of the Survey had been refused admission to the most important copper mine of the region, the United Verde, by the owner of the mine, for reasons best known to himself.

The Bradshaw quadrangle contains important deposits of both copper and gold in the same series of rocks in which those of the United Verde occur, but developments on most of them had, unfortunately, not been pushed to any great depth. The ores occur mainly as vein deposits in old Algonkian schists associated with eruptives. One important result of the work has been to detect a tendency in the ore deposits to arrange themselves peripherally around the bosses of the granite which outcrop in the area. The results of this work will be published in folio form.

Globe quadrangle.—This area was surveyed and its mines and ore deposits studied in the autumn of 1901 by F. L. Ransome, assisted during part of the time by J. D. Irving. It lies to the southeast of the Bradshaw quadrangle and in a similar relation to the great Plateau region of northeastern Arizona. It includes the important mines of the Old Dominion and United Globe companies, together with many other deposits, of both copper and silver, which are mostly replacements of limestone associated with eruptive rocks. The report on this district was completed during the summer of 1902 and will shortly appear as Professional Paper No. 12.

Clifton-Morenci quadrangle.—This area lies still farther southeast, near the borders of New Mexico and also not far from the southwestern edge of the great Plateau region. The three areas just mentioned thus give important data as to the remarkable change of structure from the horizontal attitude and comparatively undisturbed position of the strata in the plateau to their extremely broken and complicated structure in the ranges of the Basin region. This area, which is of even greater economic importance than either of the other two, was studied by W. Lindgren, assisted by J. M. Boutwell. The field work was commenced in the autumn of 1901 and continued well on into the spring of 1902. The ore occurs mainly in limestone and associated eruptive rocks. Mr. Lindgren is now engaged in the preparation of his report, of which a brief summary is given on later pages.

Bisbee mining district.—This district was studied in 1892 by F. L. Ransome, assisted by J. Morgan Clements and A. B. Rock. The area lies in the extreme southern part of the Territory, near the Mexican boundary line. It has long been one of the most important copper producers of the Territory, and, as in the last-named district, mining has received a new impetus as the result of the recent impulse given to copper mining in general through the increased demand for the metal and its consequent rise in price. The ores occur in limestone near eruptive rocks, but without the contact phenomena that characterize the Clifton-Morenci deposits. They present remarkably clear evidence of secondary enrichment by descending solutions. Mr. Ransome is at present engaged in preparing his report of the region, of which a brief statement is given in this bulletin.

CALIFORNIA.

Shasta County.—The copper deposits around the head of the Sacramento Valley in California have been assuming considerable economic importance of late years, and as they present a somewhat different type from those hitherto studied it has been judged wise to make a special study of them. In preparation for this work J. S. Diller was engaged during the summer of 1902 in making an areal survey of the Redding quadrangle, which includes the most important copper deposits. He has prepared a brief summary of the results of his work, showing the general geological relations of the deposits. Detailed topographic maps are now being prepared of the smaller areas, in which the most important ore bodies occur, preparatory to special economic surveys, which will be made as early as practicable.

Neocene river systems of the Sierra Nevada.—A very large proportion of the gold product of California is derived from gravels deposited in the beds of rivers belonging to an ancient system of drainage quite distinct and independent of the present river system of the Sierra Nevada. These gravels are now buried beneath more recent deposits and lava flows, and it is of great importance to miners to be able to trace their probable position in still undeveloped areas.

In the course of his areal studies of the geology of the Sierra Nevada Mr. Lindgren had accumulated a great many facts concerning the location of these ancient river beds, parts of which had been studied and mapped by the able engineers in charge of various large hydraulic mining undertakings. During the summers of 1901 and 1902 Mr. Lindgren was able to devote part of the time allotted to field work to a further examination of the Sierra Nevada region for the special purpose of supplementing his previous observations so as to give a comprehensive view of the whole river system and to enable him to map the probable course of the earlier or Neocene rivers. In this study, which is largely of a physiographic nature, he has been efficiently aided by J. M. Boutwell. It is a work which necessarily requires very careful platting and much deliberate consideration. It will be prepared for publication as rapidly as the press of work admits. Its condition is more fully described by Mr. Lindgren on later pages.

COLORADO.

In Colorado no new economic surveys have been commenced during the last three years. The writer, assisted by J. D. Irving, has continued the gathering of data for a supplemental report on the geology of the Leadville district during such time as could be spared from his regular duties of supervising the work in other fields. This work will be mainly of scientific interest, as at this late day it can hardly be of much value in directing the explorations of those engaged in mining. It will be chiefly valuable in furnishing a record of the immense ore bodies that have been mined in the district during the last twenty-five years, in showing the possibilities and limits of geological induction by contrasting their actual geological relations with those predicated in the first report from such facts as were open to observation. It will also afford further data for testing and modifying the theories of ore formation propounded in that report. Circumstances are such that it is impossible to determine when this report will be ready for publication.

IDAHO.

Mineral deposits of the Bitterroot Range and Clearwater Mountains.—In the summer of 1899 Mr. Lindgren was engaged in making a geological reconnaissance in those parts of Idaho and Montana lying north of the Salmon River and extending from the Bitterroot Valley westward to the lava plains of the Columbia. In the course of this work he observed the scattered ore deposits that are developed in this region, without, however, having time to make an exhaustive study of them. The area is largely of granite, with some sedimentary quartzites, slates, and limestones, principally upon the borders. It is notable that in the central part of the granite area no important ore deposits have yet been discovered. In the subsequent pages Mr. Lindgren gives an interesting summary of his observations and of the structural relations of the various deposits observed.

MISSISSIPPI BASIN.

Studies have been made during the summer of 1902 in the Mississippi Valley region, first, of the lead and zinc deposits of northern Arkansas by G. I. Adams, and, second, of the lead and zinc deposits of the Joplin district of Missouri and of the lead, zinc, and fluorspar deposits of western Kentucky by W. S. Tangier Smith.

All these deposits belong to a general type geologically distinct from those found in the mountains of the West, and are of special interest on that account. Brief summaries of the results thus far obtained will be found on later pages of this volume.

MONTANA.

Copper mines of Butte.—The first study of the extremely important vein deposits in granite at Butte Mountain was made in the summer of 1896, and the results were published in folio form the following year. Not long after the completion of this report, as a consequence of litigation which sprung up between the most important mining companies of the region, a great deal of underground exploration was done for the express purpose of ascertaining more accurately the geological structure and relations of the vein. So many new facts were thus learned, and so important was their bearing upon the theory of vein formation, that it was judged wise to make a second and more exhaustive study of the copper veins of the region. This has been carried on by Mr. Weed and his assistant since the spring of 1901 almost continuously, though his work has been interrupted at times by the necessity of completing other pieces of work. It was not thought best to hurry this work to completion, for the reason that the geological questions at issue had most important bearing in the litigation that was going on, and it was desired to avoid, as far as possible, influencing the results of this litigation, lest there might be a feeling that the opinions expressed, which must necessarily favor one side more than the other, indicated a partiality to the favored side. The work is now approaching completion, but, on account of its magnitude, will not be published for some time. A brief summary of the important results is given by Mr. Weed on later pages.

NEVADA.

A new mining district in southern Nevada has sprung into sudden prominence by its shipment of rich gold ores to the smelters, especially at Salt Lake. Nevada has hitherto been regarded as essentially a silver-producing State, and mining there has languished since the fall in the price of the white metal, hence the development of its gold resources is of the greatest importance. A brief account by the writer of the important gold mine at De Lamar, in southeastern Nevada, was published in the Transactions of the American Institute of Mining Engineers in 1901.

During the autumn of 1902, J. E. Spurr, after assisting Mr. Spencer in the Grand Encampment work during October, was detailed to examine this new (Tonopah) district of Nevada. He had been taken ill with typhoid fever just at the opening of the field season in July, hence was obliged to commence his field work at so late a date that he found it advisable during the winter to make microscopical and chemical studies of his rock specimens at Washington. He will complete his field work in the spring and early summer, and a reconnaissance will then be made of neighboring mining districts in the Silver Peak quadrangle and elsewhere.

SOUTH DAKOTA.

Economic Resources of the Northern Black Hills, by J. D. Irving and S. F. Emmons.

This work was designed to be published in conjunction with the Sturgis-Spearfish folio, for which the field work was completed some years since. Its publication has been delayed by the calling off of the principal author, T. A. Jaggar, jr., to other duties, notably to the study of the volcanic eruptions in the West Indies in 1902. As soon as his introductory sketch of the geology of the region is received the manuscript will be sent to the printer. It comprises an account of the geological relations of the various ore deposits of the region, mainly gold bearing, and a partial sketch of the famous Homestake lode, which is, unfortunately, incomplete because permission to enter the mine was withdrawn by the management before the study had been completed.

WYOMING.

During the summer of 1902 a geological party, under charge of A. C. Spencer, was engaged in an areal survey of the Grand Encampment Mountains, of Wyoming, and in a study of the copper deposits occurring there. The writer spent some time with this party in the summer, and also examined the important deposits of the New Rambler mine, in the Medicine Bow Range, on the opposite side of the North Platte Valley. The mines in this region are as yet opened to only moderate depth and the study of their deposits can not yet be expected to yield important data bearing upon their genesis, but the extremely detailed and careful study of the very complicated geological structure of the region made by Mr. Spencer and his associates will probably be of service in helping the development of its mines, and will certainly be an important contribution to our knowledge of the geology of the Rocky Mountain system. An abstract of this work is given on later pages.

INVESTIGATION OF NONMETALLIFEROUS ECONOMIC MINERALS.

By C. W. HAYES, *Geologist in Charge.*

The distinctly economic work being done by the Geological Survey has shown a steady growth in extent and importance since its organization in 1879. As pointed out by Mr. Emmons, this was at first directed largely to the investigation of the ore deposits of the precious and semiprecious metals—gold, silver, mercury, copper, etc. With the extension of areal mapping in preparing the Geologic Atlas of the United States, investigation of the more widely distributed ores of iron, manganese, and aluminum and the nonmetalliferous minerals, as clay, stone, phosphate, coal, asphalt, oil, and gas, was taken up. The natural grouping of these two classes of mineral products and the importance of their investigation were recognized by organizing, within the Geologic Branch of the Survey, in 1900, the two sections of metalliferous ores and nonmetalliferous economic minerals. Since that time systematic investigations of the nonmetalliferous minerals have been carried on, both in connection with areal geologic mapping and independently of areal work. It is impossible to describe in detail all of the work of this kind which has been done by the Survey, but its character and extent may be indicated by a brief mention of some of the more important investigations carried on in recent years.

The nonmetamorphic iron ores have been studied chiefly in connection with areal mapping, and their distribution is shown in the geologic folios for considerable areas in Virginia, West Virginia, Tennessee, Georgia, and Alabama. The same is true of manganese, ocher, stone, and slate.

All known occurrences of bauxite, the ore of aluminum, have been visited and examined by Hayes.

The slate quarries of Vermont and eastern Pennsylvania have been examined by Dale, and the more important slate localities in the Southern States by Keith and Hayes.

Special studies of the marble belt of Vermont have been made by Dale, and Keith has mapped the marble of East Tennessee.

The phosphate deposits of Florida have been investigated by Eldridge, and those of Tennessee by Hayes, Ulrich, and Eckel.

Investigation of the coal fields of the United States has been of two kinds, detailed areal mapping and general summaries. Under the first class of work large areas have been covered in the Appalachian coal field, and the results have been published in numerous folios. The work in Pennsylvania and West Virginia has been carried on by Campbell and his assistants; in Tennessee by Campbell, Keith, and Hayes, and in Georgia and Alabama by Hayes. Work has also been done in southern Indiana by Campbell, Fuller, and Ashley; in the southwestern field in Indian Territory by Taff and Adams; in the Rocky Mountain fields in Montana and Colorado by Weed, and in the Pacific fields by Diller, Willis, and George Otis Smith.

The principal work of the second class has been the preparation of a series of papers, 12 in number, summarizing existing knowledge relating to coal fields of the United States. These are more fully described on later pages.

The investigation of oil and gas fields has only recently been taken up. During the last year certain portions of the Appalachian field have been studied by Campbell, Griswold, and Fuller. The work of Griswold in the Cadiz field is especially noteworthy, since it is the most successful attempt thus far made to work out the structure of the oil-bearing sands by instrumental means and with a high degree of accuracy. A thorough reconnaissance of the oil fields of California has been made by Eldridge, and of the Texas-Louisiana fields by Hayes and Kennedy. The Boulder oil field of Colorado has been studied by Fenneman.

All known asphalt deposits of the United States have been examined and reported upon by Eldridge, and those of Arkansas and Indian Territory have been examined in detail by Hayes, Adams, and Taff.

A general reconnaissance of the clay resources of the United States east of the Mississippi River has been made by Ries, and his report is now in press. Detailed studies of particular deposits have been made by Vaughan in Georgia and Florida, and by various geologists in connection with their areal mapping.

Important economic work has also been done under the section of pre-Cambrian geology, especially upon the iron ores of the Lake Superior region. All of the iron-bearing districts have been studied by Van Hise and his assistants, Clements, Bayley, and Leith, and reports are either published or in press. Also under the supervision of Van Hise the lead and zinc mines of the Mississippi Valley have been examined in the Ozark region by Bain, Adams, and Tangier Smith, and in western Kentucky by Ulrich and Tangier Smith.

GOLD AND SILVER.

In addition to the papers here included, which represent the results of recent work by the Survey in important precious metal mining districts, other reports bearing incidentally on the subject of gold and silver will be found under the head of "Copper," on pages 105 to 186.

PROGRESS REPORT ON THE PARK CITY MINING DISTRICT, UTAH.[a]

By J. M. Boutwell.

INTRODUCTION.

Field work.—During the field season of 1901 two detailed topographic maps of portions of the Park City district were prepared by this Survey under the direction of E. M. Douglas, geographer in charge, by Pearson Chapman and J. F. McBeth. The general map, showing an area of approximately 32¼ square miles on the scale of 3 inches to 1 mile, embraces the general area in Park City through which mining operations have been conducted; and the other, on a scale of 1 inch to 1,000 feet, or 5.2 inches to a mile, includes only that portion of this area which lies in immediate proximity to the largest producing mines.

Late in the field season of 1902 a detailed study of the areal and economic geology of the Park City mining district was undertaken by J. D. Irving and J. M. Boutwell, under the supervision of S. F. Emmons, geologist in charge of metalliferous deposits, and was continued into December of that year. This was the first systematic geological work in this region since Emmons mapped the broad features of the range in 1869, while engaged in the "Geological Explorations of the Fortieth Parallel," under the late Clarence King, and was the first detailed geological examination of an extended area in the Wasatch Range. Before detailed work in the area under survey could be advantageously undertaken a general knowledge of the geological history of this portion of the range and the establishment of the geological succession were required. Accordingly, the general geology of the region surrounding the special field of work, including the main divide of the Wasatch Range to the west, its

[a]This sketch is merely a preliminary statement indicative of progress. A complete report will be published after a detailed survey has been completed.

eastern slope, and the adjacent portion of the Uintas to the east, was studied en reconnaissance, and detailed stratigraphical sections in the nearest undisturbed areas were examined and measured. The area included in the general map of the Park City district was then traversed, a considerable part of this area and also of that shown on the map of the region immediately about the mines was mapped in final form, and a reconnaissance study of the chief mines was conducted.

During the few weeks which have elapsed since the close of these field studies the nature of the writer's work has not enabled him to obtain any significant results from mineral and rock determinations and the correlation of geological data from this district beyond those which were gained in the field. It should be understood, therefore, that while broad geological conclusions have been reached, and in some cases detailed results secured, final conclusions regarding areal and economic problems have not been attained. In view of this fact it is a matter of some doubt as to how much value may lie in these general statements, based upon incomplete and unstudied data. The following brief statement is presented, however, in the hope that it may be of some service in the extensive development which is now in active progress. Only the general geological facts thus far determined, and such broad economic features as seem least likely to be altered by detailed underground studies, are given, and the statements are to be regarded as field opinions and tentative conclusions, subject to partial or complete modification after further field work.

After briefly touching on the geography, history, and production of the district these general preliminary results will be given under the following headings: Under "Areal geology" will be discussed the stratigraphy, igneous rocks, and structure; and under "Economic geology" will be treated the character and occurrence of ore and present mining activity.

Geography.—Park City is pleasantly situated on the eastern slope of the Wasatch Range, in the north-central part of Utah. It lies about 25 miles southeast of and 3,000 feet above Salt Lake City, at an elevation of 7,200 feet above sea level. In its location on the southern edge of a high-lying mountain prairie, at the junction of three great canyons which there descend to the prairie from the main range, this thriving mining town (population, census 1900, 3,759) has a position of rare commercial value. A branch line of the Rio Grande Western unites it by way of Parleys Park with Salt Lake City (35 miles), and a branch line of the Union Pacific (28 miles) extends from the main line at Echo. It thus forms a most convenient outlet point for the producing mines of the district, which are all located on the slopes of the canyons which rise from this point southward.

The Wasatch Range in the portion south of Salt Lake City is a lofty mountain unit, trending generally north and south between the Great Basin on the west and mountainous plateau regions on the east.

Its western slope presents a wall-like front of striking steepness, which is deeply incised at regular intervals by narrow rock-walled canyons. The portions intervening between these canyons show a marked type of dissection, which is characterized by ravines that rise from the level of the desert with steep sides and bottoms, and fork repeatedly and symmetrically upstream. The eastern slope, in marked contrast, is a gradual descent to upland ranges, plateaus, and high-lying meadows, which extend in a north-south belt along the eastern base of the range. This unsymmetrical range may thus be compared to a mammoth step, about 3,000 feet in height, from the Great Basin on the west up to the highlands which extend from its upper portion eastward. That part of the upland which adjoins this range is drained by streams which flow westward through the great canyons into the basin.

The Park City district embraces a tract which lies between the precipitous walls of barren rock, inaccessible cliffs, and ledges that mark the crest of the main range to the west, and the grassy, verdant, mountain meadows of Heber, Kamas, and Parleys, along its eastern foothills. This intermediate belt lies upon the northern portion of a prominent spur which stretches from Clayton Peak in the main range toward the east. This spur forms the headward portion of East Canyon, divides the Weber from the Provo, and is the connecting link between the Wasatch Range and the Uinta uplift. It comprises three topographical divisions—a steep slope southward, which overlooks an extensive, relatively level tract to the south, Bonanza Flat; a gradual descent northward, which is deeply cut by four narrow, steep-sided gulches, Thaynes, Woodside, Empire, and Ontario; and a long, steep, deeply incised slope eastward, which unites the Park City upland with the prairie belt.

The climate is remarkably bracing, with short, cool summers, short autumns, and long rigorous winters marked by heavy snowfalls and low temperature. Being on the protected sunny side of the range, however, it escapes much of the harshness of such conditions which neighboring canyons suffer. Water, although hardly abundant, is not scarce. Springs and currents cut by underground workings supply a constant flow of water the year round. Natural rock basins at the foot of the pinnacle of Clayton Peak are utilized as reservoirs, and a supply of water which is sufficient for domestic purposes is obtained from the Alliance tunnel. The outflow from the Ontario drain tunnel, which is generally believed to include the drainage from a large portion of the great mines, furnishes the power for the Park City electric-light plant. Although the slopes originally supported a growth of pine timber 3 to 5 feet in diameter, this was early utilized for underground timber. Fuel is supplied from extensive veins of good coal at Coalville, 28 miles to the north, and from the forest growth on the distant portions of this and the Uinta ranges.

History.—The earliest mining in this part of Utah was in the Miller mine, at the head of American Fork Canyon; in the Emma, Flagstaff, and other mines near Alta, at the head of Little Cottonwood Canyon; and in the adjoining districts at the head of Big Cottonwood Canyon and Snake Creek. In those days the Miller and Emma were famous mines and the Park City region received slight attention. Although desultory mining had been carried on in this area on various properties, such as the Pioneer, Clara Davis, Badger, White Pine, McHenry, etc., for a few years previous, actual mining may be said to have begun with the discovery of the Ontario mine; and the early history of this mine is generally considered to constitute the early history of the camp.

The Ontario mine is generally believed to have been discovered by Rector Steen and his associates "about June 15, 1872." He describes the discovery as follows:

> When we discovered this mine we found a little knob sticking out of the ground about 2 inches. We scraped the dirt off the lead about 50 feet along the lead. It was about 18 inches wide, and when we got down 8 feet it narrowed in to 8 inches. We had the rock assayed and it went from 100 to 400 to the ton.[a]

On August 21 of the same year the discoverers sold the property to Messrs. Hearst and Stanley for $30,000. During the succeeding years development work was energetically conducted through tunnels from the main ravine. In April, 1878, the first shaft was started. Since then two more shafts have been sunk (the deepest recently attained a depth of 2,000 feet), and extensive underground development work has been in constant progress. As a result of these operations since its final incorporation in 1883, this property has produced silver which has been sold for $33,255,950, and since 1901 dividends amounting to $13,752,500 are stated to have been paid.

The success which attended these operations stimulated exploring and locating throughout the district, and the ground through which the Ontario lode was supposed to extend from the northeast to the southwest was quickly taken up and developed. This resulted in the extension of successful mining operations to the west, in the ground now owned and operated by the Daly, Daly-West, and Daly-Judge mining companies. In 1880, eight years after the discovery of the Ontario, there were 1,270 mining locations registered in this (the Uinta) mining district, although only 500 were active. Development progressed steadily until 1893, when the decline in the price of silver seriously crippled the camp. Improvement in the lead market, the high grade of ores, and important improvements in the treatment of ores made it possible to resume mining activity at an early date,

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[a] Mr. Steen, who is still enjoying good health after a succession of arduous hardships encountered in prospecting in California, Montana, Wyoming, and Arizona, previous to his discovery of the Ontario, has kindly supplied valuable data concerning the early history of this camp, which will be included in a detailed historical sketch in the complete report.

and this activity has continued and increased consistently to the present time. Since the middle nineties, when valuable ore bodies were discovered, outside of the previously productive area, in the Mayflower, Woodside, and Silver King properties, exploration has been carried on over a large tract, and the productive area has been widely extended. At present mining is extensively conducted in the Silver King, Daly-West, Ontario, and Daly-Judge properties; important work is being carried on in the Kearns-Keith, Keystone, California, Comstock, and other properties on the west; in the Little Bell, J. I. C., and Thompson groups on the south; and in the Naildriver, Wabash, New York, etc., on the southeast. Work is contemplated for the coming season by owners of various properties on the eastern and northeastern borders of the district.

Production.—The product of the Park City mines consists chiefly of silver, and, in minor quantities, of lead, copper, and gold. The proportionate value of these four metals (silver, lead, copper, and gold) in the present output may be roughly stated as 9.1 to 2.6 to 0.39 to 0.28. The quantity and value of the output have increased strongly in recent years, and may be reasonably expected not only to have increased in 1902 but to continue that increase in the immediate future. The following table, taken from the report by B. H. Tatam in the Annual Report of the Director of the Mint for 1901, shows the kind, quantity, and value of ore produced in Salt Lake County, Utah (practically entirely from Park City), during the years 1900 and 1901.

Kind, quantity, and value of ore produced in Salt Lake County, Utah, during 1900 and 1901.

Metal.	1900.		1901.		Increase.
	Quantity.	Value.	Quantity.	Value.	
Gold ....fine ounces..	9,093.375	$187,976.74	13,731.376	$283,852.73	$95,875.99
Silver (coining value), ...fine ounces..	3,931,205	5,082,770.10	7,060,623.56	9,128,887.03	4,046,116.93
Copper........fine pounds..	703,369	113,875.44	2,477,080	399,230.98	285,355.54
Lead.................do....	46,982,647	2,053,141.67	60,232,236	2,610,465.11	557,323.44
Total..................	....	7,437,763.95	....	12,422,435.85	4,984,671.90

AREAL GEOLOGY.

General geology of the region.—In its geological structure the Wasatch Range presents a type of extreme complication, contrasting strongly with the simplicity and regularity of its nearest neighbor, the Uinta Range. The simplest expression of this structure would be that of a sharp north and south anticlinal fold over preexisting ridges of granite and unconformable Archean beds, whose axis has been so bent and contorted by longitudinal compression that it at times assumes a direction approximately east and west. In connection with the folding has been developed a widely-spread system of faulting and dislocation, in a direction generally parallel with the main line of elevation, which has cut off and thrown down the western members of the longitudinal folds and the western ends of the transverse folds, which are now buried beneath the valley plains, while the detailed structure has been still further complicated by a system of transverse faulting. * * * [a]

That portion of the range which is included between Utah Lake and Emigration Canyon forms a geological whole, consisting of a series of sedimentary formations, flexed around a body of * * * granite. * * * Horizons from the Cambrian up to the Middle Coal Measures are at different points in contact with the granite body. * * * Of the immense arch which once covered this body the western half has been faulted down, while the top of the arch, with its thickness of 30,000 feet of rock masses, has been broken up and worn away by atmospheric agencies.[b]

The composite crystalline mass comprising the granite of Lone Peak and Little Cottonwood Canyon, the granodiorite at the heads of Big and Little Cottonwood canyons, American Fork, and Snake Creek (Provo), and the diorite at the heads of Big Cottonwood, East Canyon, and Snake Creek, with its extensions northeast through the Park City district, in the form of dikes, is the dominant factor in the greater geological structure of the middle Wasatch. The ages and the relationships of these great intrusive masses have not yet been completely established. In a broad structural sense the bodies may be regarded as forming an immense composite laccolith. In this light the striking obliteration of the normal anticlinal structure of the Wasatch, and the marked quaquaversal dip in this immediate section, become significant. The Algonkian on the west, the Cambrian to Mesozoic on the north, the Carboniferous on the east, and the Cambrian to Carboniferous on the south, each dipping away from this intrusive center, are seen to be the flanks of a great laccolithic dome. This main structural feature, supported by the evidence afforded by the intrusive character of the contact between the crystallines and the clastics, by the marmorization and deformation of the adjacent country rock, and by the occurrence of an unusually complete series of typical contact-metamorphic minerals, is conclusive as to the part this intrusive mass has played in the history of the region.

Stratigraphy of the district.—The stratigraphical series in the immediate vicinity of Park City has been so modified by faulting, intrusion, and metamorphism that no reliable extended section could there be found. One on the north side of Big Cottonwood Canyon, between 1 and 2 miles west of Park City, was studied in detail. As several requests have been received for information regarding this section, for the purpose of establishing the relative position of the ore-bearing members in this mining district, a general summary of that section is given. The sedimentary series includes three chief rock types—quartzite, limestone with calcareous sandstone, and shale. In general, the succession (from the older to the younger), the thickness,

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[a] Emmons, S. F., U. S. Geol. Expl. 40th Par., Vol. II, p. 341.
[b] Ibid., pp. 353-355.

and the probable age of the larger divisions are as follows: (1) limestones of unproved thickness, probably of Lower Carboniferous age; (2) 1,500 feet of massive normal quartzite, unfossiliferous, probably of Upper Carboniferous age; (3) 590 feet of calcareous beds, mainly blue limestone, with some shale, of Carboniferous age; (4) 1,100 feet of red shale and sandstone, probably of Mesozoic age; (5) 450 feet of calcareous sandstone, interbedded limestone, shale, etc., Mesozoic; (6) 140 feet of red shale, Mesozoic; (7) 630 feet of limestone, calcareous sandstone, and gray shale, Mesozoic; and (8) an unproved thickness of red shale, Mesozoic (?).

The correlation of members of this series throws light upon their relation to the ore-bearing rocks in neighboring mining regions. The lowest limestones here may be tentatively correlated with those on the divide north of Alta and with those which underlie the main ore-bearing series at Bingham. Accordingly the main quartzite of Park City may be tentatively correlated with the great quartzite series in lower Weber Canyon in the vicinity of the railroad tunnels and with the main quartzite at Bingham. Valuable data upon the geological history of this region have been secured in the course of this stratigraphical study. They will not be considered in the present abstract, however, since the character of the country rock is of more direct economic interest.

Igneous rocks.—Within this area igneous rocks of three types have been found—a fine, even-grained dioritic type, a coarser porphyritic type, and a poorly defined type which ranges from andesitic to basaltic facies. The first two are intrusive in origin; the last, so far as it may be judged from the present incomplete data, is extrusive or volcanic in origin.

The origin of these rocks bears directly upon two practical matters of deep importance to mining men—the extent and the origin of ore. The extrusive or volcanic rocks (those which flowed out upon the surface) are often found to be in the form of a blanket overlying the country rock, and as such would not be expected to lead to ore formation nor to truncate in depth previously formed ore bodies. The intrusive masses, however, having reached their present positions and forms through injection in the state of a semiliquid pasty magma into the sedimentary country rock, may reasonably be expected both to have generated ore and to have truncated any previously existing ore bodies which lay in their paths. That is to say, the intrusions of diorite and diorite-porphyry do not underlie the sediments as a foundation of older rocks, nor do they, like the extrusives, overlie the sediments, but they break irregularly across the sediments from bed to bed. When the molten magma came in contact with certain limestones, it led to the formation of various secondary minerals, and in those limestones which possessed suitable composition it may have induced the formation of ore.

Geological structure.—The sediments in the immediate vicinity of the Park City area have a general northeast-southwest strike, and an average dip of about 40° NW. In general, then, the highest or youngest beds occur in the northwest portion of the area, and the lowest or oldest in the southern and southeastern portions. But they have suffered strong deformation from two potent factors—fissuring with faulting, and intrusion. Although intense fracturing occurred in both northeast-southwest and northwest-southeast directions, the prevailing trend of the principal fissures thus far studied is northeast-southwest. The more common dip is steeply to the northwest, although some important fissures of this series dip to the southeast. The intrusions occur as regular laccolithic masses and as dikes. They extend northeastward through the district, in a direction accordant with the zone of weakness indicated by the fissures, from the great dioritic body of Clayton Peak on the southwest to extensive extrusive masses on the northeast. They sometimes disturb the prevailing dip of the sediments and cause local doming, as on the divides to the southeast and southwest of Bald Mountain. Distinct southerly dips noted in the latter locality emphasize the general laccolithic character of this great northeast-southwest belt of intrusives.

ECONOMIC GEOLOGY.

General.—During the season of 1902 work was directed chiefly toward examining the areal geology with a view to establishing a firm foundation for later underground studies. Such information as was secured about economic questions was necessarily of a preliminary nature, so that only a few general characteristics will be given in this statement of progress.

The Park City mining district stands very prominently among the great mining districts of this country as the home of large bodies of silver-lead ore carrying minor values of gold and copper. In 1901 Park City mines supplied, roughly, seven-elevenths of the total output of silver from Utah and were the main factor in maintaining Utah's rank as third among the silver-producing States.

Although relatively young, Park City is, in several ways, a great camp. Mining is conducted on an extensive scale, according to advanced methods, by able, experienced men. Ten shafts have reached a depth of at least 1,000 feet, 6 are down 1,300 feet or more, and 1—that one, too, whose collar is lowest—has attained a depth of 2,000 feet. There are four long drain or work tunnels, the longest of which extends out to the eastern slope, a distance of about 3 miles. Three large, highly efficient concentrating mills have been erected at individual properties for private work, and an enlarged sampler and a recently remodeled zinc plant are located below the town for custom work. An aerial tramway and a broad-gage railroad transport ores from the mines to the Rio Grande Western system for shipment to the custom smelters in the Jordan Valley. These perfected plants and extensive operations, by which mining expenses are reduced to a minimum, are rendered possible by a wise consolidation of interests. Thus large tracts are owned by single companies; the bulk of the output for the last year was supplied from two properties, and the reputation of the camp rests upon the record of five great properties.

Character of the ores.—The values of the Park City ores (named in the order of their importance) lie in their silver, lead, copper, and gold contents. Silver has been reported in the form of several silver minerals, and doubtless lies principally in the galena and gray copper. Lead is present chiefly in the form of massive cleavable galena in the sulphide zone, and of crystalline cerussite, amorphous anglesite, and complex oxides in the zone of surface alteration. Copper occurs for the most part as gray copper (tetrahedrite) in the sulphide zone, and in the form of the blue and green carbonates (azurite and malachite) in the oxidized zone. The mineralogical character of the gold is not known, though it may occur as an impurity in pyrite. Zinc is a common associate in the fissure ores.

Superficial alteration has descended to great depths. Some ore bodies in limestone have been almost entirely altered to oxides, carbonates, and sulphates to the depth of 900 feet below the present surface, and the effects of oxidation may be observed upon the walls of sulphide ore bodies and adjacent to fissures cutting them, even to a depth of 1,300 feet. At present both the oxidized and the sulphide ores are mined.

These include large amounts of both first-class smelting ore and milling ore. Several bodies of very high-grade ore—bonanzas—have been discovered. Ore from the upper levels, 100 to 400, on a great lode of this district is reported to have run from $40 to $700 a ton, with an average of $130, and in 1886 "the best" Ontario "ore was sold to smelters and averaged $94.82 per ton. Ores of lower grade were milled averaging 54.32 ounces of silver."[a] The average value of crude ore shipped during the year 1902 from one of the principal properties of the camp was between $28 and $29 per ton.

Occurrence of ores.—The Park City ores do not appear to be generally distributed throughout the region in small amounts, but rather to be localized in certain well-defined occurrences in large bodies of pay grade. Three main types of occurrences have been recognized—fissure ores, replacement ores, and contact ores. In the first the ore carries either silver and lead, with or without zinc and gray copper, or gold with some silver, and occurs between well-defined fissure walls. In the second the ore holds silver and lead values chiefly and takes the form of elongated lenses within limestone, roughly parallel

[a] Almy, T. J., History of Ontario mine, Park City, Utah: Trans. Am. Inst. Min. Eng., vol. 16, p. 37.

to the bedding. In the last the ore contains copper and gold, with or without lead and silver, and forms in irregular masses, pockets, lenses, and pencils in metamorphic limestones adjacent to intrusive bodies. Gold values appear to run highest in certain fractures in quartzite; zinc is reported to increase in the southwestern extension of the great fissure zone of the camp, and copper is said to reach its maximum in amount and value in the deeper portions of certain pseudo-fissures in quartzites.

Present activity.—During the last year mining in this district has been remarkably active. Forty-eight new locations, the largest number reported from any mining district in the State, have been recorded. A number of heavily capitalized companies have been incorporated, several deep shafts begun, and exploration work vigorously prosecuted in various quarters. Precisely what the results will be no one can foresee. Several pieces of virgin ground which are now being explored have been selected with considerable judgment. In a mining boom, however, some properties are inevitably overvalued, and it can not be expected that all will prove equally profitable. Naturally among the conservative men who have developed the present district by legitimate mining there is a strong feeling of opposition to anything in the nature of booming, which might be prejudicial to the permanent prosperity of the camp. In brief, it may be said that if no serious decline in the price of silver occurs the prospects for a continued increase in the earnings of the camp through legitimate mining in the immediate future are most favorable.

PLACER GOLD MINING IN ALASKA IN 1902.

By Alfred H. Brooks.

GENERAL STATEMENT.

The great impetus given to prospecting for gold in Alaska, incident to the discovery of the rich Klondike fields, has resulted in the finding of a number of new and in the further development of several old placer districts. The gold output has shown a correspondent increase, rising from two and one-half millions in 1897 to about eight millions in 1902. While the development of quartz mining in the Pacific coast province of Alaska has steadily progressed during this time, more especially in the last two years, this development has not as yet affected the increase of output to any appreciable extent, for the production of the lode mines has remained practically the same. In southeastern Alaska plans have been formulated for extensive mining developments, and in many localities these plans are nearing completion; but as yet, outside of the older mines, such as the Treadwell, there are few which are actually producing. The increase of $5,500,000 during the last five years has, therefore, been chiefly from the placer mines. It is to be expected, however, that the quartz mines of southern Alaska, which are being opened up, will within the next two years add materially to the mineral production of the Territory.

Of the $6,000,000 or more[a] produced from the placer mines of Alaska in 1902, about $5,500,000 has come from the Seward Peninsula gold fields. The new diggings in the Copper River region have probably produced $225,000, and the Cook Inlet region and Porcupine district have probably produced $100,000, while the remainder is from the Yukon Basin, chiefly from the new diggings on Glenn Creek.

DISTRIBUTION AND SOURCE OF PLACER GOLD.

Placer gold has a wide distribution in Alaska. It has been found near the southern boundary of the Territory, and at various localities northward as far as the sixty-eighth parallel of latitude and westward as far as Bering Strait. Broadly speaking, the producing placer

[a] The exact production is not yet known, but is not less than five and one-half and possibly may be six and a half millions.

mines of Alaska which have thus far been opened up fall within a zone having a maximum width of probably 200 to 300 miles, stretching northwest from the southern Pacific coast, crossing the Arctic Circle, and bending westward to the shores of Bering Strait. It is not intended to imply that this zone in its entirety is a gold producer; such is far from being the case. This broad belt is simply drawn attention to as having, up to the present time, been the locus of the placers of commercial importance. The factors which have determined the formation of workable placers are frequently so local in their effect that the distribution of the placers is very irregular.

The field studies lead to the conclusion that the source of the gold lies, for the most part, in small quartz veins and stringers which are disseminated in metamorphic rocks. Gold also occurs in these rocks in the mineralized zone, where there is little if any gangue mineral present. Iron pyrite is the commonest mineral found in association with the gold in the parent rock. The few observations made indicate that the gold occurs both free and combined with pyrite. Quartz is a common gangue mineral, associated with some calcite. Galena is frequently associated with the gold-bearing quartz veins, and chalcopyrite and arsenopyrite have also been found. This list of minerals will undoubtedly be much extended when closer studies have been made.

The studies of the placer fields of Alaska lead to the conclusion that the gold in nearly every case has not traveled far, and can usually be traced to a local source. In the gulch and creek placers it can usually be traced to a source within basins which they drain. The exception is where a change of drainage may have introduced material derived from regions outside the creek basin. In nearly all parts of Alaska the placer gold owes its present position entirely to the erosion of the bed rock in which it was formerly disseminated, and to the sorting action of water and gravity, which has brought about its present concentrated form. This elementary principle is here emphasized because it is not uncommon to find, even among well-informed men, a tendency to entirely ignore the very simple facts, and to regard placers as the result of glacial action, or as having had a still more cataclysmic origin. As a matter of fact, all of the placers of Alaska, except a few near the southern coast, are outside of the limit of former glacial activity.

As has been stated, the gold of the placers has its source in small veins and stringers in the bed rock or was disseminated in mineralized zones. The facts now obtainable indicate that the outlook for future quartz mining in the placer fields of the interior of Alaska is not hopeful. While it is by no means impossible that larger gold-bearing veins carrying commercial values may be found, it seems probable that most of the placer gold has been freed from bed rock, where it was more or less widely disseminated, and subsequently concentrated by the sorting action of water. It is not uncommon to hear Alaskan prospectors speak of the "mother lode," as if the gold had all been derived from one lode or zone of mineralization. Of this there is no evidence whatever. In considering the question of quartz veins in the placer fields, it should be remembered that the dense coating of moss makes bed-rock prospecting difficult and uncertain.

The auriferous deposits from which the placer gold is derived occur in metamorphic rocks of various kinds. They include schists of various types, phyllites, limestones, quartzites, and altered igneous rocks. Such metamorphic terranes find a wide development in Alaska, and probably occur in a number of different horizons. The study of the geology of Alaska has not progressed far enough to permit of correlations, or of definite statement in regard to the age of the metamorphic terranes or their structural relations. The mineralized metamorphic beds of southeastern Alaska are probably Mesozoic and older. Those of the Yukon are chiefly, if not entirely, pre-Carboniferous, and those of the Seward Peninsula are chiefly Paleozoic. Within the zone which has been designated as the one in which gold placers have been found, there are many large areas of these metamorphic rocks. These form belts which are not by any means continuous, as they are interrupted by areas of younger Mesozoic and Tertiary terranes. It has also been shown that they probably belong to widely different horizons. Broadly speaking, the mineral-bearing horizons of southeastern Alaska can be placed in one group, and those of the Yukon Basin and of the Nome region in another. It will remain for future studies to determine the relation between these two belts.

The age of intrusion of the mineral-bearing solutions is largely an unsolved problem. In the coastal belt of southeastern Alaska the mineralization took place probably in Mesozoic time, while in the Yukon region it was probably considerably earlier. The studies thus far made indicate that the mineralization accompanied disturbances of the strata, either by deformation or by igneous intrusions, or both, which were rather local in their effect. They seem to be closely affiliated to igneous rocks which are everywhere found in the regions of mineralization.

The studies of the alluvial gold deposits of Alaska have shown that *mode of formation and concentration* are the determining factors of the richness of the placer deposits. The writer has elsewhere[a] emphasized this fact in regard to Nome placers, and more recent observations convince him that it is also applicable to the gold deposits of the Yukon. In the simplest form of placers the gold is washed from the parent rock and concentrated in the beds of the streams, mingled with other detrital material Such placers have been exploited in many localities and have been found to be important gold producers.

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[a] Reconnaissance of the Cape Nome and Norton Bay Regions, U. S. Geological Survey, 1901, pp. 144-151.

It is probable, however, that nearly all the very rich placers owe their origin to secondary concentration. This has been brought about by the erosion and dissection of an older placer and the reconcentration of the gold contained therein. This process of double sorting is probably the chief cause of the bonanzas which are not uncommon in the Alaskan placer mines, and will probably also account for those irregularities of distribution of the placer gold often within a single topographic basin, which are so puzzling to the miner.

A common form of the enrichment is the dissection of an auriferous gravel bench of the slopes of a stream valley by a tributary stream. This tributary stream carries the gold derived from the bench to the main stream, where it is mingled with the gold of the main stream, and causes an enrichment of the placers located at and below the junction of the two streams. In some instances the gravels of an older drainage system, lying often at considerable altitudes above the present stream floors, are dissected by the present waterways, and the gold contained in the older gravels is thus resorted and reconcentrated. Instances of this kind are not uncommon in the Nome region, and have been observed by the writer in the Rampart region of the Yukon.

Another form of concentration is that by wave action. In this mode of enrichment the waves concentrate the gold which has been deposited in the gravels of the coastal plains. It is in such a manner that the marvelously rich beach placers of Nome were formed.

It seems probable that the study of these questions of reconcentration will yet yield important commercial results, even in the better known mining districts of Alaska. A practical application of these principles would suggest that the prospector seek to trace old drainage channels and pay special attention to the junction of these with the present streams.

SEWARD PENINSULA.

During the last season the climatic conditions in the Seward Peninsula were not, by any means, favorable to a large gold output. While there were heavy rains in the fall, the months of July and August were very dry, and hence but little sluicing was done. It should be noted, however, that the experience of the last three years indicates that such meteorological conditions are to be expected every third year, if not every other year. The output, therefore, is probably not nearly as large as it would have been had water been available early in the season. Moreover, much of the development was in the nature of dead work in preparation for extensive operations during the present season. Ditches were dug, roads built, and pumping plants established, which will greatly accelerate the prosperity of the district and, undoubtedly, will materially increase its gold production. The problem of transportation is still a serious one. Under the best conditions the landing of heavy machinery and supplies on the Nome beach is a difficult task, but during stormy weather it becomes well nigh impossible. After heavy machinery has been landed it is still a grave problem how to transport it from the coast to the mines. This involves the building of roads and, in some cases, the dredging of rivers.

The region immediately tributary to Nome is better prepared to meet these conditions than the more isolated camps. The narrow-gage railroad, which runs from the beach to the head of Anvil Creek, makes the transportation problem at that particular locality a simple one. Roads, moreover, have been built to adjacent creeks from the railway, so it is now possible to handle heavy machinery.

In Anvil Creek probably the most important development was in the auriferous gravels of the benches which are found on both sides of the valley. This gave a new impetus to mining, for the gravels in the creek bed itself were nearly all run through the sluices during the two previous years. The high-bench gravels, lying at altitudes of 500 to 800 feet above the sea, which were discovered in 1900, still continued to be developed. Some of these have great depth, and the extraction of the gold has been a difficult problem.

The so-called "tundra placers," or more properly coastal plain placers, still continue to be worked, but their development has not been commensurate to their probable importance. It seems more than likely that the gravels which make up this coastal plain, in many places, carry workable placers. These may be, in part, old sea beaches, or may be the channels of abandoned streams and rivers. The problem of handling large quantities of these gravels, which are a few feet above and below sea level, has not yet been solved. Most of the mining has been confined to shallow pits and trenches, and the operations have been hampered by lack of means to handle the surface water. The extraction of the gold has been largely accomplished by use of hand rockers. Winter mining has been carried on by means of petroleum and coal-burning steam thawers. With the aid of the thawer a pit is sunk to the pay streak, which is followed by drifting. The gold-bearing gravel is then hoisted to the surface and washed out during the open summer season. It is of interest to note that drills have been successfully employed in prospecting for the pay streak in the coastal plain gravels. The ground underneath the thick coating of vegetation is frozen throughout the year, but thaws to a depth of 2 or more feet where this coating is removed. If an economic method of mining these gravels in a large way and of extracting their gold contents could be devised, large profits would undoubtedly be made.

During the four years which have elapsed since the discovery of the Nome placers, the gold seeker has gradually worked his way inland, so that now there has been some prospecting done over nearly the entire Seward Peninsula.

During the last season gold mining was going on in the Nome region proper, in the Solomon and Eldorado River region, on the streams tributary from the south to the Kruzgamepa in the Kuzitrin basin, and on streams tributary to the Niukluk. All of these belong to the Bering Sea drainage. A number of the streams which are tributary to Port Clarence were also found to carry commercial values. Some developments of placers on streams flowing northward to the Arctic Ocean have been made. None of the northerly flowing streams have, as yet, been found to be as rich as those of the older and better known districts of the South. Many have, however, produced gold in commercial quantities, and with further developments will probably become important producers.

What has been said of the Nome region proper applies in large measure to the other creeks in the region. In nearly every case where discoveries have been made the first developments are along the present stream channels. When these are worked out, which does not take long where the streams are small, the prospectors turn their attention to the benches and terraces, and these often yield good returns. In some cases placers have been practically abandoned which it seems to the writer may still carry gold in commercial quantities. Such may prove to be the case in districts like the Kugruk, where the miners have worked out the small creek beds and have neglected to thoroughly prospect the terraces and benches. Of special interest is the very large increase in the output of Ophir Creek, a northern tributary of the Niukluk. This stream was one of the first on which gold was discovered in the Seward Peninsula, and for several years was spasmodically worked, but it is only since the introduction of systematic methods of mining and extraction that Ophir Creek has become one of the largest producers of the region. It has been estimated that its production during the last year was upward of $1,000,000. These facts augur well for the future of the Seward Peninsula placer fields. It seems probable that there are other streams which may go through a history similar to that of Ophir Creek.

YUKON REGION.

Mining has been going on in the Upper Koyukuk Basin since the summer of 1899, and the basin has probably produced from $100,000 to $200,000 annually. This money has been chiefly taken out of half a dozen creeks which are tributary to the Upper Koyukuk about 600 miles from its mouth. About 500 miles of this distance can be made by river steamer. During the last season many miners returning from the Koyukuk seemed to be rather discouraged. There seems to be no question that there are workable placer fields in the district, but the high price of provisions and the short season have prevented many of these from being worked at a profit. With water transportation within a short distance of these placer mines there seems to be no reason why supplies should not be as cheap as on the Yukon. It is to be hoped that there will be a reduction in the cost of living, which will enable developments to continue in this region, which lies north of the Arctic Circle.

Rampart is a small settlement on the Yukon about 1,000 miles from tide water. It has tributary to it a number of camps which have long produced some gold, and these are still producing, but not in great quantity. The important development of the season is that of Glenn Gulch, about 30 miles south of Rampart. Glenn Gulch is tributary to Baker Creek, which flows into the Tanana about 100 miles from the Yukon. The gulch itself has proved phenomenally rich, and a number of other streams in this region give promise of becoming producers. A description of this region by Mr. Collier will be found elsewhere in this volume.

The region lying between the Yukon and the Tanana is one in which many gold-producing creeks have been found. The earliest discoveries were all made on the Yukon side of the divide, but since 1898 much prospecting has been done on strems tributaries to the Tanana from the north. In only a few cases have these yielded anything of value, and, as far as known to the writer, the gold-producing creeks are all tributary to the lower 200 miles of the Tanana. Little information is available in regard to this region, but it is stated that considerable gold has been taken out of streams which flow into the Chena River, which joins the Tanana about 300 miles from the Yukon. The daily press has recently contained references to phenomenally rich placers found somewhere in this region. Pedro Creek, whose location is not given, is said to have been found to be very rich, but these rumors have not received confirmation.

The Birch Creek region embraces the headwaters of the stream of the same name, tributary to the Yukon near the Arctic Circle. It is one of the oldest placer districts of the Yukon, and still continues to produce some gold. With the cheapening of provisions on the Yukon the placer mining on some of the older creeks took a new lease of life, and such is the case on Birch Creek. Low-grade placers are now being developed in the Birch Creek Basin, which could not be economically developed under the old conditions. During the winter of 1901–2 much mining machinery was taken into the district. It is reported that the district contains extensive deposits of low-grade placers, which it is proposed to mine with refined methods.

Fortymile River enters the Yukon 20 miles above the international boundary. That its bars carry gold has been known for the last fifteen years, and streams tributary to it have been important gold producers for the last eight years. Many of these streams are still being worked, and a few new ones have been discovered. In many instances bench claims are being developed. While the gold production of the district has not been large, the placers are by no means exhausted, and it is possible that important discoveries will still be made.

During the last year placer mining has been done on a number of small creeks tributary to the Upper Yukon. On Boundary Creek, 12 miles above Eagle, two or three claims were worked last summer. In the immediate vicinity, on American Creek and Colorado Creek, tributary to Mission Creek, some mining was also done. Seventymile River was also the scene of mining operations, about 15 miles from the Yukon, and one hydraulic plant was run. On Fourth of July Creek, 50 miles below Eagle, 12 men were at work on claims last summer. Three claims on Coal Creek and several on Woodchopper Creek, 140 miles below, also received some development of their placers.

COPPER RIVER REGION.

Gold has been found in commercial quantities at two widely separated places in the Copper River Basin. The Chistochina gold field, which has produced nearly all the gold of the region, is in the drainage basin of a river of the same name which joins the Copper about 200 miles from the coast. This district contains several gold-producing creeks which can be reached by trail from Valdes. Gold placers have also been found at a number of widely scattered localities in the Copper River Basin. A description of this district by Mr. Mendenhall will be found elsewhere in this volume.

COOK INLET REGION.

The region lying adjacent to the head of Cook Inlet and about Turnagain Arm has long been a small gold producer. No very rich placers have been found, but the accessibility of the district made it possible to develop deposits which could not have been worked at a profit if located in the interior. Hydraulic mining has been going on in a small way for a number of years, and more elaborate plants are being installed. The open season of Cook Inlet comprises about five months, which gives the district two months' advantage, or more, over that of the interior, or of Nome. The developments of the last year have been rather in the way of introducing more refined methods of mining rather than of new discoveries.

PORCUPINE DISTRICT.

This is a small placer-gold district about 30 miles from Pyramid Harbor, an embayment of Lynn Canal, whence it is easily accessible by wagon road. It lies chiefly within the catchment basin of Porcupine Creek, a small stream which enters the Klehini about 20 miles above its junction with the Chilkat. The placers are so situated that they offer peculiarly difficult conditions for mining. They occur largely in small glacial benches and in the stream bed of Porcupine Creek, which has a very sharp rock-cut valley. To work these placers it has been necessary to divert the water of the stream by means of sluices, to give access to the gravels in the creek bed. This involved a large expenditure of time and money. During the last season these developments were still going on, and the district has not yet reached a large productive stage.

THE GLENN CREEK GOLD MINING DISTRICT, ALASKA.[a]

By Arthur J. Collier.

INTRODUCTION.

Glenn Creek is a small tributary of Baker Creek, a large stream which enters the Tanana from the north, about 80 miles from the Yukon. The mining camp there located is the site of the most important discovery of placer gold made in the interior of Alaska during the seasons of 1901 and 1902. This camp is about 28 miles in a direct line nearly due south of the town of Rampart, on the Yukon River. Rampart is the distributing point for Glenn Creek, as well as for several older mining camps, and has a population of about 300. It is approximately 1,000 miles from the mouth of the Yukon and 600 miles from Dawson, and can be reached by river steamer from Dawson in about three days, or from St. Michael in about a week.

The Glenn Creek trail from Rampart follows up Big Minook Creek for a distance of 25 miles to its head, then crosses a divide having an elevation of about 1,700 feet above the river and drops down to the Glenn Creek Camp, which has an elevation of about 800 feet above the Yukon. The distance from Rampart to Glenn Creek by this trail is about 30 miles, and along it the footing is so soft that two days are usually required in summer to make the trip comfortably, either by walking or by riding.

The camp is near Baker Creek, 18 miles from its junction with the Tanana River, at which place a small trading post has been established, which can be reached by steamer coming up the Tanana from the Yukon. Baker Creek is navigable for canoes up to within a few miles of the Glenn Creek Camp, but the trail from Glenn Creek to the Tanana is reported to be very swampy.

Since only five days could be spent by the writer in making the trip from Rampart to Glenn Creek and return, the information obtained is necessarily meager and the results are in many respects unsatisfactory.

[a] This paper is an abstract of a more extensive report, now in preparation.

The Glenn Creek mining camp lies on the northern edge of an extensive lowland basin known as the Baker Flats. These flats, opposite Glenn Creek, have a width from north to south of from 7 to 10 miles, but their greatest extension is in an east-west direction. This broad lowland is a depression which has been deeply filled by fluvial deposits. Near the mouth of Eureka Creek a prospect hole penetrated 65 feet of gravel without reaching bed rock. Along its southern margin there is a range of low, flat-topped hills, which separate it from the great lowland of the Lower Tanana, and through this range Baker Creek flows in a narrow gap. The creek forks just above this gap, and the eastern fork, which is the larger, is called the Hootlenana, while the western fork retains the name Baker Creek. Eureka Creek, which receives a large part of the drainage from the northern margin of the flats, enters Baker Creek near these forks. A broad bench was observed 100 to 200 feet above the valley level at the northern margin of Baker Flat. The gold placers thus far discovered are confined to a number of small creeks flowing into the Baker Flats from the north, and in the immediate vicinity of the Glenn Creek camp these streams are known to be gold-bearing only where they cut across the above-mentioned bench. Several miles to the east Pioneer Creek and other tributaries of the Hootlenana are gold bearing and it is probable that the gold-bearing belt extends about 20 miles along the north side of the Baker Flats, but it was not examined by the writer except in the immediate vicinity of Glenn Creek.

Active mining has been in progress on Minook Creek, near Rampart, since 1896, and the creek was probably prospected as early as 1882. From Minook Creek as a center prospectors have extended their search across the divides in all directions. In the summer of 1901 colors of gold were found on Eureka Creek and mining was attempted. Gold in paying quantities was discovered on Glenn Creek July 24, 1901, by a miner who had a contract for supplying wood at the mine on Eureka Creek. Colors of gold, but not in paying quantities, had already been discovered on Rhode Island and Omega creeks in this region.

GEOLOGY.

In the vicinity of Rampart on the Yukon the bed rock consists of a series of volcanic rocks interbedded with siliceous slates and limestones, called by Spurr the Rampart series.[a] From fossils collected last season near Circle this terrane is believed to be of Devonian age.

About 8 miles south of Rampart a series of siliceous slates, quartzites, and schists was found, which continues with more or less variation across the divide to Glenn Creek. The relation of the Rampart series to this slate and schist series could not be determined with cer-

[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 155-169.

tainty, but the evidence indicates that the Rampart series is younger. If this be true, the schist series of the upper part of Minook Creek and of Glenn Creek may be correlated with either the Fortymile or the Birch Creek series of Spurr. No evidence of faulting or intrusions of granite in this series, as indicated by Spurr,[a] was seen along Minook Creek by the writer. The rocks contain small quartz veins and stringers in many places, and the débris from them includes pebbles of igneous material other than granite, suggesting the presence of intrusions of various kinds.

A few specimens of the sedimentary rocks have been examined microscopically. These vary in degree of alteration, in some cases being garnetiferous mica-schists, in others quartzites consisting of interlocking quartz grains. All the specimens examined contained more or less muscovite. Microscopically these rocks resemble the Birch Creek series as described by Spurr.[b] A similar series of schists occurring at many places along the Tanana River[c] has been described by Brooks under the name Tanana schists. They outcrop for some distance along the Tanana below the mouth of Baker Creek, making it probable that the schist series forms a continuous area from Minook Creek, 8 miles above Rampart, to the Tanana below Baker Creek. These schists have been correlated by Brooks[d] with the Birch Creek-Fortymile series of Spurr.

DESCRIPTION OF PLACERS.

Glenn Creek is a small stream, in summer carrying less than a sluice-head of water, which rises in a bench on the north side of Baker Flats and flows southward to the flats. The creek occupies a broad, shallow depression less than 50 feet deep, which makes a hardly noticeable break in the topography.

About one-half mile west of Glenn Creek, Gold Run, a still smaller stream, also flows southward to Baker Flats, and about one-half mile farther west Rhode Island Creek, a larger stream, has cut a deep trench nearly to the local base-level of Baker Flats. About a mile east of Glenn Creek, Eureka, a large creek, enters Baker Flats, also from the north, occupying a deep, well-marked trench. Each of the creeks named above carries placer gold in paying quantities for a distance of about a mile, and the bench between Glenn Creek and Gold Run also has been found in places to be covered with gold-bearing gravel rich enough for exploitation.

The productive placers of Glenn Creek are confined to four or five claims within a mile of the head of the creek. In this distance the creek bed has a fall of about 5 feet in 100.

[a] Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, Pl. XXXVIII.

[b] Ibid., p. 144.

[c] See Reconnaissance in the Tanana and White River basins, Alaska, 1898: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, map 24.

[d] Ibid., pp. 468 and 469.

On Discovery Claim, at the edge of Baker Flats and at the lower end of the productive part of the creek, a prospect hole 40 feet deep failed to reach bed rock. In all the claims above Discovery bed rock can be reached at a depth of from 5 to 20 feet. The bed rock is a schist, usually called slate by the miners. It ranges in color from dark blue to gray, and is often graphitic. It represents a rather argillaceous sediment which has been subjected to only a moderate degree of metamorphism, sufficient to produce many metamorphic minerals, but not to entirely destroy the original structure. This bed rock is often cut by stringers of quartz, which are reported to strike nearly east and west. These stringers are white and at the outcrop are decomposed along with the remainder of the bed rock, which is often so disintegrated that it can be shoveled out like fine gravel.

The width of the pay streak varies from 20 to 60 feet. In one place a pay streak 7 feet thick is reported. On the lower claims the pay streak is near the surface, so that summer work "by stripping and shoveling" is possible. In the upper claims the pay streak is found below several feet of muck and barren gravel, and is mined with steam thawers in winter and washed in the spring. Early in August, when the creek was examined, only one claim, known as Claim No. 2, was working. The others were shut down because the dumps had already been sluiced. On Claim No. 2 miners were shoveling into the sluice boxes directly from the pay streak. It was impossible to see the bed rock in place, or to see a full section of the gravel from the surface down in the deeper workings. The pay gravel consists of angular fragments of schist and a small amount of vein quartz, with occasional rounded bowlders of a basic, igneous rock. The gold is not evenly distributed in the pay streak. Sometimes the best pay is found on the surface of a layer of decomposed bed rock. "Stringers" of gold on this bed rock were found carrying $10 to $35 to the pan. These "stringers" are lines of gold parallel with the bed rock, which look when uncovered as if the rock had been sprinkled with gold. On some of the claims values are reported to have been found to a depth of 2½ feet in a hard, blocky bed rock. On some of the lower claims above the bed rock there is a waxy clay, called by the miners "gumbo," which is probably decomposed rock in situ. This clay ordinarily does not carry gold, but on one of the upper claims a gumbo ball is reported to have carried $1 in fine colors.

In the summer of 1901, after the discovery, a small amount of gold was taken out before the end of the season. During the winter of 1901–2 a large part of the pay streak was taken out by drifting, and the dumps were washed in the following spring. It was estimated by a representative of the Eagle Mining Company, which owns several of the claims, that the creek had produced approximately $150,000 prior to the 1st of August, 1902.

Gold Run occupies a very slight depression parallel with Glenn

Creek and about one-half mile to the westward. It is a tributary of Rhode Island Creek, into which it empties a short distance above the Baker Flats. Claim No. 1 of Gold Run joins with Claim No. 3, Rhode Island. The bed rock consists of schists similar to those on Glenn Creek. It is described by the prospectors as a "blocky schist."

The pay gravel consists of angular fragments of this bed rock, which show very little if any rounding, such as would be expected in channel-washed gravel. The prospecting shows a pay streak from 12 to 40 feet wide. At the lower end of Claim No. 1 the pay streak, which varies greatly in thickness, is divided by a reef. Beyond the limits of the pay streak the gravels continue to show prospects of gold. The pay streak in one instance is reported to be 3 feet thick and to underlie 11 feet of muck and barren gravel.

Very little gold has as yet been taken from this creek, though the prospecting shows a distribution of gold somewhat similar to that on Glenn Creek. Preparations were being made for mining on five claims on this creek during the winter of 1902–3. During the winter of 1901–2 the pay streak from an area 15 by 20 feet was mined out. This dump has yielded $1,000, but has not all been washed.

It was proposed to work the creek during the winter of 1902–3 with steam thawers according to the following plan: Shafts were to be sunk to bed rock, a depth of 10 to 15 feet. From the foot of each shaft the pay streak would be drifted on for a distance of about 40 feet, with a cover of 10 or 11 feet. It was regarded as impracticable to drift farther than this on account of the difficulty of carrying steam pipes and moving the pay dirt to the foot of the shaft and keeping the gangway open. Steam thawers, if properly managed, are more economical in mining frozen ground than the old method of "burning" with wood, for the reason that the steam points can be driven directly into the ground where thawing is needed, and the pay dirt can be mined immediately as it is thawed, whereas by the old method work is interrupted while the fire is burning and, at best, a night's burning will not thaw more than 1 foot of gravel.

Gold Run does not carry sufficient water for sluicing after the snows have melted in summer, and mining operations will necessarily be suspended during the summer months.

Rhode Island Creek is larger than either Glenn or Gold Run and flows in a well-marked valley cut about 100 feet below the level of the bench on which the streams described are located.

The bed rock consists of schists similar to those at Glenn Creek, except that it probably contains more graphitic schist than at Glenn Creek. The strike of the bed rock is reported to be northwest and southeast. Stringers of quartz have not been found in it.

The gravel consists of more or less angular fragments of schist similar to that at Glenn Creek, except that graphitic schists are more common, as well as pebbles and bowlders of igneous rocks. Two types of igneous rocks were recognized, one of which is a green, compact rock, probably an altered intrusive from the schist series, while the other is an unaltered rock of very basic type. The creek has not been thoroughly prospected on account of inundation of the prospect holes. In the middle of the creek, bed rock has not been reached, but good prospects have been found on the rims. At Claim No. 5, about one-fourth of a mile above the mouth of Gold Run, a shaft was being sunk on the left limit of the pay streak, with a view to draining the bed rock with a steam pump. This shaft penetrated, to a depth of 12 feet, broken bed rock similar to that on Glenn Creek. The pay streak here is believed to be from 50 to 60 feet wide. The average yield from a number of pans taken from the pay streak was reported to be 11 cents. About one-half mile above this place mining was in progress on a claim on which the bed rock has been partially drained. The claim had not been fully crosscut, but it was believed to have a pay streak 60 feet wide. Where it has been prospected the pay streak is 2 feet thick and underlies 6 feet of muck and barren gravel. Twenty-five and 50 cent pans have been obtained from this pay streak. The owners of this mine were attempting to work it in summer, stripping off the muck and barren gravel and shoveling the pay dirt into sluice boxes.

On the bench between Glenn Creek and Gold Run have been found shallow gravels carrying placer gold in paying quantities. It is reported that generally on this bench the bed rock is covered by a layer of clay, probably derived from the decomposition of the bed rock. This clay carries a little gold, the coarsest being near the surface. The gold does not extend far up the hill to the northward, but can be traced down the hill for several thousand feet. Two claims have been located on which gold is found in paying quantities. At the upper end of the upper claim the excavation shows 6 inches of reddish clay soil overlying 1 foot of gravel consisting of clay mixed with small pieces of gray schist similar to the bed rock, but containing occasionally large, well-rounded pieces of a basic igneous rock. This gravel is the pay streak and rests on bed rock. At the lower end of this excavation, about 200 feet from the point described, 4 feet of nearly barren gravel wash overlie the pay streak, which consists of 1 foot of gravel made up of broken fragments of schist bed rock. The pay streak has a width of 65 feet. Beyond the pay, however, on the south side, a prospect hole was sunk through 4½ feet of broken schist débris, showing little, if any, gravel wash. Colors of gold were found near the bottom of this hole. On this claim the attitude of the gravel indicates a current from the north.

The lower claim has been prospected at a point one-fourth mile southeast of the upper claim. Here prospect holes show the gravel to be from 6 to 8 feet thick. The position of the pebbles indicates deposition by a current flowing nearly east. The gravel contains a few large, round bowlders of igneous rock. It is claimed that this gravel from the surface down will pay for washing, and that the pay goes into the bed rock to a depth of 1 foot. The pay streak is more than 100 feet wide.

The gold on these claims is comparatively coarse, nuggets as large as one dollar being common, though the average pieces are smaller than one cent. On the lower claim the pieces of gold are probably finer than on the upper. The pay streak at the former place is reported to average 6 cents to the pan. The gold nuggets have a rough surface, showing that they have not traveled far.

At the upper claim some sluicing has been done with water collected in a system of ditches on the surface of the bench. These ditches provide a limited amount of water when the snow is going off in the spring and after heavy rains in the fall. A ditch about 2 miles long has recently been dug to bring water from Rhode Island Creek, but except in a rainy season the water from this source will probably be insufficient for sluicing.

Mining has been in progress on Eureka Creek, 1 or 2 miles east of Glenn Creek, for the last two years. These mines have not been great producers of gold, and the writer was unable to visit them. They are reported to be confined to a section of the creek bed 1 mile long, and situated nearly opposite the mines on Glenn Creek.

Good prospects of gold are reported from Omega Creek and McKinley Creek in this region, and within a few miles of Glenn Creek. Their exact location is not known and they were not examined by the writer.

During the last season gold prospects were found on Pioneer Creek and several other northern tributaries of the Hootlenana. These lie east of Glenn Creek and probably within 10 miles of it.

One prospect hole was sunk to a depth of 65 feet in the gravels of Baker Flats. While no pay streak has been located, colors of gold are reported. It will require further prospecting to show whether these gravels are workable as gold placers.

On Minook Creek and on its several tributaries, known as Hunter, Little Minook, Ruby, and Slate creeks, placer mines were in operation last summer.

SUMMARY.

In the vicinity of Glenn Creek the known gold placers are confined to the creeks and benches within an area about 1 mile wide and 2 to 3 miles long, lying parallel to the north side of the Baker Flats. This area coincides roughly with the limits of a broad bench cut on bed rock, 100 to 200 feet above the level of the lowland. Two of the creeks carrying placer gold rise within this bench, while two larger ones are gold bearing only where they cross it.

The bench generally is covered by a soil derived from the bed rock in situ, but in some places bodies of shallow gravel occur. These gravels consist principally of angular material derived from the immediate bed rock, but they contain some bowlders and pebbles which have undoubtedly been transported. The gravels of the creeks and gulches incised in the bench are essentially similar to those found on the bench.

From the evidence in hand, it seems at least possible that the lowland of the Baker Flats is the bed of an extinct lake and that the broad bench at Glenn Creek is in part a beach and in part a local peneplain produced at the base-level of this lake while it existed. The mixture of local and transported material is readily explained in this way, either by water action alone or by floating ice.

The pieces of gold found here are apparently not greatly waterworn, and have probably not been carried far from their original position in the bed rock. The bed rock of the gold-bearing area consists of schist, belonging to a series which has an extensive distribution in this region. On Glenn Creek, however, a system of quartz stringers striking parallel with the longer dimension of the gold-bearing area has been noted, making it seem probable that there is a zone of mineralization in the bed rock underlying the gold-bearing area.

The information at present available regarding the geology and physiography of this region is too meager to warrant any definite conclusions as to the origin of the placers, but the following explanation, which is believed to agree with the facts as far as known, is advanced tentatively:

The gold at Glenn Creek has been derived from a zone of mineralization in the bed rock north of Baker Flats. This zone extends eastward for 10 or 12 miles, to the northern tributaries of the Hootlenana, on which placers have recently been found, but is less than a mile in width. As the bed rock was eroded, the gold from this mineralized zone was concentrated by both wave and stream action along the margin of the old Baker Lake. By the draining of this lake the old beach was left as a high bench, and the gold from it has been partly reconcentrated in the beds of recent streams, to make the creek placers, while a part of the original beach deposit remains in the form of bench placers.

GOLD AND PYRITE DEPOSITS OF THE DAHLONEGA DISTRICT, GEORGIA.

By Edwin C. Eckel.

Field work in the Dahlonega gold district of Georgia was carried on by the writer during September, 1902, under the direction of Dr. C. W. Hayes. While this field work was merely of reconnaissance character, preliminary to the commencement of folio mapping in the area, it developed certain features of considerable importance in connection with the gold deposits of the district. A preliminary report on this work, with maps, will be issued this year as a survey bulletin, while a brief statement of the principal results as regards the gold deposits has been published in a recent issue of the Engineering and Mining Journal. That portion of the present paper which relates to the gold deposits is essentially a reprint of that last noted, though it contains certain minor changes which affect the wording rather than the conclusions.

LITERATURE OF THE SUBJECT.

Though numerous references to the Dahlonega district are to be found in geological and mining literature, the following six papers will suffice to give the reader a good idea of the geology and mining industry of the region. In 1895 Dr. George F. Becker published, in the Sixteenth Annual Report of the United States Geological Survey, Part III, pp. 251–331, a valuable account of a "Reconnaissance of the gold fields of the southern Appalachians." In the same year Messrs. Nitze and Wilkens published, in the Transactions of the American Institute of Mining Engineers, Vol. XXV, a paper on "The present condition of gold mining in the southern Appalachians." These papers are still the best summaries of the geological features of the Appalachian gold fields, and of the relations of the ore deposits. Dr. W. S. Yeates published in 1896, as Bulletin 4A of the Georgia Geological Survey, a "Preliminary report on a part of the gold deposits of Georgia." This volume, by Yeates, McCallie, and King, contains much interesting detail concerning both the mines and the mining history of the region. The principal advances in Dahlonega mining practice since that date are well described in the three following papers which have appeared in the Engineering and Mining Journal:

"The Dahlonega Consolidated Gold Mining Company's plant," by W. Colvin, August 17, 1901; "The Crown Mountain gold mine and mill," by H. V. Maxwell, September 21, 1901, and "Gold dredging in north Georgia," by the same author, November 2, 1901.

GENERAL GEOLOGY.

All the rocks of the Dahlonega district of Lumpkin County, Ga., are highly crystalline, no series of indisputably sedimentary origin occurring in the immediate vicinity. The rocks dip usually at a high angle to the east. The strike is, in general, about N. 60° E., but at the northern end of Findley Ridge this changes abruptly to N. 5° W. In consequence of this change of strike the mines, as would be shown on a mine map of the district, occur along two lines meeting almost at a right angle. Four rock types occurring in the district are sufficiently well marked and areally important to be separately described.

Mica-schists.—For convenience the normal rocks of the district (excluding the doubtful feldspathic gneisses next described, and the granites and diorite, which are undoubtedly of igneous origin) will be grouped as mica-schists. More fresh material than is at present available must be examined before finer distinctions can be profitably made.

Though the decomposed outcrops seem, in general, to be highly micaceous, examination of fresh material from several mine tunnels seems to show that these "mica-schists" are prevailingly siliceous, the mica being highly developed only along joint and shearing planes. This highly siliceous character would seem to point toward a possible sedimentary origin of at least part of these schists by metamorphism from impure sandstones. This question, however, requires much further investigation.

As to age, nothing occurs in the district which can be used as proof of the absolute age of these rocks. Lacking such proof, they have been generally regarded as pre-Cambrian, but possibly they are of Cambrian or Lower Silurian age. As to relative age, it is certain that they are the oldest rocks of the immediate district, with the possible exception of certain feldspathic gneisses, which are next described.

Feldspathic gneisses.—At several points in the area under consideration highly feldspathic gneisses occur, notably in one northeast-southwest trending ridge, parallel to and some miles east of the Chestatee River. These rocks are well banded, some bands consisting largely of mica and quartz, while others contain much feldspar. It is possible that these feldspathic gneisses constitute a true rock type, but at present the writer is inclined to believe that the more feldspathic bands simply represent granitic material injected into a preexisting mica-schist and subsequently sheared with it. In some of the larger bands of feldspathic material this derivation from granite seems to be strongly indicated, but further detailed study will be necessary to determine this point.

Diorite.—Several large bodies of hornblende-schist occur in the area under consideration, as well as in adjoining regions to the west and south. In general, this rock is a fine-grained, highly sheared hornblende-schist, its schistosity being conformable to that of the mica-schists by which it is inclosed. At several points a less metamorphosed phase of this hornblende-schist is shown, and it seems certain that it was derived from an intrusive diorite. In fresh specimens the diorite is a hard, fine-grained, greenish-black rock, occasionally spotted with white feldspar. It weathers to a reddish yellow, and is locally termed "brickbat," because, on weathering, it separates into rectangular blocks, owing to the presence of three systems of joints. The diorite appears to decay more readily than the mica-schists of the region; and this ease of decomposition seems to have fixed the location and direction of many of the valleys of the area. The hornblende-schist is well shown in the court-house square at Dahlonega, and is exposed in most of the mines in Findley Ridge. It is an igneous rock, cutting the mica-schists; but it was intruded at an early period, and has been made thoroughly schistose. In age it is therefore intermediate between the mica-schists and the granite next to be described.

Granite.—A light-colored, coarse-grained granite is exposed at the Mary Henry and Bennings mines, and also at several points west of Dahlonega. It consists largely of quartz and white feldspar, with some biotite. Near the Hand mine it is shown cutting across the lamination of the hornblende-schist. It is evidently a comparatively late igneous intrusive, having suffered little from shearing or faulting, and it may be roughly correlated, in point of age, with the Villa Rica granite described by Dr. C. W. Hayes as occurring in the Cartersville and Marietta quadrangles.

THE GOLD ORES AND ORE DEPOSITS.

As is well known, the earliest gold mining done in the district was on the placer deposits occurring along the various rivers and creeks. Later the attention of miners was called to the fact that in many places the decomposed rocks of the region carried gold, and, accordingly, sluicing these decomposed rocks came into practice. It was soon found, on working through the upper decomposed portions of these rocks to the fresh hard rocks below, that the free-milling ore found in the upper decomposed rock changed to sulphides in depth. In handling these sulphides, stamp milling and amalgamation did not recover a sufficiently large proportion of the assay values to justify exploitation of the deposits in hard rock. Chlorination of the sulphides was then tried, and has succeeded to a limited extent.

The placer deposits of the district have undergone treatment many times, and in consequence few can now be profitably worked by ordinary methods. Dredging the river bottoms is, however, still profitable, and is carried on as explained by Mr. H. V. Maxwell in the interesting paper cited above. In the present article the placer deposits will not be further discussed, attention being confined to the gold-quartz veins of the district.

From the point of view of the miner, the gold-quartz veins can be separated into two distinct classes, requiring very different treatment, both in the mine and in the mill. As is well known, the rocks in this portion of the southern Appalachians are very deeply weathered, and in many places solid rock does not occur within 100 feet of the surface.[a]

In this zone of decayed rock—which on the average includes the upper 50 to 100 feet—both the country rock and the vein material are disintegrated, and resemble sand or gravel in texture and consistency. The two important effects to the miner of this deep weathering are that (1) the ore itself is free milling, the pyrite having altered to limonite and released its gold; and (2) the entire mass of material can be mined and treated exactly like a thick placer deposit, by hydraulic mining. At present hydraulic mining is being carried on extensively in the Crown Point, Singleton, and Tahloneka properties, the material being washed into sluices by the giants and carried in this manner direct to the mills.

In a proposition of this character such a combination of soft material and free-milling ore renders the cost of mining and milling very low, and even low-grade ores can be profitably worked. The ease of working is, however, partly offset by the fact that a large amount of worthless material is washed out by the giants and sent to the mill along with the profitable matter.

As soon as the zone of weathered rock is passed in depth the workings encounter solid rock (mica-schists, etc.) containing fairly distinct veins of gold-bearing quartz. In this hard material it is possible to mine only the vein, thus reducing the handling of worthless material to a minimum. This advantage over workings in weathered rock is, however, much overbalanced by the two considerations that in deep mining in solid rock (1) the cost of mining, per ton of material moved, is very much higher than in soft material, and (2) the ores no longer carry any very large proportion of free gold, for the pyrite is not decomposed. Simple stamping and amalgamation is therefore insufficient, and some more expensive process must be substituted. Numerous "secret processes" have been tried without success. Chlorination is now practiced at two plants, but the results are not entirely satisfactory.

Relations of the gold-ore deposits.—Since the visit of Dr. Becker to this district, in 1894, the mine workings have been deepened, and in

[a]Becker suggested the use of the term "saprolite" for material such as this, which is the product of rock decay in place. Unfortunately "saprolite" has, in the Dahlonega district, been adopted by the miners and used in a sense entirely different from that intended by Becker. For this reason the term will not be used in the present discussion.

consequence the relations of the ore deposits to the country rock can be studied to better advantage than was possible at that date. The most interesting feature developed by the recent work has been in relation to the position of the ore deposits. The writer believes it can now be accepted as proved that in the large majority of mines in the Dahlonega district the more profitable and continuous veins occur along the contact between the mica-schists and an igneous rock, the igneous rock being either a granite or a sheared diorite. This occurrence was first pointed out to the writer by Gen. A. J. Warner, as occurring in the mines on Findley Ridge, and was, on further examination, found to be the common type of occurrence throughout the entire district. There are, it is true, exceptions to this rule, but they are not numerous. In a few cases (Betz mine, etc.) a body of schist, not in the immediate vicinity of an igneous rock, is so cut by minute gold-bearing quartz veins as to permit the entire mass to be profitably mined, while in other instances, as on the Walker property, a small but rich gold-quartz vein occurs entirely within the schists.

The genetic relationships existing between the ore deposits and the igneous rock, in the two cases presented (granite and diorite), are of very different character. The diorite, as noted earlier in this paper, was injected into the schists at a much earlier period than that during which the ore deposits were formed. This is proved by the fact that this diorite has been crushed and sheared to such an extent that it now appears as a hornblende-schist, the schistosity of which conforms to that of the normal mica-schists of the region; while the gold-bearing veins cut both diorites and mica-schists, and have suffered very little from either folding or faulting. The fact that many prominent gold-bearing veins occur along the contact between the diorite and the mica-schists is not due, therefore, to any direct action of the diorite considered as an igneous rock, but to the facts (*a*) that fissures are most likely to be formed along the contact between two formations differing in hardness and rigidity, and (*b*) that such fissures, minute at first, may have been enlarged by the solution of the relatively unstable diorite.

With regard to those deposits which occur along the contact between granite and mica-schist the case is somewhat different. Here the intrusion of the granite may possibly have some direct genetic connection with the formation of the ore deposits. As noted above, the granite is younger than the diorite, cutting the latter at several points in the area; it shows little or no banding and has been relatively little folded. At several points the granite shows slight banding; at other points minor faults occur within it. Rock movements have evidently occurred in the region since the intrusion of the granite, but such movements have been slight compared to those which occurred in the interval between the intrusion of the diorite and the intrusion of the granite, as is evidenced by the relative amount of shearing shown by the two rocks.

Age of the gold-ore deposits.—The statement has frequently been made that the gold-bearing quartz veins of eastern United States are of pre-Cambrian age. While this may be true of certain areas, there seems to be little evidence anywhere in its favor. Gold-quartz veins occur, on the other hand, in Ocoee (Cambro-Silurian) rocks in Georgia and Tennessee, while in New York the three authenticated occurrences of gold-quartz veins are all in rocks of Lower Silurian age.

In the Dahlonega district, even if the country rocks be regarded as pre-Cambrian in age (which the writer would not be inclined to believe), the structural relations of the ore deposits are such as to make it certain that they are not pre-Cambrian. It is possible, indeed, that the gold-quartz veins were not formed until late in the Paleozoic.

PYRITE DEPOSIT IN THE DAHLONEGA DISTRICT.

The most interesting development of the last year in the Dahlonega district has been the opening of a large high-grade body of pyrite in the vicinity of the town. The occurrence of this mineral in at least one body of workable size has been known for some time, but until 1902 the deposit had not been opened up sufficiently to justify any statement as to its value. During the last year, however, exploitation has been carried far enough to permit some idea being formed as to the size, uniformity, and grade of the deposit.

The writer visited the mine in September, 1902, in company with Mr. N. P. Pratt, and the present description is the first based on an actual examination of the workings, as access to the incline and tunnels had been denied to all previous visitors.

The property of the Chestatee Pyrites Company is located about 6 miles from Dahlonega, in a direction a little north of east. The openings are located on the south side of the Chestatee River, about 2 miles west of its junction with the Tessantee.

The outcrop of the pyrite body has a direction about N. 45° E., while it dips at an angle of about 45° to the northwest. On examining the stratigraphy it is found that in position, form, and associations this pyrite deposit closely resembles the typical gold deposits of Dahlonega, as described on pages 59 to 61 of the present bulletin. The pyrite forms a "bedded" vein at this point, being conformable to the quartzose mica-schists which overlie it on the west. The rock adjoining the pyrite on the east, however, is of the same type of hornblende-schist as that described above in connection with the Dahlonega gold veins. As with those deposits, the pyrite body occurs on the contact between a normal (and possibly sedimentary) mica-schist and a hornblende-schist, which is a much metamorphosed igneous rock of early date.

The deposit has been thoroughly opened at two points, in addition to the pits and trenches which have been dug in order to test the continuity of the deposit. The northeastern opening is a tunnel, driven completely through the vein. Two drifts diverge from the tunnel at right angles, both being run parallel to the trend of the vein. One of the drifts is run on the western or hanging wall of the vein; the other on the foot wall. About 100 feet southwest of the tunnel opening an incline has been sunk on the dip of the vein, a depth of 60 feet below the mouth level having been attained at the time of visit.

These workings, taken in connection with somewhat extensive diamond-drill explorations and the examination of natural outcrops, would seem to give a fair basis for calculation of the size of the deposits. The outcrop extends for a distance of at least 2,000 feet along the surface of the ground. Where it has been effectively crosscut by tunnels and incline, the pyrite body is shown to be about 30 feet in thickness, and trenches and drill borings would appear to prove that its thickness at no point along the 2,000 feet of exposure falls below 20 feet. It has been followed down on the dip for a distance of almost 150 feet.

The body of ore seems, therefore, amply large enough for profitable exploitation. The operating company has adopted a wise policy in this respect, the intentions being to push underground working and accumulate a large supply of stock ore before commencing to build a treatment plant.

The ore highest in sulphur occurs in the middle 20 feet of the vein, the ores along each wall running lower in sulphur and higher in copper than the average. Eight carloads of ore were taken from the tunnel, thus securing a sample entirely across the vein. The average of the analyses is as follows:

Analysis (average) of Chestatee pyrite.

	Per cent.
Sulphur	43.52
Iron	39.70
Copper	3.09
Zinc	.72
Alumina	2.53
Magnesia	.43
Arsenic	None.
Silica, etc	9.26
Moisture	.36

Analyses from the middle 20 feet would show a higher sulphur and lower copper content than the average analysis quoted, while analyses of the portions of the pyrite body near the walls would give lower sulphur and higher copper. It is probable that this difference in composition, which can be noticed even in a hand specimen, will be taken advantage of in planning the treatment of the ores.

In conclusion it is necessary for the writer to acknowledge the aid received from Mr. N. P. Pratt in this investigation, as the results obtainable would have been very slight if Mr. Pratt's assistance had been less freely and courteously given.

NEOCENE RIVERS OF THE SIERRA NEVADA.

By Waldemar Lindgren.

During the geological mapping of the gold belt of the Sierra Nevada much information was gathered relating to the gravel mines, and attempts were made to reconstruct the drainage systems of the Neocene rivers, now represented by detached masses of lava-covered detritus, generally at high elevations above the present drainage level. Many of these deposits were described in the texts of the folios of the gold belt by Mr. H. W. Turner or myself. A very brief review of the gravel mines and the channels of the central gold-bearing region was given in the bulletin of the Geological Society of America.[a] None of these publications, however, does full justice to the important and interesting problem of the Neocene stream gravels of the Sierra Nevada, a subject fascinating alike from the economic and the scientific side. Whitney's monograph on this same subject, while containing an enormous amount of valuable observations, is out of date, because of the careful geological mapping by which the country has been covered since that volume was written.

It seemed advisable, therefore, to collect in one publication the principal facts and conclusions regarding the Neocene gravels. Some supplementary work was found to be necessary, and four months of the season of 1901—from the beginning of July to the end of October—were devoted to the study of the gravels in Butte, Placer, Calaveras, and Tuolumne counties. In this work I was assisted by Mr. J. M. Boutwell, who made a special reexamination of the Forest Hill divide in Placer County. About one month of the summer of 1902 was also given to a reexamination of certain deposits in the same county.

The data which have been brought together are very voluminous, and their compilation has necessarily been delayed by the pressure of other work, but it is hoped will be finished during the present year. It is intended to review briefly the present state of this mining industry, its probable future, its production, and the methods of mining peculiar to it. The structure of the Sierra Nevada will be described, and some attention will be devoted to the interesting

[a] Lindgren, W., Bull. Geol. Soc. Am., Vol. IV, 1893, pp. 257-298.

region of the eastern slope. The gravels and the covering volcanic material are to be discussed from a geological and petrographical standpoint; and much space will be given to the question of the connection of the isolated gravel areas with Neocene river systems, a question which also includes a physiographical description of the Sierra Nevada during the Neocene period. As a general result the Neocene Sierra Nevada will be shown to have existed at that time as a well-defined range, similar to though lower than the present mountains. The rivers headed near the present divide, and flowing in a general westerly direction, emptied into the bay or marshes of the Sacramento and San Joaquin valleys. Finally, the probable character of the orographic disturbance to which the range owes its present elevation will be discussed.

MINERAL DEPOSITS OF THE BITTERROOT RANGE AND CLEARWATER MOUNTAINS, MONTANA.

By Waldemar Lindgren.

INTRODUCTION.

In 1899 a geological reconnaissance was undertaken of the country between the Bitterroot Valley in Montana on the east and the Lewiston Plateau on the west. During the reconnaissance I was assisted by Mr. G. W. Stose, of the United States Geological Survey, and Mr. H. R. Johnson.

The region visited is bordered on the south by the Salmon River and on the north by the North Fork of the Clearwater. The fertile Bitterroot Valley lies at the eastern foot of the imposing range of the Bitterroot. This range, which attains an elevation of 11,000 feet, westward merges into the great dissected plateau of the Clearwater Mountains, which in turn at their western edge descend rather abruptly to the plateaus of Camas Prairie and Cold Spring Prairie, forming part of the great Columbia River lava plateau. This latter plateau has a general elevation of 2,500 to 3,000 feet, and is built up of horizontal lava flows.

From great glacial cirques in the western slopes of the Bitterroot Range the Salmon River and the several forks of the Clearwater River find their way westward in canyons from 3,000 to 5,000 feet deep. The canyon of the Salmon especially is remarkable for its great length and depth. In the lower plateau country these rivers flow in more sharply incised but less deep canyons, which continue to their junction with the master stream, the Snake River.

The area indicated forms a wild and very sparsely populated mountain region, heavily timbered except on the highest ridges, which usually show clear evidence of glacial action. The geology is comparatively simple. The main Bitterroot Range and the larger part of the Clearwater Mountains consist of a massive biotite-granite, or, defining it more correctly, a quartz-monzonite, which is the northward continuation of the great batholith of the same rock which occupies so large an area in south-central Idaho. In the latter region this intrusive mass is of post-Carboniferous and probably late Mesozoic age, and there is no reason to believe that the granite of the Clearwater and the Bitterroots is of different age.

Along the whole eastern slope of the Bitterroot Mountains this granite is made schistose by pressure, and forms a zone a few miles in width and 60 miles long, following the front of the range. A great fault accompanies this schistose zone, dipping, like the schistosity, about 18° E. Otherwise the granite is generally massive and but little altered. Several smaller areas of a much older gneiss (pre-Cambrian?) occur in the Clearwater Mountains, the largest appearing near Elk City. The granite is intrusive in this gneiss. Along Lolo Fork at the northern end of the Bitterroot Mountains and near the head of the Bitterroot River are areas of quartzites and slates (probably of Cambrian or pre-Cambrian age) into which the granite is also intrusive. Finally, along the western foot of the Clearwater Mountains, near Harpster and Mount Idaho, occur slates, limestones, and greenstones, which continue, with a northeasterly strike, up from the vicinity of the Seven Devils and the Lower Salmon River, and which are believed to be of Mesozoic age. Into this series, also, the granite is intrusive.

The main structural features consist of the great Bitterroot fault and the uplift of the Clearwater Plateau. There is some evidence of comparatively recent movement along the former, although faulting is believed to have begun along that line in pre-Miocene times. The latter uplift is of pre-Miocene age.

ECONOMIC GEOLOGY.

Character of mineral deposits.—The valuable mineral deposits occurring in the area described in this report consist chiefly of fissure veins containing gold, together with associated placers derived from the disintegration of the veins. Deposits containing lead and copper, and usually silver, occur also in several isolated places. Coal of a fair quality has also been found in the upper Bitterroot Valley and in the lower Clearwater drainage. The lead-silver veins of the Cœur d'Alene Mountains are outside of the limits of this reconnaissance.

Distribution of deposits.—The metalliferous deposits are grouped in two belts, the first along the western side of the Bitterroot Mountains, chiefly in Montana; the second along the western foot of the Clearwater Mountains in Idaho. The deposits of each of these two belts are again grouped principally in two regions forming the four corners of the mountain area involved, while the central part of the Clearwater Mountains appears to be practically barren. The four metalliferous areas are distributed as follows: The first occupies the lower Lolo Fork and the northern end of the Bitterroot Mountains; the second is found on the headwaters of the South Fork of the Bitterroot River and reaches over into Idaho, connecting with the mineral belts at Shoup and Gibbonsville; the third and most important area includes Elk City, Buffalo Hump, Dixie, and Florence, as well as numerous places along the South Fork of the Clearwater River; the fourth area centers in Pierce, but also extends to the headwaters of Lolo Fork on the south and to the North Fork of the Clearwater on the north.

Character of ore.—The primary deposits are almost exclusively fissure veins, and with them are associated extensive placers of an age ranging from Neocene to Recent. In the northern Bitterroot Mountains and on Lolo Fork veins occurring in pre-Cambrian (?) schists contain chiefly copper, lead, and silver, although some gold is also found on Lolo Fork. The Curlew mine, at the eastern foot of the Bitterroot Mountains, contains argentiferous galena, and is located on a fissure with limestone (pre-Cambrian?) as the foot wall and, according to accounts, Pleistocene valley gravels as a hanging wall. The mine is not worked at the present time. On the Upper Bitterroot River veins cutting porphyry likewise carry chiefly copper and silver, while argentiferous galena is also known from the Monitor mine, worked on a vein in gneiss on the divide between the Bitterroot and Salmon rivers. Gold-bearing gravels have been mined for many years on Hughe Creek. Southward this belt connects with the gold-bearing deposits at Gibbonsville and Shoup. The rocks at Hughe Creek and Gibbonsville are pre-Cambrian (?) quartzites and slates.

West of these districts extends a wide granite area which, as far as known, is barren of mineral deposits. There can be no doubt that the Clearwater drainage was very thoroughly prospected for placers during the early days of mining, but outside of the South Fork very little of value has been found. In the upper part of the mountains the glaciation would naturally have swept away any placer deposits which may have existed, and in this denuded portion it is not impossible that veins may be found. Nothing of much value has yet been encountered. A large vein containing silver is reported to occur on Rhodes Peak north of the Lolo trail. Along the Salmon River the conditions are probably more favorable, and prospecting in the isolated region between Dixie and Shoup might develop something of value.

As stated before, the western belt contains chiefly gold; only a few scattered copper deposits are known. The placers of Elk City and Florence are well known in the history of Idaho and are still worked to some extent. Veins which furnish the material for these placers are known to occur in all these localities. The principal mining districts are those of Florence, Dixie, Elk City, and Newsome Creek. The veins, occurring chiefly in gneiss, are almost exclusively of quartzose character and contain from 1 to 10 per cent of sulphurets, besides more or less native gold. The Buffalo Hump district, discovered in 1898, is situated on the high divide between the Clearwater and the Salmon. It contains many strong quartz veins in granite and slate, with a varying percentage of free gold and auriferous sulphides. Active work is in progress there at the present time. The northwestern mineral-bearing area contains placers along Lolo Fork, Musselshell Creek, and Oro Fino Creek. Many quartz veins similar in character to those of the southwestern belt are also worked in these districts. They are generally incased in schists, more rarely in granite. Veins of sulphide ores containing gold and copper occur in amphibolite close to Mount Idaho.

History and production.—The deposits on the eastern slope of the mountains have not proved of great importance and have chiefly been discovered and worked at a comparatively recent time. The production of all the mines on this side of the mountains probably does not exceed $1,000,000, of which the larger part has been derived from the Curlew mine on the north and from the placers of Hughe Creek, near the head of the Bitterroot River. The important gold belt on the western slope was discovered about 1860 and was very actively worked during the following years. Oro Fino or Pierce is reported to be the earliest discovery in Idaho. It was found in 1860, and during that season 25 men wintered there. The gravel near Pierce was not remarkably rich, but paid fairly well in 1861 and 1862.[a] In 1874 Pierce produced $70,000. But soon after this the discoveries in Montana drew most of the miners away from this place and in 1867 but little mining was going on. Since that time, however, the placers and quartz mines have been worked each year, although in a somewhat desultory manner. The total production it is impossible to ascertain, but probably it has not exceeded a few million dollars.

During late years placer mining has been carried on both in the low-stream gravels and on the benches. There has also been considerable activity in quartz mining and several small mills have been built. The output of the placer mines in 1902 is estimated at $30,000, and that of the quartz veins at the same amount.

Elk City and vicinity proved to be of greater richness. Few quartz mines have been worked there, practically the whole production being derived from the placers. In 1863 or 1864 the white miners began to leave this field, which they considered about worked out, and for nearly thirty years there were only two or three of them left in the district, which was almost entirely turned over to the Chinese. In 1892 the white miners began to come back and the Chinese simultaneously disappeared, very few of the latter being left now. A certain amount of placer work is still done in this vicinity each year, chiefly on bench gravels. The bars of the Clearwater River, which were worked extensively during the early days, are still occasionally washed. Regarding the total output of Elk City no satisfactory figures are available, but not unlikely the production amounts to about $5,000,000.

After the first few years of abundant production the output fell rapidly. In 1874 Elk City (including Newsome Creek and Clearwater station) produced $120,000. From 1882 to 1887 the Elk City district produced from $35,000 to $73,000 per annum. During recent years the output has again increased, due to the introduction of dredging

[a] Browne, J. Ross, Report on the Mineral Resources, Washington, 1860.

and hydraulic operation, and during the last years it has probably been from $20,000 to $40,000. Very similar were the conditions during later years in Florence, which camp has been described in a previous report.[a] The total output of Florence was, however, considerably larger than that of Elk City.

Florence, Warren, and Elk City are situated in Idaho County. According to the Mint reports, this county has, since 1880, produced an average of $200,000 per annum, or a total of about $6,000,000. Something like one-half of this amount probably comes from Warren, leaving $3,000,000 as the production of Florence and Elk City for the last twenty years. Pierce is located in Shoshone County.

It is a somewhat surprising fact that in spite of the recent activity in prospecting and working quartz veins the production of Idaho County should have decreased during the last few years. The Mint reports give for Idaho County the following amounts:

Precious-metal production of Idaho County, Idaho, 1895–1901.

1895	$243,700
1896	155,350
1897	236,500
1898	203,500
1899	166,000
1900	152,000
1901	161,500

GEOLOGICAL RELATIONS.

Nearly all the vein deposits occur in granite or gneiss, and the prevailing strike of the veins seems to be in an east-west direction. The granite, which is the prevailing rock, represents the northward continuation of the great area of central Idaho north of Snake River. Gold-bearing veins occur both within this area and along its contacts with the surrounding, older, sedimentary rocks. But for a long distance north and south of Salmon River the central large granite areas seem comparatively barren, contain ng few deposits, with the exception of the Warren camp.

Within the region here discussed a peculiar relation obtains: The large central areas of granite, whether sheared, as along the eastern margin of the Bitterroot Mountains, or massive, as is usually the case, seem conspicuously barren of deposits. The vein systems appear in or close to the four smaller areas of sedimentary or metamorphic rocks which are found at the perip ery of the great central granite area. This is the case in the quartzitic series of Lolo Fork, in the quartzites, slates, and gneisses of the upper South Fork of the Bitterroot, and in the old gneiss areas of Elk City and Pierce. While the age of the quartz veins is not established beyond doubt, it is probable that they were formed during the later part of the Mesozoic.

[a] Lindgren, W., The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 233.

THE CHISTOCHINA GOLD FIELD, ALASKA.[a]

By Walter C. Mendenhall.

GENERAL DESCRIPTION.

The Chistochina gold field is a small placer area in the northwestern part of the Copper River Basin, Alaska, near the intersection of the one hundred and forty-fifth meridian west longitude and the sixty-third parallel north latitude. The district is among the foothills just south of the Alaskan Range, which rises to heights of 8,000 or 9,000 feet in the vicinity, and serves as a gathering ground for ice fields and glaciers, from which torrential rivers flow north to the Tanana and south to the Copper. All of the diggings at present are on two streams, both tributary to Chistochina River, which flows into the Copper. The larger, but not the more important of these, the Chesna, is about 12 miles long and empties into the Chistochina 11 miles below its source, in the Chistochina Glacier; the smaller, Slate Creek, which, with its tributary, Miller Gulch, yields nine-tenths of the gold of the district, is only 4 or 5 miles long and joins the Chistochina just as the latter emerges from the glacier.

The field is usually entered over the military trail from Valdes, the nearest seaport, 225 miles to the south, but is accessible from Eagle City on the Yukon, about 250 miles north. The lack of navigable streams along these routes means that supplies must be transported practically the entire distance by pack train or sled, and that therefore the district is one of the most remote and difficult of access in Alaska.

GEOLOGY.

Our present knowledge of the geology of the region may be briefly summarized as follows:

That part of the Alaskan Range lying immediately north of the gold area is made up principally of micaceous schists whose thickness and age are unknown.

Immediately south of the schists and separated from them by a fault, whose throw probably exceeds 10,000 feet, is a belt of Permian

[a]This paper is an abstract from a more complete discussion which is shortly to appear in a paper entitled: The Mineral Resources of the Mount Wrangell District, Alaska.

beds consisting in the upper part of shales and limestones, but including, at lower horizons, tuffaceous sediments and flows, which have an aggregate thickness of 6,000 or 7,000 feet. Many basic igneous masses occur as dikes or intrusive sheets in these sediments. They are especially abundant near the fault. The shales are slightly metamorphosed in the vicinity of Slate Creek and Miller Gulch, where some cleavage has developed and a few quartz stringers are found cutting them. Eocene lignite-bearing beds occur here and there in small patches infolded with the Permian.

South of the Permian belt occurs a complex terrane of older rocks, consisting of conglomerates, quartzites, tufaceous beds and probably flows, which appear to be faulted against the Permian. This terrane is intruded and altered by dikes and greater masses of granite and quartz-porphyry. One effect of the intrusion and alteration is a general impregnation by pyrite, whose oxidation products color the rocks rust-red and render them especially conspicuous.

In addition to these easily separable consolidated rock masses, unconsolidated clays and gravels, either primarily or secondarily of glacial origin, occur in the valleys generally. Near the sources of the streams these deposits are confined to flood plains or narrow bordering terraces, but downstream the area covered by them widens, until it merges with the broad drift-filled valley of the upper Copper Basin, from whose borders isolated bed-rock areas rise as islands.

Besides these Pleistocene deposits in the lowlands, a thin sheet of cobbles, called by the prospectors the "round wash," is conspicuous on the hilltops about the head of Slate Creek, Miller Gulch, and some of the tributaries of the upper Chesna.

GOLD OCCURRENCES.

Practically all of the gold mined at present is taken from Miller Gulch, Slate Creek, and the Chesna River, whose combined yield for 1902 is estimated at $225,000. Of this amount, Miller Gulch probably furnished $175,000, Slate Creek $30,000, and Chesna River $20,000.

Miller Gulch, whose yield is thus seen to be much greater than that of any other stream in the district, is a steep ravine, less than a mile long, tributary to Slate Creek. Its bed, decreasing in width from 200 or 300 feet near its mouth to but 4 or 5 feet near its source, is sheeted over with gravel to a depth of from 4 to 8 feet. This gravel is composed principally of fragments of the somewhat metamorphosed Permian shales in which the ravine is cut, but has an admixture of diabase and "bird's-eye porphyry" from the intrusives in the shale, and of cobbles from the "round wash" which occurs over the tops of the adjacent hills. The gold is rather uniformly distributed across the gulch, but vertically exhibits the usual concentration near bed rock. The richness and shallowness of the gravels, and the steep gradient of the stream, giving abundant fall, have made it easy to win the gold by simple sluicing methods, and have caused the early development of Miller Gulch to a maximum of production, while the poorer or deeper diggings in the other creeks, where in some instances expensive plants are required, have been neglected.

The waters of Miller Gulch, discharging into Slate Creek, carry with them some of the gold from the gulch. As a consequence, for a short distance below the junction, Slate Creek is rich; indeed, nearly all of the gold which it has yielded has been obtained here. Above Miller Gulch, on Slate Creek, bed rock is not always within easy reach, in part because of burial beneath alluvial fans from tributary creeks, in part because of irregularities attributable to glacial action; and where bed rock is accessible, the yield is not more than $10 or $15 a day to the man—about the wage of the district.

The gravels of Slate Creek contain representatives of all the rock types found in Miller Gulch, and in addition a certain proportion of material derived from the older quartzites, pyroclastics, and granitic intrusives occuring on the south side of its lower valley.

On Chesna River the diggings are confined to two localities about 8 miles apart, one near the source, the other near the mouth of the stream. The greater part of the work on the upper Chesna has been confined to a small tributary called Ruby Gulch. In the upper part of this gulch the conditions of accessibility of bed rock and of geologic relations resemble those of Miller Gulch, but the gravels are not so rich, and the workable ground is not so extensive. The operators, however, have been able to make satisfactory profits in their work. Along the lower course of Ruby Gulch the operations have been rather in the nature of development. Bed rock is not reached, the gravel being removed by ground sluicing to a clay stratum on whose surface the gold is found. The yield here is reported to about pay expenses.

The valley of the middle Chesna is clogged by glacial deposits, and for a number of miles the cursory attempts to find bed rock have not been successful, but along the lower Chesna, beginning at a point about 1½ miles above the mouth and extending thence upstream nearly the same distance, bed rock is within easy reach for short distances on either side of the river. There is a shallow canyon a few hundred feet long near the lower end of this stretch, and present operations are confined to small areas above and below this canyon on the discovery claim of the district.

The Chesna has been tapped a few thousand feet above the canyon and the water conducted by a ditch along the south bank of the river to a point just below the canyon, where a hydraulic plant has been installed with a head of 125 feet.

Although over considerable areas the gravel is but 4 to 8 feet deep, it was found impracticable to handle it effectively by ordinary sluicing methods, because of the presence of large bowlders and much water, but those who have installed the hydraulic plant anticipate that by its use and the construction of drainage ditches the gold can be easily and profitably secured. As pans are reported to run from 1.7 to 5.5 cents each below the canyon, with a maximum yield of $1 on bed rock, their anticipations seem to be justified.

ORIGIN OF THE GOLD.

The gold from the various streams on which operations are conducted is rather uniform in form, color, and assay value. It generally occurs in flattened scales or grains, and is but rarely rough and irregular. It is clean looking and bright yellow in color, and its assay values are reported to vary from $18 or $18.50 per ounce on Miller Gulch and the upper Chesna to $18.72 on the lower Chesna.

One-ounce nuggets are not unusual on Miller Gulch, and one piece is reported which weighed 4 ounces. On Ruby Gulch the largest nugget found is valued at $12.75, but nuggets are very rare on the lower Chesna, the gold being in the form of thin, flat scales. These variations in coarseness and in assay value are of the kind which would be expected if the source of the gold were in the region near the head of Miller and Ruby gulches, where the gold is coarser and the values are lower.

Some of the operators of the district, admitting that the gold comes from the vicinity of upper Slate Creek and Chesna River, maintain, with much show of reason, that it is derived there from the "round wash," which is particularly heavy about the head of Miller Gulch and Slate Creek. It is also present on the divide between Ruby Gulch and the next stream east, so that the advocates of this theory are able to prove that each stream at present worked to a profit drains an area in which the "round wash" is found. They likewise regard the smooth surface of the gold as evidence that it is waterworn and has therefore been brought from some extraneous source, as is so evidently true of the "round wash."

Some facts, however, are distinctly opposed to this hypothesis, and others admit of as ready explanation on another basis.

A small stream, on which a group of claims known as the "Big Four" has been staked, heads opposite Miller Gulch and flows down to the Chistochina Glacier. The heaviest deposit of the "round wash" known in the region occurs on the slopes drained by this brook, which seems therefore to be more favorably situated than Miller Gulch, relative to this deposit as a source of the gold; but the Big Four claims yield fine gold in moderate amount and are not to be compared in richness to Miller Gulch. Furthermore, Ruby Gulch and the creek next east of it seem to be equally favorably situated in relation to the deposit of the "wash" which occupies the divide between them, yet one has yielded operators a handsome return and the other is not profitable.

It is even more significant that the sources of the gold-bearing creeks are all within an area whose extent coincides with a region of local metamorphism in the Permian shales, and that no other metamorphosed areas of these beds and no other gold districts within them are known. Where they have been metamorphosed an incipient cleavage is developed and the shales carry a few narrow quartz stringers. It is believed that the flat, smooth character of much of the gold is sufficiently accounted for by its origin in these shales and by its purity and consequent softness, which lead to rapid smoothing and polishing with but little transportation.

It is therefore concluded that the gold originates in these Permian beds, and that in its genesis it is related to the local metamorphism which they have suffered. It is evidently post-Permian in age, and since Eocene beds deposited unconformably upon the Permian are but little folded and wholly unmetamorphosed, it is probably also pre-Eocene.

GOLD MINING IN CENTRAL WASHINGTON.

By George Otis Smith.

HISTORY OF THE DISTRICT.

The three principal gold-mining districts of central Washington are included in the Mount Stuart quadrangle. This area has been surveyed geologically, and the descriptive folio is in preparation. The Peshastin placers were discovered in 1860 and have been worked intermittently ever since. The Swauk placers have been worked rather more steadily since their discovery in 1868. Gold-bearing veins were first located in the Peshastin district in 1873, and in the Swauk in 1881. The mineral veins of the Negro Creek district constitute a continuation of those in the Peshastin district. Swauk Creek is a tributary of Yakima River, and Peshastin Creek of Wenache River, so that both districts are on the eastern slope of the Cascade Range.

Mining in these districts has been conducted by small owners, and it is impossible to secure any definite data regarding production. The output of gold of Kittitas County for the years 1884 to 1895, as reported by the Director of the Mint, aggregates $764,163. About $5,000 of silver was reported from that county for the same period. The Peshastin district is now included in Chelan County, but during this period was a part of Kittitas County. The years 1892 and 1895 were seasons of maximum production, and the area would have probably steadily increased its output had it not been for the exodus of miners to Alaska. In view of the activity in these districts in the years preceding 1884, as well as the production of the last seven years, it seems that $2,000,000 would be a conservative estimate of the total gold production of the districts. In the last five years companies with larger capital have purchased the claims of the small operators, and mining operations will now be conducted more economically and with a probable marked increase in the gold production.

AURIFEROUS GRAVELS.

Swauk district.—The Pleistocene gravels along Swauk Creek and many of its tributaries are gold bearing. These alluvial gravels form the terraces, which are especially prominent and extensive at the junctions of Swauk and Williams creeks and of Boulder and Williams creeks. The gravel deposits are from a few feet to 70 or 80 feet in thickness, and while red or yellow in color at the surface, the gravel is blue below. The upper portions of the gravel are also less easily worked, since induration of the gravel has followed the oxidation of the cementing material.

While fine gold is found throughout the gravel deposits at some localities, most of the gold occurs close to bed rock and in channels other than those occupied by the present streams. Its marked characteristic is coarseness. Pieces several ounces in weight are common, while a number of nuggets weighing 20 ounces or more have been found, and one or more nuggets of about 50 ounces have been reported, the largest nugget of the district having a value of $1,100. These larger nuggets are usually well rounded, but on the tributary streams wire and leaf gold is found. The gold is not pure, containing considerable silver, which materially decreases its value.

The bed rock, which belongs to the Swauk formation, of Eocene age, is usually of a nature to favor the collection of the gold. The inclined beds of hard shale form natural "riffles," and from the narrow crevices in the shale the best nuggets are often taken. The sandstone beds wear smooth, in which case the bed rock is apt to be barren. The old channels, both of Swauk Creek and of its tributaries, vary somewhat in position from the present course of the stream, but only within definite limits. The old valleys and the present valleys are coincident, but, within the wide terraced valleys of the present, older channels may be found, now on one side and now on the other. Thus, on Williams Creek and the lower portion of Boulder Creek, the old water course has been found to the south of the present channel of the stream, and is in other cases below the bed of the creek. On Swauk Creek the deposits worked are above the level of the stream, being essentially bench workings. Here hydraulic plants have been employed, but elsewhere the practice has been to drift on bed rock. While the endeavor is to follow the old channels, it is found that the "pay streak" can not be traced continuously. Ground that will yield $40 to the cubic yard of gravel handled may lie next to ground that does not contain more than 50 cents to the cubic yard. In the last few years the operations in the Swauk Basin have been on a larger scale. Williams Creek has been dammed and methods have been devised to handle the tailings and bowlders on the lower courses of Swauk Creek, where the gradient of the valley is low.

The source of the alluvial gold is readily seen to be the quartz veins known to occur in the immediate vicinity. These will be discussed in a following paragraph. The noticeable lack of rounding of much of the gold shows that it has not been transported far, and indeed the limited area of the Swauk drainage basin precludes any very distant source for the gold. It is only along the Swauk within a few miles of Liberty and on Williams Creek and its tributaries that gold has been found in paying quantities, and, as will be noted later, this is approximately the area in which the gold-quartz veins have been discovered. From the outcrops of these ledges the gold and quartz have been detached and washed down into the beds of the streams, where the heavier metal soon became covered by the rounded bowlders and pebbles with which the channel became filled. The conditions under which the gold was washed into the streams probably differed little from those of to-day, except that the streams were then filling up their valleys.

Peshastin district.—The gravel deposits in the valley of the Peshastin are less extensive than in the Swauk district. The alluvial filling of the canyon-like valley of the upper half of Peshastin Creek is not as deep and does not show the well-marked terraces so prominent in the Swauk Valley. The gravel appears to be gold bearing throughout, and the gold is quite uniform in distribution. The largest nuggets are found on the irregular surface of the pre-Eocene slate which forms the bed rock. While the largest nuggets found in the Peshastin placers are less than an ounce in weight, and therefore not comparable with some of the Swauk gold, the Peshastin gold is fairly coarse and easily saved. The gold is high grade, being worth about $18 an ounce.

The principal claims on the creek, below Blewett, are owned by the Mohawk Mining Company, which is hydraulicking the gravels with water from the upper Peshastin and from Negro Creek. Work which has been done on Shaser Creek shows the gravels to be gold bearing, and here also the gold is high grade. This fact is interesting, since, while the Shaser Creek drainage basin is almost wholly in the same formation as that of the Swauk Basin, the gold found in the two creeks is quite different, the Swauk gold containing a considerable amount of silver.

GOLD-QUARTZ VEINS.

Peshastin district.—A few mines in the vicinity of Blewett have been producers for about twenty-five years. The many changes of management and methods of operating these properties, however, make it impossible at the present time to determine accurately the character of the ore that has been mined, or to estimate even approximately the product during this period. Much of the ore has been low grade, and the gold has been extracted by means of arrastres, stamp mills, and a small cyanide plant, but not always with very successful results. The small stamp mill first built in this district was the first erected in the State of Washington. Another mill, with 20 stamps, has lately been rebuilt under the Warrior General management.

The best-known property in the district is the Culver group, comprising the Culver, Bobtail, and Humming Bird claims, and now known as the Warrior General mine. This mine in its geologic relations and vein conditions is typical of the mines of the district. The country rock is the altered peridotite or serpentine, probably of Mesozoic age, which exhibits the usual variations in color and structure. The Warrior General and the other mines are located in a zone of sheared serpentine, where the mineral-bearing solutions have found conditions favorable for ore deposition. This mineral zone has a general east-west course, and extends from east of Blewett across the Peshastin, up Culver Gulch, and across to the valley of Negro Creek.

The Warrior General vein has a trend of N. 70°–80° E., and is very irregular in its width. In the walls the serpentine is often talc-like in appearance, while the compact white quartz of the vein is sometimes banded with green talcose material. Sulphides are present in the ore, but are not all prominent. The values are mostly in free gold, which is fine, although in some of the richer quartz the flakes may be detected with the unaided eye.

The workings in this mine consist of a number of tunnels driven at different levels into the north wall of Culver Gulch. These follow the vein for different distances, the vertical distance between the lowest tunnel, No. 9, and the highest opening of importance, No. 5, being about 650 feet, and connections have been made between most of the levels. The vein is approximately vertical, although it has minor irregularities. The quartz is 7 to 8 feet in width in some places, but shows pinches in others. In the upper tunnel, No. 5, the ore appears to be broken, quartz of the same character as that in the lower tunnels occurring here much more irregularly, although the richest ore has been taken from the upper workings. Some very rich ore bodies have been mined, but they are small and their connections have not been traced. The most extensive work has been done from the lowest tunnel, and the latest work here shows that the serpentine, which is so much broken in many parts of this mineralized belt, is here more solid, a remarkably well-defined and regular wall having been followed for over 300 feet.

Other properties in the same zone as the Warrior General are the Polepick, Peshastin, Fraction, Tiptop, Olden, and Lucky Queen. These have all produced ore which has been worked in the Blewett mill.

Swauk district.—The gold-quartz veins of the Swauk are quite different from those in the vicinity of Blewett. They are in part narrow fissure veins of quartz with some calcite and talcose material, the wall rock being the sandstone or shale of the Swauk formation, of Eocene age, or in some cases a diabase or basalt dike may form one wall. Quartz stringers running off from the vein are common, and at one locality thin bands of quartz follow the bedding planes of the sandstone. A peculiar type of vein material is locally termed "bird's-eye" quartz. This occurs in several mines, and may be described as a friction breccia in which the angular fragments of black shale are inclosed in a matrix of quartz and calcite. The quartz shows radial crystallization outward from the separated fragments, and often open spaces remain into which the small crystals of quartz project. The walls of such veins are sometimes sharply defined, but in other cases many small veins of quartz traverse the shattered wall rock in every direction, so as to render it difficult to draw the limits of the vein itself. This transition from the peculiar type of vein into the shattered rock shows the "bird's-eye" quartz to be due to brecciation along more or less well-defined zones, followed by mineralization.

The "bird's-eye" quartz has its gold content very irregularly distributed. The values are mostly in free gold, with a small amount of sulphurets present. The gold occurs in fine grains within the quartz or next to the included shale fragments, and the approximate value of the ore may be readily found by panning, while in many cases the gold may be seen on the surface of the quartz, in the form of incrustations of leaf or wire gold. In a specimen from the Gold Leaf mine perfect octahedral crystals of gold lie upon the ends of the quartz crystals. The silicification sometimes extends into the country rock, and some values are found there. The gold of the quartz veins, like that of the gravels, is light colored and contains a considerable percentage of silver. In the Little York this silver is reported as amounting to about 20 per cent.

The quartz veins that have been opened up in the upper basin of Williams Creek have a general northeast trend, being thus roughly parallel with the basalt dikes. In the Cougar the hanging wall of the vein appears to be a badly decomposed basalt dike, while in the Gold Leaf one vein is wholly in sandstone and shale and another in a large diabase dike. The relation of the veins to the dikes is therefore not constant, but it may be noted that the fractures which have been filled by the vein material are usually approximately parallel to the fractures in the vicinity which have been filled by the intrusion of basalt. That there has been more than one period of fracturing, and that the period of mineralization was not exactly contemporaneous with the time of igneous intrusion, is shown by the occurrence of veins cutting the dikes themselves. It is quite probable, however, that the two processes occurred within the same geologic period and that the ore-bearing solutions derived their heat, and possibly their mineral content, from the intrusive and eruptive basalt of the area.

A number of quartz veins on Swauk, Williams, Boulder, and Baker creeks are being prospected at the present time, and in view of the richness of the alluvial gold which has been derived from the veins in this vicinity it would seem that the prospecting is well warranted.

ORE DEPOSITS OF TONOPAH AND NEIGHBORING DISTRICTS, NEVADA.[a]

By J. E. Spurr.

LOCATION AND DISCOVERY OF THE DISTRICT.

Tonopah is situated in central Nevada, in a range of low, scattered volcanic mountains which form the southern continuation of the San Antonio Range, and which themselves, on the south, pass into the Ralston Desert. It lies about 60 miles east of Sodaville, on the Carson and Colorado Railway, whence it can be reached by stage, and also about the same distance from Candelaria, on the same railroad, from which point another stage line runs. It can be reached by a long carriage drive from Belmont, the county seat of Nye County, and roads radiate from it to the other important points in the State.

This region has been known for a long time and has not been more inaccessible to prospectors than other similarly situated districts in the desert region. A few years ago ore was discovered in the Tonapah range of hills, some miles south of the present camp. This locality was called the Southern Klondike and attracted a considerable number of prospectors. Among others, Mr. James Butler, a resident of Belmont, on his way from that place to the Southern Klondike camp, passed over the site of the present Tonapah district. Perceiving a great deal of white quartz scattered upon the ground, he picked up some pieces and took them to an assayer in the Southern Klondike; but as they did not look particularly promising they were thrown aside and not tested. On his return trip, however, Mr. Butler picked up some more samples and carried them to Belmont, where he turned them over to Mr. Oddie, a young lawyer and miner, offering him a share of the claims if he would pay for the assay. Mr. Oddie sent the samples to an assayer and promised him half of his share if he would assay them. When the assays came back, as they did after some delay, they were found to be astonishingly rich, and Mr. Butler and his wife started out from Belmont and located their claims in due form.

It is known from certain monuments composed of piled-up quartz fragments that Mr. Butler was not the original discoverer, but who this was remains a mystery. The monuments are evidently old.

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[a] A more detailed report on this area is in preparation.

Present developments.—The development of the new camp has been astonishingly quick. The property was offered to and refused by Western capitalists for a very small sum when the exploration pits were only down a few feet, the reason for refusal being that the rich ores were probably only superficial Later on, when the developments had progressed a little further, the property was acquired at a larger figure by a Philadelphia company. They adopted the principle of leasing to develop their mine. The leasers set to work vigorously and in a short time a number of them had extracted sufficient rich ore to make fortunes of various sizes. Being satisfied with the prospects of the mine, the company gave out no more leases, but took the management into their own hands as soon as possible. From that time to the present the chief mine, the Mizpah, has been conducted with a view to developing the resources as a basis for future operations rather than to extracting ore. A number of fine shafts have been sunk, and the country has been and is being thoroughly investigated, both by drifts along the principal vein and by crosscuts.

Outside of Mr. Butler's original locations, which became the property of the Mizpah Company, and those immediately adjoining, numerous other locations were soon made, until now it is doubtful if there is a bit of unclaimed ground within several miles. Soon a number of other shafts were sunk, although with few or no surface indications. The Fraction shaft, not far from the Mizpah, passed downward through a body of cap rock of volcanic nature and found mineral veins containing large values in some places. Later on, the Mizpah Extension, on the other side of the Mizpah, encountered veins of the same system after passing through several hundred feet of cap rock. This has encouraged other companies to sink shafts through the capping, and many of them are down several hundred feet. Among these may be mentioned the Ohio Tonopah, the California Tonopah, the Montana Tonopah, the New York Tonopah, the Tonopah City, and the MacNamara. Work is being pushed vigorously, and before long much of the underground composition of the district will be shown up.

TOPOGRAPHY.

The topography around Tonopah is not one of great relief. A series of low and small, detached, and irregular mountains surrounds the town. The mountains are of volcanic origin, but have been worn down by erosion so that they have rugged and characteristic erosion features. The town itself lies in a shallow valley or wash, and from here a long, gentle wash-slope comes down to a nearly level desert valley both on the east and on the west.

GENERAL GEOLOGY.

A few miles north of Tonopah ancient limestones, probably Cambrian or Silurian, outcrop, and similar limestones are found some miles to the south, in the southern Klondike district. In the immediate vicinity of Tonopah, however, only volcanic rocks are found. These consist of flows, breccias, and derived tuff and ash accumulations. These volcanics are probably of Tertiary age, and represent a number of successive flows, with intervening showers of ash and breccia, and erosion intervals. On account of the confusion of these volcanics the relative order of eruption has not yet been certainly made out, but at the present time the sequence is considered to be somewhat as follows:

1. Earlier andesite (latite?).
2. Earlier rhyolite and breccias.
3. Later andesite.
4. Erosion interval.
5. Volcanic breccias and flows.
6. Great water-laid tuff formation containing infusorial silica.
7. Later rhyolite.
8. Latest lava flow (dacite?).

The oldest volcanic rock is the earlier andesite, which is commonly called the lode porphyry. Although originally an andesite, it is now, so far as examined, everywhere almost entirely decomposed and transformed into secondary products, consisting of fibrous muscovite, secondary quartz, pyrite, chlorite, iron carbonate, etc. In its present decomposed form, therefore, it is not an andesite, although originally one. Some forms of the altered rock are what has been described by early writers in this region as propylite; but Dr. G. F. Becker showed that the propylite of the Comstock region was an altered andesite, just as it is at Tonopah. The Tonopah rock and the Comstock rock are, as a matter of fact, apparently similar in composition, and probably are also in point of age.

The important veins of the district occur only in this earlier andesite or lode porphyry, and not, so far as yet found, in the later rocks. So it seems that the mineralization must have followed the first andesitic eruption. Therefore it is that the overlying volcanics do not show these veins, and constitute cap rocks which overlie them, and which must be pierced in order to reach the lode porphyry and its associated ores.

The ores are in the form of quartz veins of the kind which have been described by some writers as the noble quartz formation—that is to say, the quartz constitutes almost the whole of the ore, and the valuable metals are very finely distributed, so as to appear barely or not at all to the naked eye. There is also a very small quantity of the less valuable metallic minerals. Silver is found in the form of chloride, sulphide (argentite), and ruby silver. Gold has been seen in a free state in the ore.

The deposits are well-defined veins, maintaining a nearly regular strike and dip. The principal veins average a few feet in width. The chief trend of the veins is east and west, but in the developed region the different veins diverge regularly from one another, so that they lie like the spokes of a wheel. Where they come together near the center from which they radiate, they join and fork in the manner of linked veins. There is evidence to show that these veins, although having the characteristics of true fissure veins, have formed along zones of fracturing or sheeting in the lode porphyry, and have replaced the porphyry in these zones to a more or less perfect extent. Therefore, in passing along the veins, at some places they are found to consist of pure quartz, in other places chiefly of highly silicified porphyry.

Probably contemporaneous with the mineralization has been the extreme alteration of the original hornblende-andesite. This alteration, together with the subsequent weathering, has produced a great variety of appearance in the originally nearly uniform rock. Pyrite and iron carbonate have been derived from the decomposition of the dark minerals (mica, hornblende, and pyroxene) of the original andesite. The decomposition of the feldspars and other minerals has furnished an abundance of secondary quartz. In some of the most decomposed and altered phases, therefore, the appearance is that of a highly siliceous, nearly fresh rock, apparently a rhyolite. This is one of the common phases in the vicinity of the Mizpah. Other phases are soft and light colored; others comparatively firm and dark colored, with abundant pyrite.

The mass of Oddie Mountain is made up of a true rhyolite, later in point of age than the lode porphyry and containing, so far as yet known, no veins belonging to this period. It is also somewhat decomposed, but not nearly to so great an extent as the lode porphyry.

The later andesite occurs on Mizpah Hill in the same localities as the earlier andesite, and between certain phases of the two rocks it is often difficult to distinguish. Originally they both had nearly the same composition, and they have often been altered in nearly the same way. The large feldspar crystals of the later andesite, however, are generally of greater size and more thickly set together than in the earlier andesite or lode porphyry. The mica or biotite crystals of the later andesite are also frequently intact and can be recognized in the hand specimen, while the micas of the older andesite have generally completely disappeared. The later andesite is also apt to be more highly colored in its present state than the earlier rock. It has often assumed various shades of purple and green, which led the writer to give it the field name of "purple porphyry." This later andesite is found in dike form, cutting the earlier eruptives, and also occurs in the form of extensive flows. It was possibly accompanied by breccias.

About this time, and perhaps succeeding the later andesite, came the formation of the great series of stratified white volcanic tuffs which is exposed around Tonapah. At one point a thickness of several hundred feet is shown. The perfect stratification indicates that this formation was laid down in a lake which must have been of considerable depth. Part of the formation is made up entirely of myriads of the microscopic siliceous shells of infusoria. Since the lake epoch, however, erosion has been considerable, leaving the tuff forming some of the low mountains in the vicinity.

There was apparently a later flow of rhyolite, in general composition like the earlier flow, but distinct in point of age and now consequently fresher in appearance. Some mineralization followed this flow, producing veins and coatings of chalcedony, iron carbonate, iron oxide, etc., along the contact and in crevices in the adjoining rocks. These veins also carry small amounts of gold and silver, but have no connection with the earlier, more important mineralization.

Latest of all was the eruption of lava which forms most of the mountains around Tonopah. The nature of this lava is dacitic.[a]

The writer spent two months in the autumn of 1902 making a preliminary investigation of the Tonapah mining district. Mr. W. J. Peters, of the topographic branch of the Survey, has just finished making a careful map of that portion of the district which is of greatest economic importance. This map is on a scale of 800 feet to the inch. The writer will continue and finish his investigation in the spring of 1903; will map the different geologic formations, and will prepare a report showing the relation of the ore deposits to the different rocks.

There are several perplexing problems which are to be worked out in the district. One of the most important is the location, as nearly as possible, of the underground course of the upper contact of the earlier andesite or lode porphyry, so that mining men may know approximately where to sink their shafts with the chances of reaching the porphyry soonest. Another difficult problem will be to ascertain, if possible, the probable course and extension of the vein systems of the district. A third problem, perhaps the most important of all, is the study of the distribution of the rich ores within these veins. These questions will be dealt with in the forthcoming report.

ORE DEPOSITS IN VICINITY OF TONOPAH.

The writer made a number of brief examinations of certain ore deposits in the vicinity of Tonopah.

Silver Peak district.—A slight examination was made of the principal mine in the Silver Peak district. This mine is on quartz veins of great thickness and surface extent, which hold relatively small quantities of gold. The veins have been worked near the surface for many years past, although lately activity has not been very great. It is claimed that three-quarters of a million dollars' worth of ore has already been extracted. There are two parallel veins lying close to

[a] Dacite is quartz-bearing andesite.

one another, both of unusual size. The work which has been done lately is purely in the nature of development, and consists in running a tunnel to tap the vein at a lower level than has been reached in the workings from the surface. This tunnel has reached and explored the vein for some distance, and it is claimed that careful assays show that the values are as good there as nearer the surface. Taken in connection with the vast quantity of ore, these values are sufficient to make the mine a great low-grade proposition, provided that power, water, etc., can be procured with sufficient cheapness to leave a margin of profit. There is, of course, a scarcity of water in the Silver Peak region, but hot springs occur in the valley below Silver Peak, and electrical transmission of power from the streams of the neighboring White Mountain Range or from the Sierras is one of the possibilities.

The veins lie in close connection with a mass of granite which is apparently intrusive into the ancient limestones, and it is believed that the vein has a close genetic relation to this granite. This point will be investigated more thoroughly the coming summer, and is an important one, inasmuch as it bears strongly upon the question of the persistence of the vein and its values in depth.

Southern Klondike district.—This district has already been referred to as lying 9 or 10 miles south of Tonopah. Its geology in general and its ore deposits are of an entirely distinct class from those at the first-mentioned camp. Topographically the country is much the same as at Tonopah, there being a number of low irregular mountains which do not rise greatly above the level of the desert valleys on each side. The district is surrounded by volcanic rocks, chiefly rhyolites, and these rhyolites occupy a portion of the district itself. The rest of the district is occupied chiefly by Paleozoic limestones, probably Cambrian or Silurian.

There are two divisions of the Klondike camp—Klondike proper and East Klondike. In the former, which is the older camp, there is a long dike-like intrusion, in the limestone, of a siliceous granitic rock, of which some specimens examined seem to consist chiefly of quartz and muscovite, and are evidently closely related to similar rock described some years ago from Belmont, Nev., by the writer, and shown to be the same as the beresite of the Ural Mountains in Russia. The Belmont district lies nearly due north of Tonopah and Klondike. Close to the contact of this granitic mass with the limestone, and following the contact closely for a mile or more, is a quartz vein which at the surface carried scattered high values of silver and gold. The values were chiefly in silver chloride. Some parts of the vein contain galena, which is segregated in bunches. At the very contact of the granite or beresite with the limestone there is in places a deposit of hard, nearly black hematite, which is seen to have been derived from the oxidation of original pyrite, which accompanied the contact in the granite, and probably also in the limestone. Deeper exploration of these deposits has shown them to be almost entirely barren. In the main vein the quartz has continued in full strength downward, but the values have become insignificant. Similarly, a tunnel driven to the contact of granite and limestone, beneath the iron-ore deposits of the surface, shows nothing. These facts indicate that we have here an excellent example of the concentration of values near the surface, in the extreme upper part of the zone of oxidation, by the same surface waters that have operated to wear away the district and produce its topographic relief.

At East Klondike the same limestone is cut into and surrounded by rhyolite, which has produced almost exactly the same contact phenomena as the granite at the Southern Klondike. Indeed, the two rocks are probably closely connected in point of composition and origin. At East Klondike the contact of the rhyolite is marked by a broad belt of jasperoid, and similar belts are found farther away in the limestone, along lines of original easy circulation for waters. The chief vein near this contact consists largely of white quartz, but is evidently due to the same solutions which produced the dark-blue jasperoid. The vein and the metallic contents are exactly like the vein at Klondike. In some places high values have been taken out of the vein, but exploration has not been pushed far enough to show the character of the vein in depth. Along certain fracture systems, which are later than the vein and have broken and displaced it to some extent, there seems to be a segregation of higher values, accomplished probably by more recent circulating surface waters.

Gold Mountain district.—This lies nearly halfway between Tonopah and Klondike and is in the stage of development. Gold Mountain is composed of rhyolite, both in solid flows and in consolidated tuffs and breccias. Through these rhyolites run strong and persistent veins of quartz and delicately colored chalcedony veins, sometimes containing pyrite. In some parts of some of these veins, especially in the oxidized portions, rich assays have been obtained. The mineralization is probably of a later date than that which has produced the ores at Tonopah, but may be of the same age as those at Klondike, although the ore deposits themselves are of a different character.

Hennepah district.—The Hennepah district was at the time of the writer's visit very young and so little developed that not much could be seen. It lies nearly east of Tonopah, on the other side of a broad desert valley. The rocks of the district are volcanic, bearing a general resemblance to those at Tonopah. The veins also, of which two or three were observed, are of the same general character as the Tonopah veins, although so far they have not been shown to have anything like the strength of the better class of veins in the older camp.

GOLD MINES OF THE MARYSVILLE DISTRICT, MONTANA.

By Walter Harvey Weed.

The Marysville mining district is the most important producer of the precious metals in the State of Montana, one mine alone having yielded a total of nearly $15,000,000, while the aggregate production of the mines of the district has been roughly estimated at double that figure. The district is located 18 miles northwest of Helena, and is reached by a branch railroad running north from the main line of the Northern Pacific Railway. The Great Northern Railway runs a few miles east of the district. The district comprises a mountainous country traversed by the continental divide, a few of the mines being on the western or Pacific slope. The development of the region began in the early seventies, the rich placer diggings of Silver Creek leading to the discovery of the ledges which have made the region famous. Although within its area there have been many productive mines, as a rule the values have been in rich ore shoots, and after these were exhausted the property has been abandoned. The most famous property of the district is undoubtedly the Drumlummon mine, which has yielded a larger amount of gold than any other mine in the State. A later discovery, the Bald Butte mine, has been steadily worked for many years, one year's dividends approximating the total amount of capitalization. At the present time the Bald Butte is the only mine actively worked, and the district therefore may be said to be in decline.

Geologic features.—The Marysville district consists of a central mass of granitic rock surrounded by slaty shales and thin-bedded argillaceous sandstones. The granitic rock is probably part of the great granite area which underlies so much of the western portion of Montana. The rock is technically a quartz-diorite of even and coarse grain, showing little variation in appearance or mineralogic development. The shaly rocks into which this diorite has been intruded belong to the Belt terrane and consist of a thickness of many thousand feet of thin-bedded argillaceous rocks. Near the granite contact these rocks are altered to hard and dense hornstones, while farther away they show a slaty fracture, the laminæ corresponding, however, to the bedding planes. Outside of the district proper, to the south and west, the Cambrian and later sedimentary rocks appear. There are a few dikes of acidic porphyry and of dark trap rocks which cut the granite near its borders and penetrate the sedimentary rocks. These are especially abundant near Bald Butte.

The veins.—The geologic map which was prepared in the summer of 1901 shows that the veins occur either in close proximity to the granite contact or adjacent to the intrusive dikes. The vein systems developed near the town of Marysville show three distinct directions. The northeast system, exemplified in the North Star vein, cuts through the sedimentary rocks and into the granite. The northwest system is prominent in the granite area, but has not produced any large ore bodies. The north-south system is the one to which the Drumlummon lode belongs, and at the Drumlummon mine is parallel to the granite contact. The ores occur in fissure veins, showing a distinct quartz filling, either as a solid mass or enveloping angular fragments of the country rock. The Drumlummon vein is the best known and may be taken as a type. It is a fault plane with white opaque quartz inclosing angular fragments of black, green, and drab slates, which are sometimes distinct and unaltered and at others have been much decomposed. Where the ore bodies are found the replacement has been complete and the former presence of the fragments is only recognizable by the outlines of the banded quartz. The vein has distinct walls, which are rather wavy and vary from 2 to 20 feet apart. Southward the Drumlummon vein itself splits into several branches. It has been developed for a distance of about 3,000 feet horizontally and to a depth of 1,600 feet, but no ore was found below the 1,000-foot level. This vein, which is the largest and the most productive in the district, consists in its lower levels of a mass of angular rubbish, derived from the walls of the fissure, and in places cemented by quartz, in other places still retaining its original character. Compared with the Empire and other veins, it is much more extensive, both laterally and vertically, and the values have gone deeper. In general it may be said that all the veins of the district carry rich ores in bonanzas and ore shoots within the first 200 feet from the surface, but that in depth the ores rapidly decrease in value until the vein is no longer workable. It may also be said that the ore shoots were well defined, and the intervening vein matter barren and unworkable. The pitch of the ore shoots conforms to the usual habit, dipping to the right when looking down the dip of the vein. The ores consist of sulphides and sulphantimonides of silver, with gold aggregating 60 per cent of the total value. In the upper levels the ore is somewhat oxidized, and in the ore shoots of the Drumlummon mine carried extremely high values. In the Bald Butte mine the larger veins are clear instances of filled fissures with but little evidence of replacement, and the new vein recently opened contains a streak a few inches wide of soft ore whose value is extremely high. Recent attempts have been made to open up some of the large properties which have been idle for many years. The Empire mine, particularly, has been opened and new development work begun. There seems reason to believe that with the low rates of treatment now available many of these properties may be reopened and worked.

GEOLOGICAL SURVEY PUBLICATIONS ON GOLD AND SILVER.

The following list includes the more important publications by the United States Geological Survey on precious metals and mining districts. Certain mining camps, while principally copper producers, also produce smaller amounts of gold and silver. Publications on such districts will be found in the bibliography for copper, on page 186. For a list of the geologic folios in which gold and silver deposits are mapped and described, reference should be made to the table on pages 11 to 13 of the present bulletin:

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——— Gold fields of the southern Appalachians. In Sixteenth Ann. Rept., Pt. III, pp. 251–331. 1895.

——— Witwatersrand banket, with notes on other gold-bearing pudding stones. In Eighteenth Ann. Rept., Pt. V, pp. 153–184. 1897.

——— Reconnaissance of the gold fields of southern Alaska, with some notes on the general geology. In Eighteenth Ann. Rept., Pt. III, pp. 1–86, maps. 1897.

——— Brief memorandum on the geology of the Philippine Islands. In Twentieth Ann. Rept., Pt. II, pp. 3–7. 1900.

BROOKS, A. H. Reconnaissance in the Tanana and White river basins, Alaska, in 1898. In Twentieth Ann. Rept., Pt. VII, pp. 429–494. 1900.

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——— Preliminary report on the Ketchikan mining district, Alaska. Professional Paper No. 1. 120 pp. 1902.

BROOKS, A. H., RICHARDSON, G. B., and COLLIER, A. J. Reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, Alaska, in 1900. In reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900; a royal octavo pamphlet published in 1901 by order of Congress, pp. 1–184.

COLLIER, A. J. A reconnaissance of the northwestern portion of Seward Peninsula, Alaska. Professional Paper No. 2. 68 pp. 1902.

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ELDRIDGE, G. H. Reconnaissance in the Sushitna Basin and adjacent territory in Alaska in 1898. In Twentieth Ann. Rept., Pt. VII, pp. 1–29. 1900.

EMMONS, S. F. Geology and mining industry of Leadville, Colorado; with atlas. Monograph XII. 870 pp. 1886.

——— Progress of the precious metal industry in the United States since 1880. In Mineral Resources U. S. for 1891, pp. 46–94. 1892.

——— Economic geology of the Mercur mining district, Utah. In Sixteenth Ann. Rept., Pt. II, pp. 349–369. 1895.

——— The mines of Custer County, Colorado. In Seventeenth Ann. Rept., Pt. II, pp. 411–472. 1896.

HAGUE, ARNOLD. Geology of the Eureka district, Nevada. Monograph XX. 419 pp. 1892.

HAHN, O. H. The smelting of argentiferous lead ores in the far West. In Mineral Resources U. S. for 1882, pp. 324-345. 1883.

LINDGREN, WALDEMAR. The gold-silver mines of Ophir, California. In Fourteenth Ann. Rept., Pt. II, pp. 243-284. 1894.

——— The gold-quartz veins of Nevada City and Grass Valley districts, California. In Seventeenth Ann. Rept., Pt. II, pp. 1-262. 1896.

——— The mining districts of the Idaho Basin and the Boise Ridge, Idaho. In Eighteenth Ann. Rept., Pt. III, pp. 625-736. 1898.

——— The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho. In Twentieth Ann. Rept., Pt. III, pp. 75-256. 1900.

——— The gold belt of the Blue Mountains of Oregon. In Twenty-second Ann. Rept., Pt. II, pp. 551-776. 1902.

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——— Reconnaissance from Resurrection Bay to the Tanana River in 1898. In Twentieth Ann. Rept., Pt. VII, pp. 264-340. 1900.

NITZE, H. B. C. History of gold mining and metallurgy in the Southern States. In Twentieth Ann. Rept., Pt. VI, pp. 111-123. 1899.

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——— The ore deposits of the Rico Mountains, Colorado. In Twenty-second Ann. Rept., Pt. II, pp, 229-398. 1902.

SCHRADER, F. C. Preliminary report of a reconnaissance along Chandler and Koyukuk rivers, Alaska, in 1899. In Twenty-first Ann. Rept., Pt. II, pp. 447-485. 1900.

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QUICKSILVER, PLATINUM, TIN, TUNGSTEN, CHROMIUM, AND NICKEL.

Of the metals here grouped only two—quicksilver and chromium—are at present worked on a large scale in the United States. The papers on tin and tungsten presented below are reprints, in slightly condensed form, of reports which have recently appeared in Survey publications. A description of the Rambler copper mine, in Wyoming, is included, as platinum has recently been discovered in the ores of this mine.

STREAM TIN IN ALASKA.

By Alfred H. Brooks.

While studying the gold placers at York, on the Seward Peninsula, Alaska, the writer's attention was called to the occurrence of stream tin (cassiterite) in the placers. The stream tin was found at two localities in the region. The first is on Buhner Creek, a westerly tributary of the Anikovik River. The mouth of Buhner Creek is about 3 miles from Bering Sea. The occurrence is best located by stating that it lies about 10 miles east of Cape Prince of Wales, and very near the northwestern extremity of the continent. On Buhner Creek 2 to 3 feet of gravel overlies the bed rock, which consists of arenaceous schists, often graphitic, together with some graphitic slates. The bed rock is much jointed, the schists being broken up into pencil-shaped fragments. They strike nearly at right angles to the course of the stream and offer natural riffles for the concentration of heavier material. A hasty reconnaissance of the drainage basin of this stream, which includes not more than a square mile of area, showed the same series of rocks throughout its extent. At a few localities some deeply weathered, dark-green intrusives were found, probably of a diabasic character. The slates and schists are everywhere penetrated by small veins, consisting usually of quartz with some calcite, and frequently carrying pyrite and sometimes gold. These veins are very irregular, often widening out to form blebs, and again contracting so as not to be easily traceable.

The stream tin is concentrated on the bed rock with other heavy minerals, and was found by the miners in the sluice boxes. A sample of the concentrate in one of the sluice boxes was examined by Mr. Arthur J. Collier, and yielded the following minerals: Cassiterite, magnetite, ilmenite, limonite, pyrite, fluorite, garnets, and gold. The determination of percentage by weight was as follows: 90 per cent tin-stone; 5 per cent magnetite; other minerals, 5 per cent. The cassiterite occurs in grains and pebbles, from those microscopic in size to those half an inch in diameter; they have subrounded and rounded forms. In some cases there is a suggestion of pyramidal and prismatic crystal forms. The cassiterite varies in color from a light brown to a lustrous black.

A second locality of this mineral was found on the Anikovik River about half a mile below the mouth of Buhner Creek. Here the cassiterite was also found with the concentrates from the mining operations. One pebble of stream tin obtained from this locality was about 2 inches in diameter.

It will be necessary to make a more detailed examination of this region to determine where this mineral occurs in the bed rock. The facts obtained by the writer point toward the conclusion that its source was in the quartz and calcite veins in which the gold was found. No cassiterite was, however, found in this vein material.

No evidence was found that this cassiterite is in any way connected with granitic intrusions, which is its usual association in other regions. As far as known there are no intrusives of such rocks within the drainage basins of streams where the tin was found. The nearest known granitic rock is the biotite-granite stock which forms the promontory of Cape Prince of Wales and which is at least 10 miles distant.

This discovery of stream tin has, at present, scientific rather than commercial interest. No developments have been made which would warrant the conclusion that valuable tin deposits exist in the York district. It is worth while, however, for the prospectors who visit this region to familiarize themselves with the physical properties of the mineral, so as to be able to recognize it if found. By this means deposits carrying values may be discovered, and the cassiterite will probably be traced to its source in the bed rock.

PLATINUM IN COPPER ORES IN WYOMING.

By S. F. Emmons.

INTRODUCTION.

The occurrence of platinum in the form of sperrylite (arsenide of platinum), associated with copper ores in the Sudbury district of Canada, has been known since 1889.[a] It has since been discovered by Hidden[b] in North Carolina. In the past winter the occurrence of platinum in the ore of the New Rambler mine of Wyoming was announced by Prof. Wilbur C. Knight,[c] and upon examination of the ore by H. L. Wells and S. L. Penfield,[d] of Yale University, it was found to occur in well-defined crystals in association with covellite and pyrite.

The known occurrences of platinum in definite mineral combination are so rare as to render this new locality of considerable importance; hence a brief visit to the mine was made by the writer during the past summer, after spending some time in camp with Mr. A. C. Spencer, who was engaged in a geological survey of the Encampment group of mountains, a northern extension of the Park Range of Colorado, lying on the west side of the North Platte River. The following is a brief but necessarily incomplete statement of the geological relations of the deposits as far as they were ascertained:

The mine is situated a little east of south of Medicine Peak, the highest point of the Medicine Bow Mountains on Beaver Creek, a little stream tributary to the headwaters of Douglas Creek. It is connected with Laramie City on the Union Pacific Railroad by mail and stage line, the distance being about 32 miles in a straight line, though by the windings of the road it is about half as much again. A slightly shorter but more precipitous road runs westward across the North Platte Valley to the town of Encampment, where there is a smelter in which 2,000 to 3,000 tons of ore from the Rambler mine were smelted during the winter of 1901–2. The little settlement which has sprung up about the mine is designated by the postal authorities "Holmes," from the name of the manager and principal owner of the

[a] Am. Jour. Sci., 3d series, Vol. XXXVII, 1889, pp. 67–71.
[b] Idem, 4th series, Vol. I, 1898, pp. 381, 467.
[c] Eng. and Min. Jour., Dec. 31, 1901, p. 845.
[d] Am. Jour. Sci., Feb., 1902, 4th series, Vol. XIII, p. 95.

mine. A railroad is now building from Laramie City westward, which it is expected will eventually connect with Holmes.

The mine is at present opened by a vertical shaft 200 feet deep, but at the time of visit, owing to certain changes which were taking place in machinery and ownership, the lower 100 feet were not accessible; hence a study of the unaltered ore must be postponed to a later date. A small matting furnace has been erected near the shaft for treating second-class ore. The ore shipped away from the mine is said to aggregate nearly 4,000 tons and to have assayed 25 to 30 per cent copper. According to Professor Knight, it all contained more or less platinum.

TOPOGRAPHY.

The Medicine Bow Range is topographically a northwestern continuation of the Front Range of Colorado, which, as it enters Wyoming, spreads out into two forks that inclose the broad valley known as the Laramie Plains. The eastern boundary of these plains is formed by the Black Hills of Wyoming, sometimes known as the "Laramie" Hills—a north-south uplift of older rocks, mainly granite, which ends at the north bend of the North Platte River, where these rocks disappear under Mesozoic sediments.

The Medicine Bow Range on the west likewise dips down under the Mesozoic sediments and is lost as a range, its almost isolated northern point being known as "Elk" Mountain. As seen from the Laramie Plains a striking feature is the plateau-like structure of the main mass of the uplift. On its eastern flanks it rises abruptly from the plains about 2,000 feet; then slopes back almost at a level with an average elevation of 9,000 to 10,000 feet to the central uplift around Medicine Peak, which is again about 2,000 feet above the plateau.

This plateau-like portion of the range is, for the most part, covered with a comparatively abundant forest growth, and its streams run in shallow swale-like valleys which change rapidly to deep rocky gorges in their lower courses as they leave the plateau. At Holmes, which is on the higher part of the plateau, the forest covering is unusually dense and the rock surface is covered by 6 to 16 feet of wash, so that rock outcrops are rare and prospecting has to be done by trenching and shaft sinking, and the geological relations are correspondingly difficult to decipher.

GEOLOGY.

In its geological composition and structure the Medicine Bow Range appears to resemble more closely the Encampment Mountains on the opposite side of the Platte Valley than the Colorado ranges, and there is some reason for assuming that the two once formed part of one and the same mountain uplift, and that their separation by the cutting of the Platte Valley has been of comparatively recent geological date.

The principal distinction from the other ranges that have a core that has generally been assumed to be Archean is the prevalence of distinctly sedimentary beds, largely quartzites of pre-Cambrian age, which form the crest of the ridges in either group of hills. Around the lower flanks of the ranges, on the other hand, and, so far as can be seen, in the intermediate Platte Valley, the basement rocks are granite and gneisses like those called Archean in Colorado, and the sedimentary rocks are seldom, if ever, seen.

The sedimentary series in the Encampment Range are quartzites, with some limestones and conglomerates, penetrated by sheets and dikes of eruptive rock, mainly diorite, and closely compressed into folds with an east-west strike, the whole highly metamorphosed. That the same series of rocks occurs in the Medicine Bow Range is evident from observation, though the structure could not be made out with any definiteness in so short a visit, owing to the covering of forest and wash on the plateau. According to the Fortieth Parallel reports, Medicine Peak is a mass of white quartzite with a general synclinal structure. The same rock is said to occur on Douglas Creek a few miles below the Rambler mine, and quartzites were observed in considerable masses on the ridge between French and Mullan creeks a few miles west of that mine. At the Rambler mine itself and for a considerable distance on either side, as shown by the dumps of the different prospects, the rock is diorite. That at the Rambler mine is coarsely granular, with thoroughly granitic structure and some development of pegmatitic phases, and is thought to be part of a considerable stock breaking through quartzites and underlying gneisses.

Microscopical study of two specimens from the bottom of the shaft, by Mr. Waldemar Lindgren, shows the latter rock to be a hornblende-biotite-diorite of normal type, its feldspars being labradorite, with quartz occurring sparingly in grains between the feldspars, and magnetite in small contact grains, mostly embedded in hornblende or biotite. As secondary minerals are found sericite and epidote in the feldspars, and a little chlorite in places in hornblende and biotite. Some red hematite occurs in seams, and pyrite in grains and cubical crystals, generally in the hornblende, and always associated with a little chlorite.

RAMBLER MINE.

The mine was originally opened by an incline, but after the discovery of the large bodies of ore a vertical two-compartment shaft was sunk, through which access is now had to the workings. At time of visit the mine below the 100-foot level was inaccessible. Above this level and for some little distance below, both ore and country rock are much altered, and so much transmigration of the former has taken place that it was quite impossible to determine the original form and nature of the deposit.

Thus far three large bodies, about 40 to 50 feet in diameter and 12 to 30 feet high, have been opened. The upper one immediately below the wash was a gossan of iron oxide carrying about 9 ounces of silver per ton, with a trace of gold, from which the copper had been pretty completely leached out. Below this came silicates and carbonates of copper. The zone of enriched sulphide below the oxidized body, which alone was accessible, is apparently larger and certainly richer, and extends 30 feet or more above the level. It shows two large ore bodies of no definite outline inclosed in highly decomposed diorite. The latter, in its extreme form called "talc" by the miners, is a white kaolinized mass of the consistency of soft clay, but often retaining something of the original granular structure of the rock. Near the ore bodies covellite grains are so uniformly distributed through it as to give the appearance at a little distance of basic silicates in a white feldspathic rock. The remarkable feature of the ore is the abundance of the rather uncommon indigo-blue copper sulphide, covellite (CuS). The upper part of the body is slightly stained with iron oxide, while in the lower part some pyrite is visible, but not in relatively large proportion. Cuprite occurs here and there in brilliant vermilion red crystals, and is sometimes reduced to native copper. The covellite is rather irregularly distributed through the kaolin-like mass, but sometimes occurs in massive lenses up to 2 feet thick. In so plastic a mass no definite structure could be observed in the mine, but some of the pyritous ore on the dump showed a certain vein-like structure. A specimen of this, which was examined microscopically by Mr. Lindgren, shows that the covellite replaces the pyrite directly, without the formation of intermediate minerals; that the ore has a cellular structure, apparently resulting from reduction in volume during its conversion, and that the roughly rounded cavities are often lined with soft white silica in mammillary crusts, the manner of occurrence indicating that it was formed by solution, either simultaneously with or immediately after the formation of the covellite. In two places secondary pyrite of later formation than some of the covellite was observed.

Sperrylite could not be distinguished in the thin section. From the description given by Wells and Penfield of that which they were able to separate, it probably occurred in ore similar in character to this, and from its fresh appearance it seems probable that the sperrylite was an original constituent of the sulphide ore. More definite knowledge as to its manner of occurrence will probably be obtained when the deposit has been opened at greater depths and beyond the reach of surface alteration.

TUNGSTEN MINING AT TRUMBULL, CONN.

By W. H. Hobbs.

A deposit of tungsten ore of considerable economic importance is found at Trumbull, Conn. The ore occurs along the planes of contact between crystalline limestone and two bodies of hornblende-schist, the latter being a metamorphosed igneous rock. The tungsten minerals (wolframite and scheelite) seem to be concentrated just below the contact of the limestone with the lower body of hornblende-schist, while in lateral distribution they are very variable. In 1898 exploitation of this deposit for the tungsten ores was commenced and was carried on until 1901, when operations were temporarily abandoned. The companies which managed the property carried out somewhat extensive mining operations, and expended considerable sums for buildings and machinery.

The method of mining has been to sink pits at the contact and follow down the tungsten-bearing zone. The larger blocks obtained by blasting are broken with sledges and the picked ore sent to the mill. The ore on reaching the mill is sent through a 15 by 24 inch Blake crusher, with a capacity of 10 tons per hour. This crusher discharges its product on the upper end of the picking table. An endless rubber belt acts as carrier and feeds to two small crushers on the floor below. These crushers deliver their product to two sets of Cornish rolls, running one-fourth inch apart and having a 22-inch diameter and 16-inch face. From the rolls the material is elevated to the top of the mill and delivered to a pair of revolving wire screens 36 inches in diameter and 8 feet in length. These screens are one-eighth-inch mesh, and therefore refuse most of the material. A considerable portion of the dust is here drawn out by a current of air which passes under the screens. The material refused by the screens is carried by gravity to a pair of high-speed rolls, of 30-inch diameter and 18-inch face, running one-eighth inch apart. From them it is returned to the elevator and again sent to the one-eighth-inch screens. All the material passing the one-eighth-inch screens at either the first or second trial is sent to Wolf gyrating screens of three sizes, the mesh being 40, 60, and 90, respectively.

Concentration is effected by a dry process, the Hooper pneumatic concentrator being used. This delivers a clean concentrate and leaves little ore in the tailings. Each machine is capable of treating 10 tons of material a day, and the yield of tungsten ore is said to be 5 per cent. The ore carries a little pyrite, which must be removed by roasting. No attempt is made at the mine to reduce the mineral to tungstic oxide.

TIN DEPOSITS AT EL PASO, TEX.

By W. H. Weed.

The El Paso tin deposits lie on the east flank of the Franklin Mountains, the southern extension of the Oregon or San Andreas Range, about 10 miles north of El Paso. The ores were discovered in 1899 and have been prospected by several open cuts and pits, the deepest of which is about 50 feet below the surface. The place is distant about 14 miles by wagon road from El Paso. The Rock Island Railroad crosses the flat 3 or 4 miles east of the property, and the main line of the Southern Pacific lies 10 miles to the south. There is a good spring one-fourth of a mile from the ledges, but there is no large supply of water nearer than the Rio Grande. The mesa is underlain by water, the city of El Paso being supplied from driven wells sunk in the mesa gravels.

GEOLOGICAL STRUCTURE AND FORMATION.

The geological structure is simple and easily made out. The mountain range consists of Cambrian and other Paleozoic limestones, upturned by and resting upon an intrusive mass of coarse-grained granite that forms the central core of the range. This granite is well exposed for a distance of 4 or 5 miles along the eastern side of the mountains, forming the lower half of the mountains proper, and in places extending out to the foothills. The crest of the range consists of steeply tilted, heavily bedded, dark-gray limestones dipping westward. The basal quartzites were observed in the drift seen in arroyos, so that the granite is probably intruded between the base of the Cambrian rocks and the underlying Archean complex.

The eastern foothills consist mainly of limestones, but near the tin deposits these bedded rocks have been cut through and granite now forms the surface, remnants of the limestone cover showing as isolated masses capping the hillocks. North of the tin mines a transverse ridge of the range shows the granite to be sheeted by well-marked planes, dipping eastward at an angle of about 45° to 50°. The granite is very much altered by surface decomposition, and crumbles readily to a coarse sand. The granite is sheeted near the veins, the planes of sheeting being parallel to the veins themselves. The general sheeting, however, is in a different direction, the average strike being N. 20° E., and the dip 70° SE. A thin section of this granite, examined under the microscope, shows the rock to be a coarse-grained normal soda granite, with much anhedral quartz and anhedral feldspar, largely microperthite, with some few grains of microcline. A few small flakes of brownish-green hornblende and some small grains of magnetite were also seen.

White aplite-granite occurs in veinlets and irregular masses intrusive in the granite, but none was observed close to the veins.

ORES AND VEINS.

The ores consist of cassiterite, or oxide of tin, with wolframite (tungstate of iron and manganese) in a gangue of quartz. Specimens of nearly pure cassiterite weighing several pounds have been found on the surface, and this mineral occurs in the quartz, either alone or associated with wolframite. The most abundant ore is a granular mixture of tin ore and quartz which resembles a coarse granite and corresponds to the greisen ore of European tin deposits. Pyrite occurs rarely in the eastern exposures of the vein, but appears to constitute the bulk of the metallic contents in exposures seen in the westernmost openings. These ores occur in well-defined veins, which run up the slopes nearly at right angles to the direction of the range, the strike being approximately east-west and the veins dipping steeply to the north. Three veins have been discovered, all of which have been exposed by open-cut work and by pits for several hundred feet in length. The most northerly vein is traceable along the surface for a distance of about 1,200 feet. The middle vein lies about 300 feet south of the east end of the northern one, but apparently converges westward toward the northern vein. The southern vein, which is the smallest of the three, lies about 600 feet farther south.

The veins exhibit the usual characters of the European tin veins, notably those of Cornwall, England, their clearly defined fissures showing a central core or lead of coarse quartz, sometimes containing tin ore, and flanked on either side by altered rock in which the tin ore replaces the feldspar of the granite. Where this metasomatic replacement is complete the ore shows a mixture of cassiterite, with or without wolframite and quartz. Where the replacement is only partial the greisen ore fades off into the unaltered granite. A cross section of the veins shows, therefore, the same phenomena seen in Cornwall. The central mass of quartz corresponds to the "leader" of the Cornish veins. It is composed of massive, coarsely crystalline quartz, sometimes showing comb structure, and it is clearly the result of the filling of the open fissure by quartz. The adjacent ore-bearing material is a replacement deposit in which the mineral solutions have substituted ore for the feldspar of the granite by metasomatic action; in other words, the main mass of the ore occurs alongside of a quartz vein, and is due to the alteration of the granite forming the walls of the fissure. In general, the ore passes into the granite by insensible transition and there are no distinct walls.

From a thin section of the ore, examined under the microscope, the rock is seen to be quartz cassiterite. It is a coarsely granular rock consisting of anhedral quartz, with grains of slightly brownish cassiterite intimately intergrown with quartz along the edges. The quartz is full of fluid inclusions and makes up about 75 per cent of the mass. One small grain of tourmaline and a few flakes of sericite were seen. Neither topaz nor mica occurs in the section, and no remains of feldspar were observed. If this is a metasomatic form of the granite a silicification has taken place. The microscope affords no direct evidence, however, that this ore is metasomatic.

The north vein has a course of N. 85½° W. magnetic, as determined from the openings at the east end. At the west end of the workings the course observed, looking back along the outcrop, appears to be N. 80° E. for the northern vein and N. 80° W. for the middle vein; so that if these observations are correct the veins must intersect toward the west. The surveys by the owners of the property show a course N. 85½° W. for the middle and 65° W. for the south vein.

DEVELOPMENT.

A shaft 35 feet deep has been sunk on the north vein at the eastern end of the vein outcrop. This shaft is about 5 by 10 feet across and shows a very well-defined vein about 5 feet wide, having a dip of about 70° to the north. The sides of the shaft show excellent ore, mostly of the greisen variety, extending down for 8 to 15 feet below the top. At this point a slip crosses the shaft and cuts out the ore. This slip, or fault, is a clay seam, but one-fourth to one-half inch in thickness, and seems to have thrown the upper part of the vein to the north. The lower half of the shaft reveals only rusty granite, shattered and showing films of quartz, but without recognizable ore. A crosscut south from the bottom of the shaft should reach the vein if the fault is a normal one. In the exposure seen in the upper part of the shaft the ore occurs in bunches in altered granite and lies on the north side of a 15-inch streak of sheeted and rusty quartz. A second shaft on the north vein has been sunk at a point about 300 feet west of the one just noted. This shaft is about 25 feet deep. The vein is well exposed at the top, and shows a dip northward, but the shaft passes out of the vein into the sheeted granite, forming the foot wall. A crosscut about 8 feet in length, driven from the bottom of the shaft, cuts the vein, but does not pass through it. The sheeting of the granite seen in this shaft is very pronounced, the rock being divided into plates from one-fourth inch to 12 inches in thickness by planes dipping 61° E. and crossing the vein at 90°. The outcrop of the vein is traceable westward up the slopes by its rusty quartz, and a nearly continuous ledge can be followed. This outcrop has been opened at intervals of a few yards by trenches, which expose the vein and show it to have a thickness of from 2 to 6 feet, with about half this thickness of ore. No samples were, however, taken, and it is uncertain whether the altered granite does not contain a percentage of tin oxide. The most westerly working that could be surely identified as being upon the north vein is a pit 6 feet deep, which shows a 6-foot vein in which the quartz is bluish in color and the tin ore is associated with much pyrite. This point is about 600 or more feet west of the first shaft. West of this point the ledge can not be traced across the slopes, but tin ore is seen on the slope 100 feet higher, and still farther north a good vein shows, carrying much pyrite, but devoid of any recognizable tin ore.

The middle vein is developed by a shaft 50 feet deep, which shows a vein having a central leader of quartz 2 feet wide at the top and tapering to 1 foot 4 inches wide at the bottom of the shaft. The dip, as shown by the walls of the shaft, is 70° N. The central quartz mass is spotted with cassiterite, and the altered granite on either side contains recognizable grains of tin oxide.

The south vein lies 500 to 600 feet south of the middle vein. This vein is much narrower than the veins on the north, having an average width of about 1 foot. The strike, as shown near the shaft, is N. 50° W., and the dip 50° N. The vein walls are sometimes defined by a clay selvage one-sixteenth inch wide, but more often show a gradual fading off into the granite.

It will be noticed from what has been said that the veins are all well defined at the surface and carry good values in tin ore, but that the ore apparently dies out in depth. Further development is needed to establish the existence of the ore at a greater depth than 50 feet, but it is believed that the veins have been thrown by local slips or faults and will be found by crosscutting from the bottom of the present workings. The character of the fissures and the nature of the ore both indicate that the veins are the result of deep-seated agencies, and are not merely segregations due to descending surface waters. For this reason it is believed that further exploration will develop well-defined tin veins.

TUNGSTEN ORE IN EASTERN NEVADA.

By F. B. Weeks.

A hübnerite-bearing vein was discovered about 12 miles south of Osceola, Nev., in 1900. It occurs in the foothills on the west slope of the Snake Mountains, near the base of Wheeler Peak. The nearest railway point is Frisco, Utah, on the Oregon Short Line Railway, about 100 miles distant.

The country rock is a rather coarse porphyritic granite, composed of quartz, mica, and hornblende, and having a rudely bedded structure parallel to that of the overlying Cambrian quartzite, which dips 20° to 25° SSW. The vein cuts across this granite, striking N. 68° E. and dipping 65° NW. The main vein is normally about 3 feet wide, pinching in places to a few inches, but rapidly regaining its usual width. Several smaller veins, from a few inches to a foot in width, outcrop on the slopes and can be traced to the main vein, entering it at a sharply acute angle. The main vein was traced for a distance of 2,100 feet by croppings and float from its outcrop near the base of the lowest foothill up the slope of the mountain.

Sufficient development had not been made at the time of visit to determine the extent of ore deposition. The vein walls are well defined. Where the vein has its average thickness, it is formed of milky-white quartz, carrying a large amount of hübnerite. Where the vein pinches, the quartz is schistose, and the ore is in small stringers and small in amount. The ore occurs in solid masses, frequently attaining a thickness of 6 to 12 inches. It is also disseminated through the quartz in thick plate-like forms, and also occurs crystallized with the quartz crystals. Small shoots of ore penetrate the country rock for a few inches. The vein material is easily crushed, and the hübnerite, because of its weight, can be readily separated by jigging.

At one locality on the vein there was a somewhat remarkable occurrence of the ore. It was found in large bunches or blocks averaging 75 per cent tungstic acid, and from a small space 4½ tons of ore were obtained. Scheelite has been found in small bunches and streaks with the hübnerite.

More recent information regarding the development of this ore body may be found in a paper by Mr. Fred B. Smith in the Engineering and Mining Journal, volume 73, pages 304–305, 1902.

GEOLOGICAL SURVEY PUBLICATIONS ON QUICKSILVER, PLATINUM, TIN, TUNGSTEN, CHROMIUM, AND NICKEL.

The principal publications, by the United States Geological Survey, on the metals here grouped are the following:

BECKER, G. F. Geology of the quicksilver deposits of the Pacific slope; with atlas. Monograph XIII. 486 pp. 1888.

——— Quicksilver ore deposits. In Mineral Resources U. S. for 1892, pp. 139–168. 1893.

BLAKE, W. P. Nickel; its ores, distribution, and metallurgy. In Mineral Resources U. S. for 1882, pp. 399–420. 1883.

——— Tin ores and deposits. In Mineral Resources U. S. for 1883–84, pp. 592–640. 1885.

BROOKS, A. H. An occurrence of stream tin in the York region, Alaska. In Mineral Resources U. S. for 1900, pp. 267–271. 1901.

CHRISTY, S. B. Quicksilver reduction at New Almaden [California]. In Mineral Resources U. S. for 1883–84, pp. 503–536. 1885.

GLENN, W. Chromic iron. In Seventeenth Ann. Rept., Pt. III, pp. 261–273. 1896.

HOBBS, W. H. The old tungsten mine at Trumbull, Conn. In Twenty-second Ann. Rept., Pt. II, pp. 7–22. 1902.

KEMP, J. F. Geological relations and distribution of platinum and associated metals. Bulletin No. 193. 95 pp. 1902.

PACKARD, R. L. Genesis of nickel ores. In Mineral Resources U. S. for 1892, pp. 170–177. 1893.

ROLKER, C. M. The production of tin in various parts of the world. In Sixteenth Ann. Rept., Pt. III, pp. 458–538. 1895.

ULKE, T. Occurrence of tin ore in North Carolina and Virginia. In Mineral Resources U. S. for 1893, pp. 178–182. 1894.

WEED, W. H. The El Paso tin deposits [Texas]. Bulletin No. 178. 6 pp. 1901.

WEEKS, F. B. An occurrence of tungsten ore in eastern Nevada. In Twenty-first Ann. Rept., Pt. VI, pp. 319–320. 1901.

COPPER.

The papers here presented represent the results of the last year's field work by the Survey in various copper-mining districts. These papers give, practically, a summary of the copper-mining industry of the United States, with the exception of the important Lake Superior district. The Lake Superior copper deposits were examined by the Survey at an early date, and the resulting report will be found catalogued in the "List of Survey publications on copper," on page 186. Other districts producing copper, but to a less value than the precious metals, will be found discussed under "Gold and silver," pages 31 to 90.

ORE DEPOSITS OF BINGHAM, UTAH.[a]

By J. M. BOUTWELL.

INTRODUCTION.

Field work.—During the field season of 1900 a detailed geologic examination of the Bingham Canyon district in the West Mountain Mining District, Utah, was conducted under the immediate direction of S. F. Emmons, geologist in charge, by Arthur Keith and J. M. Boutwell. The areal mapping was taken up in the summer by Arthur Keith and J. M. Boutwell and continued into the fall by the latter, and the ore deposits were studied in the winter by J. M. Boutwell. In the summer of 1900 G. H. Girty was engaged for one week in special paleontological studies in this field. During brief visits by the writer in 1901-2 additional data on special areal and economic problems were obtained.

An area of 24 square miles, embracing the Bingham Canyon mining district, was mapped geologically on a scale of 1,666+ feet to the inch. Those portions of the Oquirrh Range which adjoin this area on the north, west, and south were studied en reconnaissance, and the ore deposits in all accessible underground workings were examined. Owing to the fact that the geologists engaged in this work were detailed to other fields during the field season of 1901 and 1902 for exceptionally long periods, insufficient time for the earlier preparation of this report has remained. The complete report on the results

[a] The complete report, of which this paper is an abstract, will appear at an early date as a professional paper.

of these studies is now well advanced, however, and will appear shortly. In the present sketch, conclusions on several important economic problems must be reserved, awaiting results of special investigations now being conducted; and those here given are tentative and subject to revision in the complete report.

A brief sketch of the geography, history, and production introduces general statements on such major features of areal geology as stratigraphy, intrusions, general structure of the Oquirrhs, and structure of the district; and on such major features of economic geology as the character and occurrence of the ores, placer deposits, and commercial considerations.

GEOGRAPHY.

The Bingham district, which is the chief mining section in the West Mountain Mining District, lies in the north-central part of Utah, in latitude 112° 9′ north, longitude 40° 32′ west, and is situated on the east slope of the Oquirrh Range, 20 miles due southwest from Salt Lake City. It is connected with the main line of the Rio Grande Western Railway by a branch line which extends westward from Bingham Junction (11 miles due south of Salt Lake City) a distance of 14 miles to the main settlement in Bingham Canyon.

The Oquirrh Range, the most eastern of the desert ranges of the Great Basin, lies 25 miles west of the Wasatch Mountains, and extends in a general north-south direction southward from Great Salt Lake for a distance of 30 miles. In its general form it may be likened to that of a mason's trowel, with a handle-shaped portion at the north expanding at a point about 12 miles south of the lake from an average width of 6 or 7 miles to a width at the head of the blade of about 15 miles, and then gradually narrowing southward for a distance of about 18 miles to a point.

The main slopes rise rapidly from elevations of about 5,000 feet on the surrounding desert—except at the junction with the Traverse Mountains on the east and the Stockton bench on the west—to elevations on the main divide of over 9,000 feet at the northern and over 10,000 feet at the southern portion of the range. These general slopes to the east and west are deeply incised by many narrow, steep-sided canyons, which extend from the deserts far in toward the main divide on comparatively gently rising, partially graded slopes, and then rise abruptly by exceedingly steep slopes. The slopes inclosing these canyons are steepest at the lowest and highest portions, being often precipitous immediately over the narrow, occasionally graded canyon bottoms, and similarly steep and ledgy along the major divides; while a partially graded slope sometimes marks the intermediate stretches. These topographic characteristics are also true of the branches and subbranches of the main canyon, with the qualification that grading is much less advanced.

Snow falls commonly in late October, accumulates to great depths, and lasts until late in May. The range as a whole is not well watered. In the region embracing Bingham Canyon only the main canyons and their immediate tributaries carry water, and after the spring passage of the accumulated precipitation of the winter the flow gradually decreases until in mid and late summer water becomes scarce, occasionally disappears for considerable stretches from the stream beds during the day, and seeps through the discrete material constituting the stream beds in their lower courses. Several good springs are known in the range, such as that in Ophir Canyon, those at the head of Butterfield Canyon, and that in Tooele Canyon. In the vicinity of the mining regions, however, the main sources of water supply for domestic and commercial use are subterranean courses tapped by underground workings.

The vegetation is relatively sparse. This fact is doubtless due to the steepness and ledgy character of the slopes, and consequent thinness of the soil, and to low precipitation. Although more favored than many of the basin ranges, the Oquirrhs, particularly in the region about Bingham, support neither the variety nor the extent of vegetable growth which flourishes upon their more lofty and better watered neighbor, the Wasatch Mountains. Sagebrush (*Artemisia*) is the chief growth on the lower slopes adjoining the deserts. Scrub oak with an occasional cactus plant (*Puntia vulgaris*), juniper, spruces, and some pine characterize the middle elevations; and mountain mahogany, certain grasses, and Alpine varieties of wild flowers alone inhabit the higher peaks.

HISTORY AND PRODUCTION.

The Bingham district is unique in that it includes the oldest recorded mining claim in the State, is the only district in Utah in which placer mining has been successfully prosecuted, and to-day leads the camps of Utah in the production of copper. Only the more important stages in the extremely interesting and instructive history of this unique camp may be noted here.

Early in the fall of 1863 ore was discovered by George B. Ogilvie, an apostate Mormon, near the head of the main Bingham Canyon. On September 17, 1863, each of the 25 members of the Jordan Silver Mining Company formally located there "for mining purposes" one claim "of 200 feet each and one additional claim of 200 feet for the original discoverer."[a] This is the earliest recorded mining claim in Utah. Active prospecting led to the discovery and location of promising croppings, but lack of facilities for transportation rendered extensive mining operations at this time impracticable. "The first shipment of ores from Utah was a carload of copper ore from Bingham Canyon, hauled to Uintah on the Union Pacific, and forwarded by Walker Brothers to Baltimore in June, 1868."[b]

[a] Records at office of surveyor-general of Utah, Salt Lake City.

[b] Bancroft, H. H., History of Utah, p. 741.

In 1870 the connection of the Union Pacific and Central Pacific railroads by the Utah Central with Salt Lake City, the inauguration of the branch road to Bingham, the gradual removal of the early opposition of Mormon authorities to the entrance of their followers into mining operations, the results of experiments in the reduction of local ores, and the successful exploitation of the Emma mine and adjoining properties in the Wasatch Mountains, all combined to stimulate mining activities in Bingham. Many bodies of lead ore, mainly carbonate, were exploited. The first efficient development of the mines of the district was conducted by Messrs. Bristol & Daggett in the Winamuck and Spanish, and the largest body of argentiferous lead ore was developed in the Jordan and Galena mines. In 1874 the bulk of lead-carbonate ore was exhausted, and in the Winamuck, Neptune, Kempton, Spanish, and Utah sulphides had been encountered.

Special attention was directed toward saving the gold in the superficial oxidized portions of the ore shoots in the silicified limestones. Various experiments in milling and cyaniding were conducted, and large stamp mills were erected. Despite claims that in special cases cyaniding was successful, the general opinion prevails that the presence of copper necessitated the use of so much cyanide that no profit could be made, and, further, that the siliceous gold ores of Bingham have never been worked successfully. In the early eighties there were developed in the outer western slopes of the range bodies of carbonate ore which continued to afford an increasing output for about a decade. In 1891 and 1892 the leading productive mines were the Old Jordan and Galena, Brooklyn, Highland, Telegraph, York, Petro, and Yosemite mines. In 1893 the decline in silver brought this period of activity to a close.

A few years later the discovery of pay shoots of sulphide-copper ore at a time of strong demand for copper and a rise in the market value of lead inaugurated a new era in the camp. Reduction of copper sulphides having been successfully conducted, and the value of the Bingham copper ores having been demonstrated in 1890 on a shipment of 5,000 tons from the Highland Boy, exploitation for copper was vigorously begun and has continued to the date of writing. This has resulted in the disclosure of strong and valuable shoots of low-grade copper-sulphide ore.

These bodies are now worked on both a large and a small scale. The largest ones are controlled by consolidations, including the Utah Consolidated, the United States Mining, Bingham Consolidated, and the Boston Consolidated companies, which (with exception of the latter, which has not yet begun to ship from its well-proven shoot) transport their output either by aërial tramways or narrow-gage railroad to the Bingham terminal of the Rio Grande road, and thence by rail to smelters built and operated by each company at Bingham Junction.

During 1900 the total output from 32 properties aggregated 101,132 tons of ore, of an estimated value of $1,700,000. For the year 1901 the value of the output of gold, copper, and silver increased, and that of lead decreased, with a result of a net increase in the value of the output for 1901 over that of 1900 amounting to about $2,000,000. In this total the copper shipments constitute the chief factor, their value as compared with the combined values of gold, silver, and lead shipments being roughly at a ratio of 23 to 16. The output for the present year promises to show a continued increase. The value of the approximated total output of Bingham to 1899, inclusive, as calculated from the most complete data obtainable, is between $26,000,000 and $27,000,000.

AREAL GEOLOGY.

Stratigraphy.—In a general sense the sediments in the Bingham district are siliceous. Exceptions to this general character—first the relatively thin intercalated limestone, and second the calcareous shales—are, however, of greatest economic importance. The entire section may be broadly divided on lithologic grounds into two parts—a lower, which is characterized by a great thickness of massive normal quartzite with a few relatively thin interbedded limestones, and an upper, which is composed largely of quartzites with black calcareous shales, sandstones, and impure limestones.

The lower part includes three series of beds of geological and economic interest. The first of these is a thin calcareous member associated in quartzite with other limestones which cross Butterfield Canyon near its head at an elevation of about 7,000 to 7,500 feet. It carries a fauna which has been correlated by Dr. G. H. Girty with those of Lower Carboniferous age in the Mississippi Valley. Overlying this is a thickness of about 1,250 feet of massive quartzite. The second series is composed of at least two heavy limestones, which aggregate, with intercalated quartzite, about 5,000 to 8,000 feet in thickness. In these limestones have been found a large portion of the ore bodies of this camp, and near the top of the lower limestone of this series occurs a fauna characteristic of the Upper Carboniferous. Extensive deformation by fissuring, faulting, and intrusion gives rise to some uncertainty as to the normal succession from this point to the top of this lower great division. The structure of an extensive region to the south, west, and north of this immediate area, beyond that which the writer could find time to study, must be carefully determined before this and some other large structural problems involving this immediate area can be conclusively settled. But the field evidence gained by thorough study in this immediate area and the country immediately adjacent thereto indicates that overlying this second limestone series is a thickness of approximately 1,500 feet of quartzite with intercalated thin blue limestones and calcareous sandstones, and that over this and at the top of the lower great division is a series of at least three limestones of a semilenticular character. The lower of these limestones included the largest single body of copper ore yet discovered in Bingham.

The upper great division of the Bingham section, several thousand feet in thickness, is made up in the main of normal quartzite, and includes in addition relatively thin calcareous sandstones, calcareous carbonaceous shales which occasionally attain a thickness of a few hundred feet, and thin blue limestones. No particular horizon in this series is of special economic importance. The principal bodies known to occur in it, however, are associated with calcareous shales. Scanty faunas indicate the series to be of Upper Carboniferous age.

Igneous rocks.—Igneous rocks of at least two distinct types and ages are recognized. The area studied was too limited to afford the data necessary to prove the origin, source, and direction of movement of their magmas. Accordingly all statements concerning these subjects must be regarded for the present as in the nature of tentative suppositions. In brief, molten masses have been injected into the sediments in this area from the lowest nearly up to the highest. These broke upward across and along the beds in an extremely irregular manner and cooled in the form of irregular dikes, sills, and laccoliths.

The petrographic character of this intrusive varies from the fine-grained, rather basic porphyry of the laccolith at Upper Bingham to a coarse, slightly more acid type in Keystone Gulch, and to the coarse acid type north of Carr Fork toward its headward portion, and finally to the altered acid type between Bingham Canyon and Carr Fork.

For general purposes these may be considered as several facies of a single magma characterized by the occurrence in the Bingham laccolith. Under the microscope thin sections appeared to be augite-biotite-diorite-porphyry, but chemical analyses show the content of potash to exceed considerably the average potash content of diorite-porphyry and to agree with that of monzonite. Accordingly the rock may be regarded as an intermediate type between diorite-porphyry and monzonite. It occurs chiefly in the lower half of the section, and assumes considerable economic significance, first in connection with the main limestones, and second as the home of valuable mineral deposits.

The second type of igneous rock within this area is restricted to the lower slopes of the outer extreme eastern part of the range. Petrographically it differs from the intrusive just described in being more acid and allied to the andesites. No positive proof regarding the age and origin of this volcanic body has been found. A small prospect tunnel exposes the andesite breccia overlying an old surface débris of quartzite similar to that which characterizes the present slopes. Accordingly it may be regarded as an extrusive mass which over-flowed and submerged an ancient topography. Nothing bearing upon the source of this rock has been found since the work of Mr. Emmons in connection with the early survey of this region, when he determined that—

> the Traverse Mountains, which form a partial connection between the Wasatch Range and the Oquirrh Mountains, * * * seem to be composed mainly of trachyte, the flows of which extend * * * along the foothills of the Oquirrhs so far as the mouth of Bingham Canyon.[a]

The date of the porphyry intrusions is not definitely fixed, although it was probably earlier than the date of the extrusion of the volcanic flows, and abundant underground evidence proves that it was earlier than the late faulting on northeast-southwest fissures, earlier than the period of mineralization on those fissures, and probably earlier than the fissuring which preceded this period of mineralization.

Correlated studies, which the writer is now undertaking in another field, will, it is believed, throw much light upon the geological history of the igneous rocks of Bingham. So far as known, these extrusives have never been found to carry mineral values. An interesting economic problem associated with this andesitic flow involves the eastward extension of ore bodies. For if the prevolcanic land forms simulated present forms, and the andesitic breccia simply blankets an earlier surface, then there is no structural reason why the ore bodies in Carboniferous sediments may not be followed eastward under the volcanic flow. On the other hand, if this volcanic mass broke up at or in proximity to the present surface contact, then it is probable that this contact descends in depth approximately vertically and truncates the ore bodies.

Structure of the range.—The general structure of the Oquirrh Range, so far as it has been studied, is characterized by broad extensive folds and complex fracturing and faulting on a small scale. It is not improbable, however, that further field work, which shall extend our knowledge beyond the limited areas that have thus far been studied in detail, will reveal extensive faulting.

The beds in the southern portion of the range have been folded along northwest-southeast axes into two great anticlines, whose connecting syncline is occupied by Pole Canyon.[b] Northward "the main crest of the range, between Tooele and Lewiston peaks, is the remnant of the flat arch of an anticlinal fold."[c] The northern extension of this anticline may be identical with the anticline which crosses Tooele Canyon about two miles below its head. Thence the Carboniferous limestones, with the overlying siliceous series above described, strike eastward across Bingham Canyon until, at a point near its mouth, they turn up steeply on edge and strike northward.

[a] Emmons, S. F., U. S. Geol. Expl. Fortieth Par., Vol. II, p. 440.
[b] Ibid., p. 443.
[c] Ibid., p. 443.

Beyond here the structure is not as well known. In a general way it is believed that the beds dip northwardly and pass through several minor folds and considerable faulting until "beyond Connor Peak the beds of the Lower Coal Measure group are found to be pushed up and crumpled together in short sharp folds, giving no less than three small anticlines."[a] At the extreme north end of the range, along the general northeast-southwest strike, the dip is much disturbed and varies from vertical and 40° N. on the mainland to 5°, 10°, and 30° S. in Sheep Rock and outlying outcrops along the shore to the north.

Structure of the district.—The Bingham district itself thus lies in a broad, shallow, synclinal basin which pitches gently northward and is limited on the west by the Tooele anticline and on the east by the abrupt Bingham upturn. Minor folds occur with various irregularities of strike, but they are relatively unimportant. Fracturing and fissuring has taken place very extensively throughout the district. The amount of displacement in the instances studied is not, however, great, rarely amounting to 100 feet.

The general distribution of these sediments and intrusives is simple, but the detailed distribution is most complex and irregular. Briefly, the three great limestone series and the massive quartzites which separate them occupy the southern and southeastern portions of the area, and strike from the main divide on the west northeastward through the district. The great siliceous upper series of quartzites, calcareous shales, sandstones, and thin limestones overlie them and occupy the north and northwest half of the area. The intrusives lie mainly in the southern portion of the area in two great divisions, the lower, lying south of the middle limestone series (Old Jordan-Telegraph-Yosemite and Commercial-Brooklyn limestones), and the upper, which overlies this lime series. The sediments and their associated intrusives disappear on the east along a generally north-south line under the later volcanics, which in turn are blanketed by Quaternary deposits. In brief, the geological map of this area may be pictured roughly as follows: Conceive an oblong area in which the four points of the compass lie at the four corners; draw a straight line from the north corner to the middle of the southeast side, a second line from the same corner to the middle of the southwest side, and a third across the south corner in an east-west direction; then the first line will delimit the contact between the late deposits (Quaternary and volcanic) on the east and the Carboniferous on the west, the second will delimit the great siliceous series on the north from the main mineralized area comprising the limestone series with separating quartzites and intrusives on the south, and the third will delimit the Lower Carboniferous to the south from the Upper Carboniferous to the north.

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[a] Emmons, S. F., U. S. Geol. Expl. Fortieth Par., Vol. II, p. 444.

ECONOMIC GEOLOGY.

General.—The principal mines of this district are located on the slopes of Bingham Canyon, of its tributaries, and of the headward portions of the northeastern tributaries of Butterfield Canyon. They have revealed valuable ore bodies of two great types, those which occur as lenses, roughly parallel to the bedding, and those which occur in fracture or fissure zones. Under each of these forms of occurrence ores of copper, lead, silver, and gold occur, though the copper lies mainly in the lenses in limestone, and the lead and silver in fissures. For the purpose of this abstract the economic geology may best be considered with regard to character and occurrence of ores, placers, and commercial considerations.

Character of the ores.—The ores of Bingham include a valuable variety of the desirable metals. Thus mining activity has been devoted successively to oxidized gold ores, carbonate ores of lead and copper, sulphide of lead, and finally sulphides of copper. The oxidized gold ores carried good values, but were not commercially profitable. Although some of the gold was free, no satisfactory treatment of its ores was obtained, the commonly accepted explanation being that the presence of copper required too much cyanide to leave a profit. The carbonates of lead and silver carried high values and were treated with comparative success, but are to-day worked out. Lead-silver sulphides later assumed commercial importance, and under the influence of good market values lead is still extensively mined. This ore is made up of galena, tetrahedrite, considerable zinc sulphide, pyrite, and chalcopyrite, with a gangue of quartz and calcite. The mainstay of the district, however, is copper sulphide ore. This is composed of cupriferous pyrite, chalcopyrite, and the black sulphides of copper, which may prove to be chiefly tetrahedrite and chalcocite, with occasionally a little galena, zinc, and a siliceous gangue.

Pyrite (sulphide of iron with copper as an impurity: iron pyrites), the most common metallic mineral known in Bingham, forms the bulk of immense replacement ore bodies in limestone, plays a secondary rôle in fissure ores, and is freely disseminated through the igneous rocks. Although large masses of perfect crystals of exceptional purity were found, its more prevalent occurrence is in massive form intimately combined with chalcopyrite, small amounts of bornite, pyrrhotite, and alteration products of primary sulphides. Chalcopyrite (sulphide of copper and iron: copper pyrites) occurs scattered in small patches throughout bodies of massive pyrite in limestone associated with pyrite bands; in fissures of lead-silver ores, and in grains disseminated through the main porphyry bodies. It appears, from leached and unleached specimens, and from a study of thin sections, that much of the copper of cupriferous pyrite occurs as chalcopyrite in the state of a physical mixture with pyrite. Certain samples of rich black copper-sulphide ore associated with cupriferous pyrite from the large mines have been found by Dr. H. N. Stokes, chemist of the Survey, to consist mainly of tetrahedrite (copper-antimony sulphide with silver, zinc, and arsenic associated; gray copper). This is not like normal tetrahedrite of some camps, and is believed to be intimately associated wlth chalcocite (black sulphide of copper) and possibly some melaconite (black oxide of copper).

In this camp tetrahedrite occurs occasionally in crystalline form, but more commonly, and far more prevalently than has hitherto been recognized, under two facies of the massive form. In the copper ores in limestone it occurs in large masses as a dull-black powder and a crushed gray metallic substance associated with cupriferous pyrite. In the lead-silver fissure ores it occurs in regular bands and patches, is fine grained, compact, homogeneous, with metallic luster, steel-lead gray color, pale-bronze hue, and gives a dark-red streak. This species, freibergite, contains silver, and is commonly mistaken for ruby silver. Exceptionally fine crystals of enargite (sulphide of copper and arsenic) were obtained from a single occurrence. An excellent specimen of pisanite (hydrous sulphate of copper and iron), an alteration product of copper ores, was supplied by Mr. A. F. Holden, who suggested that it might be this mineral. It is believed that this is the first occurrence of the mineral reported in this country. Other copper-bearing minerals which occur in Bingham are bornite, covellite, cuprite, malachite, azurite, chalcanthite, native copper, and possibly cubanite, binnite, bournonite, and tennantite.

Galena (lead sulphide), which forms the bulk of all the present shipments of lead and silver, occurs in tabular bodies in or adjacent to fractures which intersect limestone, shale, porphyry, or quartzite, or in two or more of these. Although it is sometimes scattered in small amounts through the limestone, it occurs more commonly in irregular bands roughly intercrustified with similar bands of pyrite and chalcopyrite, calcite or quartz, and blende. Lead occurs here also in cerussite (carbonate of lead), anglesite (sulphate of lead), yellow oxide, and dufrenoysite.

Silver values probably lie chiefly in galena. It is a matter of common report among mining men that the granular variety of galena carries higher silver values than the cleavable variety. An assay by Dr. E. T. Allen, chemist of this Survey, of a composite sample of cleavable galena from four of the best-known silver-lead mines in Bingham, shows 18.9 ounces silver present, and of a sample of granular galena only 10 ounces. Native silver has been reported, but was not found during the present survey, although it was suspected to occur. Ruby silver has not been found. Crystalline specimens reported to be ruby silver have been proved, on study of the crystal forms, to belong to a different crystal system, and on chemical determinations by Dr. Hillebrand and Dr. Allen, of this Survey, have been found to be tetrahedrite. In a mixture of the crystal and massive tetrahedrite Dr. Allen found 325 ounces of silver, which indicates that the mineral usually called ruby silver is the silver-bearing species of tetrahedrite, freibergite.

Gold has been mined in Bingham in two forms—in its primary occurrence in country rock and in its secondary occurrence in detrital deposits. In the former it has been found in pay values included in sulphides, both in fissure ores, in pyrite, and possibly in galena and in tetrahedrite, and in replacement bodies in limestone. In the secondary occurrence rich gravel has been worked, though no free gold was obtained during the study of the camp. Unlike the primary gold, which is said to have been rough and jagged, placer gold is said to occur in thin beaten scales and washed nuggets. Flour gold has been found to be evenly distributed through the gravel for a distance of 30 feet above bed rock. In the early days when gold ores were mined from the silicified superficial portions of the great mineralized limestones and treated in stamp mills, only a portion of the gold was found to be free and no successful process was secured for treating the remainder of the gold content. In the present low-grade copper ores gold is an important associate, for it is the gold contained in these ores, low as it is, which renders more than one Bingham property a commercial possibility.

Zinc is present in the gangue of lode ores and is most abundant in those which lie within porphyry. It forms uneven layers roughly parallel to those of its associates, and irregular bunches and stringers intermixed with them. A few minute crystals of the light honey-yellow variety and of the black variety occur in vugs in veins, but by far the greater portion of this mineral is of the blackjack type and occurs occasionally granular, but usually massive cleavable. The Bingham occurrences of zinc deserve the attention of owners (see p. 121).

Some other minerals which under suitable commercial conditions are of economic value occur here sparingly. Molybdenum occurs in grains and bands in the porphyry of the Bingham laccolith, but in too small quantities to be of economic value. Gypsum is found in fibrous and selenitic form in small amounts in calcareous shale. Barite in radiating plates lies at the cores of some veins. Iron is found besides in copper sulphides, in magnetite, specularite, and limonite, but does not assume commercial importance. In brief, then, the valuable ores of Bingham are the copper-iron-gold-silver replacement ore, and the lead-silver-copper-gold lode ore.

Values.—The values of the Bingham ores average very low. Pay ore is widely distributed; prospecting in country rock in any part of the camp rarely fails to disclose some metals, but bonanzas have rarely been found. With very few exceptions the ore which is being mined to-day carries such low values as to render its successful extraction and reduction either a close-smelting or a concentrating proposition. Thus in certain instances it is the accessory gold, lead, and silver contents which raise the total value of low-grade copper ores safely above the commercial limit. It has been reliably estimated that a profit can not be guaranteed on a mixed copper ore from Bingham whose aggregate value falls below $6. It is understood, however, that this minimum limit has been lowered and may reasonably be expected to be still further reduced. The combination of a few higher grade bodies, several of medium grade, and many of low grade, together with the variety of types of ore, including copper, lead-silver, and gold, has proved most essential. This fact, by providing the mining industry against early exhaustion, baseless speculation, and market fluctuations, has made possible practically continuous mining operations from the date of the earliest mining in Utah to the present.

Little reliable information regarding the copper values is available. The average of the assays of three characteristic shipments from a typical fissure mine shows a copper content of 6.5 per cent. In the limestone replacement ore bodies the copper values are understood to run somewhat lower. Thus the average of three averages of a great number of assays on ore from two of the great copper properties shows a copper content of between 3 and 4 per cent. An assay of an average shipment from ore in a fissure in quartzite and porphyry gave 44.25 per cent lead, and the average of shipments for three years from a mine on a fissure in limestone is reported to be 45 per cent. These facts, taken in connection with assays from many mines, warrant the conclusion that the average of typical lead ore in Bingham is about 45 per cent lead. The silver content in two famous lead bonanzas averages 25.18 ounces per ton. In sulphide-copper ore from the replacement bodies silver runs from 2 to 4 ounces, and in fissure ores it ranges from 18 to several hundred, while ore from a fissure in quartzite and porphyry affords an average, based upon assays of three normal shipments, of 81.6 ounces. Gold values from the crests of the great replacement bodies average $10 to $12 a ton. Those in cupriferous pyritic ores average about $2, and those in the porphyry ores average about 25 cents. The pay in detrital deposits is stated in the description of placers.

Occurrence of the ores.—The productive area in the Bingham district is not restricted to any local ore deposit nor to a single zone of deposits. The most important productive belt comprises those massive limestones described under "Areal geology" as the middle and upper series of the lower great division. They have been found to be productive from the desert on the east to West Mountain on the west, a distance in a direct line of about 3½ miles. The known productive area of Bingham extends from the Richmond mine on the east to the Star mine on the west and from the Midland and Broad

Gauge mines on the north to the Queen and Lucky Boy mines on the south, an area of approximately 15 square miles. The vertical range of known ore deposits is marked by those in the Zelnora (8375) and the lowest levels in the Brooklyn (5875) and Dalton and Lark (5810), a vertical extent of 2,565 feet.

Ore bodies occur in each of the lithologic types of rocks of the district, including limestones, quartzite, shale, and porphyry. The limestones, which have afforded the largest ore bodies, compose the main belt and include the Brooklyn-Telegraph and the Commercial and Highland Boy members. No ore bodies are known in the massive dark-blue limestone underlying these series, but some have been found in the siliceous limestone above the Highland Boy horizon and in the thin mottled limestone of the Petro-York "bedded vein." Although ore occurs in the calcareous shales which characterize the great siliceous series over the main limestone belt, exploration shows that the rich lead-silver bodies formed under rather than within these shales. High-grade lead-silver ore carrying minor values of copper and gold occur in fissures which transect the quartzite, porphyry, or shale.

If we may judge from the occurrence of known ore bodies, two lithologic types appear to have exerted the strongest influence upon their formation, namely, limestone and porphyry; for it is in the main limestones in the neighborhood of intrusive masses that the large shoots of copper sulphides have been discovered. Thus the country rock inclosing the great Highland Boy shoots overlies a broad, irregular dike sill. The newly proven shoot in the Boston Consolidated overlies the great Last Chance intrusive, and is cut and overlain by porphyry. The bodies in the Jordan-Telegraph-Brooklyn and in the Commercial-Yosemite limestones are complexly associated with dikes and sills.

In influencing the position, form, and extent of ore bodies, deformation of the country rock appears to have constituted a third important factor in the formation of ore bodies, for in Bingham those limestones which have been intruded by porphyry inclose the larger and more numerous shoots in regions in which strong fracturing and fissuring have occurred. The entire country rock is excessively fractured, crushed, and fissured. These fissures are distinct loci of movement, of considerable horizontal and vertical extent, bounded by highly slickensided and polished walls, and possess in a general way the form of planes, but in detail exhibit many inequalities. They are not restricted to a few distinct trends, but trend in about equal number toward practically all points of the compass.

The ore-bearing fissures, however, in far the greater number trend toward the northeast and southwest, and dip steeply to the northwest. Underground evidence shows that fissuring took place in northeast-southwest directions, and that later, following a period of mineralization and fissuring and faulting in northwest-southeast directions, recurrent fissuring and faulting took place on northeast-southwest planes. It is in connection with the great limestones which have thus suffered intrusion and recurrent fissuring and faulting at several periods that the larger bodies of copper ore occur, and in the fissures that the smaller but valuable bodies of lead-silver ore formed.

The copper-sulphide ores occur in the general form of flat, attenuated lenses, mainly within the great limestone beds, and lie roughly parallel with the stratification. In the vicinity of fissures these bedded ore bodies thicken into well-marked shoots which, following the trends of the fissures, often pitch slightly. When these shoots display distinct structure, that of the original stratification is seen to be perfectly preserved.

The fissure ores carrying lead and silver, with subordinate amounts of gold and considerable zinc, differ much from the copper ores in the character of their occurrence. They form tabular bodies which may or may not be sharply limited by fissure walls, and extend several hundred feet horizontally and in depth. These lodes occur as a series of thin, sinuous, irregular pay streaks, which combined constitute bodies which are relatively thin when the fissures lie in a quartzite or porphyry country, but are of much greater width where the fissures cut calcareous beds. This selective action, indicated by bulging or increased lateral extent, which is exhibited between calcareous and noncalcareous rocks, is manifested in precisely similar manner between different beds of the same calcareous mineral. In addition to this change in the size of fissure veins, lesser variations occur, within lenses lying in a noncalcareous country, which constitute recognized shoots. The structure of the fissure ore consists of a rough banding of the several constituent minerals which form the vein, in roughly systematic arrangement from the center of the vein to either wall. In brief, there is a rough comb or crustified structure.

The copper-gold ores inclosed in the porphyry of the Bingham laccolith, however, present an interesting form of occurrence of an entirely different character. This ore, which consists of grains of cupriferous pyrite and chalcopyrite, is thoroughly disseminated throughout the intrusive mass, and seems to increase slightly in value in the areas which have suffered the maximum shattering and crushing.

The facts which have been observed with regard to the occurrence of the ore deposits of Bingham afford evidence for a very reasonable explanation of their formation, and these conclusions lead to several suggestions which it is hoped may prove to possess much commercial value. As the present abstract does not admit of such theoretical discussions, however, they must be deferred until the publication of the complete report.

PLACER DEPOSITS.

History of placer mining.—Bingham Canyon stands alone among the numerous successful mining districts of Utah as the only locality in the State where placer mining has been successfully prosecuted.

Free gold was first discovered in Bingham in 1864 by a party of veteran California miners who, returning from Montana to pass the winter in Salt Lake, prospected the canyon in the early part of that year. It was not, however, before the spring of 1865 that much work was done in prospecting for that metal.[a]

It is also stated[b] that gold in the gravels was first discovered in the fall of 1866 and was mined then by Peter Clays and G. W. Crowley.

The chief period of placer mining in Bingham extended from the date of discovery to 1871. Since then there has been a steady decline in the output of placer gold, except during the year 1881, until the present day. As late as 1898, however, the Arganaut was hydraulicked at the mouth of Carr Fork, and at present desultory work is conducted by the veteran gravel miner Bartholomew Gardella upon gravels on the continuation of this channel known as Dixon Bar and at the head of Bear Gulch. Late in the nineties the West Mountain Placer Company conducted extensive explorations in the gravels at the bottom of main Bingham Canyon, immediately below Dry Fork, and reported that gold occurred there in pay quantities, but that they were unable to handle the water. Since then this property has remained idle.

Occurrence.—Detrital gold has been found at several points in Bingham in gravels of different ages. These lie at various elevations in the canyon, and range from the rock bottom of the present canyon up to points on its side slopes several hundred feet above. They indicate former positions of the canyon bed, and the pay inclosed by the gravels then deposited shows that the streams were then transporting gold shed into them from their inclosing walls, and depositing it with their other burdens. The deepening and widening of the canyon through the same agencies which are to-day continuing that work resulted in cutting down through and removing the gravels from the early stream beds. So the high gravels or bars seem to be remnants of stream gravels deposited during the earlier stages of canyon cutting, and, occurring at different levels, they mark successive stages in the work of cutting down to the present level.

The bars consist of isolated deposits of waterworn gravel lying upon waterworn bed rock at the noses of spurs and at such points as have escaped removal by development of the present topography. In some cases these are patches on the sides of the canyon—in one instance there is a complete section of an earlier channel showing both walls, which are truncated upstream and downstream by later transverse valleys; and in another, extensive buried stretches of an

[a] Murray, J. R., Mineral Resources, Territory of Utah, 1872, p. 5.
[b] Personal communication, 1900, from Daniel Clays.

earlier channel have been preserved. The only possibility for placer mining on a large scale is in the gravels which cover the bed rock of the main canyon in its lower extent to a great depth.

Values.—Values, as a rule, have been good. While some of the high-lying patches panned rather low, rich bars were not uncommon. Gravel from the bottom of main Bingham Canyon in this same vicinity is reported to have brought 18 to 20 cents a yard. The pay levels of the West Mountain gravel are said to yield 8 to 10 cents a pan, and some of them 6 and 9 and 15 cents a yard. A recent sampling of the gravel in the Arganaut cut shows that the lower 30 feet of gravel averages 6 cents per cubic yard, and that the lowest 6 feet averages 18 cents.

In general the gold is coarse, varying from half an ounce downward. A nugget reported to be the largest ever found in Utah was discovered in the Clays bar near the mouth of Damphool Gulch by Daniel Clays. This is stated to have weighed 17 ounces 15 pennyweight, and to have been valued at $128. The fineness is generally considered to range from 850 to 875. In round numbers the total known output of placer gold from Bingham is about $1,500,000, while the entire output would undoubtedly aggregate about $2,000,000.

COMMERCIAL CONSIDERATIONS.

Although in the economic work of the Geological Survey "the fundamental principle * * * has been that its primary object is to determine the general laws which govern the foundation of ore deposits,"[a] matters come to notice on which suggestions have been given which have frequently proved of immediate commercial value. During the progress of the work in Bingham, several points have appeared in which it would seem that some improvement would be advantageous. It is hoped to develop some of these suggestions in the complete report. At present they may be barely stated.

The geology of Bingham presents many extremely discouraging difficulties. A great thickness of rocks of similar physical character and structure have been intruded, crushed, and faulted to a degree of complexity which might reasonably have been considered impossible. Instances are known in which good miners and able experts have been thoroughly baffled by this complexity, and so it is not strange that mining men familiar with the camp should believe that successful mining in Bingham requires, to an unusual degree, thorough practical geological experience. One familiar with these problems appreciates the significance of the common saying among miners, that to direct underground work in Bingham successfully one must have "grown up with the camp."

The irregular porphyry bodies have led to unwise exploration through failure to comprehend their origin, and thus their form and

[a] Emmons, S. F., Eng. and Min. Jour., Vol. LXXIV, p. 43.

extent. The Bingham porphyry is intrusive in origin. It was forced into the country rock from below along the ways of least resistance when in a molten, semiliquid state, and on cooling assumed forms of irregular dome-like masses, laccoliths; roughly vertical wall-like bodies, dikes; and nearly flat bed-like bodies, sills. Thorough examination of the form of the body on the surface should give the key to the type of the intrusive, and thus determine the most direct and economic method of attack.

Again, faulting, that common and characteristic feature of Bingham structure, has caused loss through misdirected exploration. Extensive detailed underground work throughout the camp goes to show that the prevalent idea among Bingham miners, that faulting is systematically of one type, with the character of displacement universally the same, is an error. Instances are at hand which prove that many types of faulting exist at Bingham, and that the character of the displacement is not restricted to one form, but includes many. In view of this fact each case must be worked out on its own evidence. Further, no little time and money have been lost by guessing on the direction of offset of ore bodies by faulting, and driving aimlessly in accordance with such guesses. When a lens of copper ore which lies along the strike of the beds and well within a thick limestone is found to be cut, displaced, and temporarily lost by faulting, it is usually advisable, in case the surface geology does not afford a clue, to drive to the nearest wall, quartzite foot or hanging. There the member which has been brought opposite to the contact may be found, the usual criteria indicative of the direction of movement observed, and the fault duly proved. The fact that a lens of copper sulphide pinches when followed down on its dip is not necessarily an indication that the ore has permanently disappeared. It is the habit of such lenticular bodies to thicken and thin irregularly. Accordingly continued exploration in depth might reasonably be expected to be rewarded by the discovery of similar lenticular ore shoots. Although copper shoots of this type attain great size and value in the large limestones, they are erratic and should not be expected to prove as constant in extent, either perpendicularly or horizontally, as smaller but more faithful fissure ore bodies.

The zinc contents of the Bingham ores have never received the attention they merit. Highly zinciferous ores have not only been disdainfully rejected, but they have been regarded as losing propositions, owing to extra smelting charges.

In several cases Bingham ores are reported to have carried regularly 15 per cent of zinc. In some instances values of 32 and 45 per cent zinc have been reported in Bingham. Although these ores may present some problems different from those encountered in camps where zinc ores are successfully worked, it would seem highly advisable to conduct more extensive experiments on them before abandoning ore containing so high a percentage of this valuable metal. A recent proposal of the American Smelting and Refining Company in the Jordan Valley to treat zinc ore from southern Utah, the present remodeling of the Anchor mill, and the recent thorough equipment of the custom zinc plant of Park City, afford Bingham owners a further opportunity to attempt to save their zinc values.

Even without either this additional saving or the discovery of new ore bodies, the present condition of the camp is promising. Unless the price of copper falls sufficiently to necessitate the suspension of mining operations, the fact that the United States Mining Company has begun regular heavy shipments from the ore shoots which have been developed in their properties during the last few years; that valuable additional shoots of pay ore have recently been discovered in the Utah Consolidated property; that a valuable shoot of sulphide copper ore of pay grade has been proved in the Boston Consolidated ground; that the work of opening and developing the consolidated mines on the east slope of the range, acquired by the Bingham Gold and Copper Company, is well advanced; and that extensive bodies of high-grade lead-silver ore have recently been discovered in the Commercial and Ashland properties, assure a strong consistent increase in the output from Bingham in the immediate future. Furthermore, although the camp has been rather thoroughly prospected, it is reasonable to expect that future exploration will reveal (1) new shoots of valuable copper-sulphide ore in the few stretches of the great limestones which remain unexplored, (2) pay lodes of the Silver Sheald type in fissures in the quartzite and porphyry about the upper portion of Bingham Canyon, and (3) new lead-silver bodies of the Montezuma-Ben Butler-Erie type in fractured or fissured zones in or adjacent to the calcareous carbonaceous shales of the upper series lying northwest of Bingham Canyon and Carr Fork.

COPPER DEPOSITS OF THE REDDING REGION CALIFORNIA.

By J. S. Diller.

SITUATION AND DISTRICTS.

The copper deposits of the Redding region of California lie among the foothills and mountains about the northern end of the Sacramento Valley, within the Redding quadrangle. This quadrangle was surveyed geologically in 1901–2, with a view to discovering the general relations of the ore deposits, and only such results can be announced at the present time, as detailed surveys have not yet been made. Four copper districts occur, more or less completely isolated, in which there has been extensive prospecting, but only the two largest, Bully Hill and Iron Mountain, have thus far yielded paying mines.

ROCKS OF THE COPPER REGION.

Sedimentary rocks.—The copper region contains an extensive series of sedimentary rocks, ranging from the Devonian into the Miocene, associated with igneous masses of various ages, shapes, and kinds, which have been intercalated or intruded into the sediments. The general abundance of fossils in the Cretaceous, Jurassic, Triassic, Carboniferous, and Devonian sediments, from all of which large collections have been made, has rendered it possible to work out the structure in detail with a high degree of probability.

Unconformities.—The great succession of sediments is wholly of marine origin; but their relation to one another, whether conformable or unconformable, is not easily determined, for in most cases igneous rocks lie between them. Thus the relation in succession between the Devonian, Carboniferous, Triassic, and Jurassic is much obscured by igneous rocks, but between the Jurassic and Cretaceous there is a conspicuous unconformity which represents not only a long interval of time, but a great epoch of mountain building followed by erosion. The mountain-building epoch at the close of the Jurassic was a time of rock folding, faulting, and crushing, as well as igneous intrusion, which greatly modified the rocks and prepared the way for the associated ore deposits.

Relation of ores to sedimentary rocks.—Disseminated ores occur at many points in all the sediments of the copper region older than the

Cretaceous, but thus far no large bodies of ore commercially workable have been observed in the sedimentary rocks, although such rocks occur in the neighborhood of some of the mines. In the Afterthought and Bully Hill districts the nearest sedimentary rocks are chiefly shales and limestones of Triassic age; in the Black Diamond district, shales and limestones of Carboniferous age; and in the Iron Mountain district, shales and limestones of Devonian age. Neither the kind of sediment (except the limestone at Black Diamond, to be noted later) nor its age is of special importance in relation to the ore bodies.

Igneous rocks.—The more important rocks of the copper region, so far as the ore deposits are concerned, are of igneous origin, and of these there is a great variety occurring in various forms. They may be most conveniently treated in this connection as lavas or surface flows, granitic rocks, and dike rocks.

Lavas.—The most important body of igneous rocks of this type is an extensive series of lavas which penetrate the older formations and lie to a large extent between the Triassic and Carboniferous strata. The volcanoes from which they flowed burst forth during the closing stages of the Carboniferous, for the tuffs resulting from the earliest eruptions contain carboniferous fossils. The thick mass of volcanics made up of tuffs and sheets of lava extends into the Triassic, for fossils of that group are found in the later tuffs. Many of the interbedded tuffs contain minute fossils of marine organisms, suggesting that the eruptions were largely submarine.

Much of the lava contains porphyritic quartz, and in general may be designated metarhyolite, but a large part, being without free quartz and less siliceous, has the appearance of metaandesite. A peculiarity of many of these rocks is that they are rich in soda.

A great belt of these ancient volcanic rocks lies east of the Carboniferous limestone, between Squaw Creek and the McCloud, and forms a succession of prominent peaks from Bollibokka Mountain, through Salt Creek Mountain, Minnesota Mountain, Town Mountain, and Horse Mountain to Pit River and beyond a lower ridge to the Sacramento Valley. A second belt west of this lies about the Sacramento River, embracing the Iron Mountain district and extending as far north as Backbone Creek. These two areas of ancient lavas, with associated dikes, include all the productive copper mines and the most active prospects of the region.

Ancient lavas occur also about Bagley Mountain, west of the Great Bend of Pit River, but they are usually of more basic types than those mentioned above.

Granitic rocks.—Two areas of granitic rocks occur, one about Shasta, between Keswick and Iron Mountain, and the other about Bayha and Pit River ferry, but neither of these masses is yet known to contain important bodies of copper ores, although they contain some auriferous quartz veins. Dikes from these granitic masses cut the lavas noted above, and are themselves intersected locally by dikes of diabase, so that in order of age the granitic rocks come between the great mass of older lavas and younger dike rocks.

Dike rocks.—The dikes are of a large variety of rocks, and range in size from a few inches to a hundred feet or more in width. They intersect older igneous rocks as well as sedimentary rocks, and are widely distributed throughout the field. Some are decidedly porphyritic, but the majority are fine grained and compact, without prominent crystals.

Of the porphyritic type some contain prominent crystals of both quartz and feldspar, and are closely related to the granitic rocks, with which they may be connected. They may hold an important relation to the ore bodies, but the relation can not be fully determined without detailed investigation. Dikes of this sort occur most abundantly in the western portion of the field, where they may be seen in places directly connected with the granitic rocks.

A decidedly porphyritic type, containing prominent crystals of feldspar only, occurs near the Uncle Sam mine of Squaw Creek and at a number of points about Bear Valley, but deposits of ore have not been noted in their vicinity.

The most abundant dike rock is an altered variety of basalt or metabasalt in which the feldspars usually have that ophitic arrangement which characterizes diabase. It is generally not porphyritic like the other diabasic rocks, but compact and greenish in color, especially on fresh fracture. Large areas of it occur about the Carboniferous limestone from Gray Rock northward, and dikes of it cut through the limestone, giving rise to interesting and important contact deposits of ore unlike any others in the region. South and east of Bass Mountain is a large mass of this ancient igneous rock, and along the Sacramento River there are numerous dikes of it cutting the older lavas.

Folding and displacement of the rocks.—The rocks of the copper region are folded and faulted, but the extent in both cases is limited, and varies with the kind of rock and locality. The shales, sandstones, and tuffs are usually soft rocks with little rigidity. They show many sharp folds and faults, but an attempt to trace them reveals their very local character and small extent. To determine whether large folds and faults are present the Triassic, Carboniferous, and Devonian limestones afford the best horizons for observation. Owing to their light color these rocks may be seen from a long distance in tracing structure, and each, having its own characteristic fossils, may be identified with certainty. The general course of these rocks across the region is nearly north and south, but in the Furnaceville district, as well as about the head of Squaw Creek, the Triassic limestone turns easterly, sending a synclinal point in the one case southwest to Bear Mountain and in the other northwest to the head of Claiborne

Creek. With these exceptions there are no irregularities in distribution of the Triassic and Carboniferous limestone to indicate folding or faulting on a large scale, although small gentle folds and faults are common along the limestone front in each case. The Devonian limestone is so cut by igneous rock as to afford no decisive evidence.

The geological date of the folding and faulting accompanied by much crushing of the rocks was at the close of the Jurassic, when the Sierra Nevada and the Klamath Mountains were formed and raised above the ocean to initiate an epoch of vigorous erosion represented by the unconformity between the Cretaceous and Jurassic. The epoch of rock crushing gave rise to the shear zones which later became the seat of circulating waters and finally the ore deposits of to-day.

AFTERTHOUGHT DISTRICT.

The Afterthought district is very small. It lies near Cow Creek, where the copper-bearing rocks run under the later lavas from the volcanic ridge north of Lassen Peak.

The country rock is chiefly igneous metarhyolite, and cuts Triassic slates, with large limestones near by. The ore bodies, which are chalcopyrite with other sulphides, as far as may be judged from surface openings—the tunnels, long unused, have caved in—occur near the contact between the two rocks without additional evidence of contact metamorphism. The adjacent rocks show extensive iron and copper staining. The conditions here appear to be similar to those of Bully Hill and Iron Mountain districts, but the extensive prospecting of years ago failed at that time to develop a paying mine. Later improvements in smelting low-grade ores may have changed the status of this property.

BULLY HILL DISTRICT.

Location and extent.—The Bully Hill district lies about 15 miles directly north of the branch railroad at Bellevista. It has a length of several miles in a direction a little east of north, and embraces not only the openings in Bully Hill, but also those about Copper City. Some openings on the slope of Horse Mountain might here be included, but at present the prospects, although in the same volcanic masses, are not sufficiently extensive to furnish good ground for judgment. It is especially interesting, however, to note that Horse Mountain is the only locality in the region where native copper was found in the comparatively fresh-looking igneous rock.

Country rocks.—The common country rocks are wholly igneous, generally metarhyolite, rich in porphyritic quartz like that of Bully Hill, of which an analysis by Dr. E. T. Allen is given below (1). Some of the rock is metabasalt without porphyritic quartz. This is especially the case in the Bully Hill mine, where the rock most intimately associated with the largest ore bodies yet discovered is basaltic in character and particularly rich in soda, as indicated by the following chemical analysis (2) by Dr. Allen.

Analyses of country rock of Bully Hill district.

	1.	2.
SiO_2	81.25	49.85
Al_2O_3	9.03	17.00
Fe_2O_3	.63	4.02
FeO	.40	5.51
MgO	2.48	7.65
CaO	Trace?	1.18
Na_2O	.25	4.78
K_2O	1.82	None.
$H_2O -$	1.09	2.16
$H_2O +$	2.81	6.65
TiO_2	.08	.97
ZrO_2	None.	None.
CO_2	None.	None.
P_2O_5	Trace.	.10
S	.35	.07
Cr_2O_3	None.	None.
MnO	Trace.	None.
BaO	.05	Trace.
	100.24	99.94
	.13	.03
	100.11	99.91

1. Bully Hill mine 400 feet west of ore body, west end of tunnel 2.
2. Bully Hill mine east of ore body, in tunnel 3.

This interesting rock (2) occurs in the form of a dike cutting through the older igneous rocks and the Triassic slates. Much of the rock in the mine, especially in the Copper City workings, looks like slate and is so called by the miners. The resemblance, however, is only superficial and results from the squeezing and shearing of the metarhyolite until it possesses a slaty structure. The ore deposits are found in the zones of shearing.

The shear zones are usually of limited extent; none have been traced upon the surface for over a mile. They vary in width from a few inches to nearly a score of feet, and are either vertical or dip steeply to the west, trending a few degrees east of north. In Bully Hill there appear to be three shear zones, two of which are well mineralized and contain valuable ore bodies. They are nearly parallel and only a few hundred feet apart. The western one is wholly in the metarhyolite of Bully Hill; the other, near the surface, is within the dike of metabasalt, and farther down follows the contact between the metabasalt and the metarhyolite more or less regularly to a depth of about 500 feet.

The walls are sometimes sharp, but at many places are indistinct, grading into the material of the shear zone.

Ore bodies.—The ore bodies occur very irregularly distributed in shear zones and range in size from lenticular or sheet-like nodules less than an inch in diameter to hundreds of feet long and up to nearly a score of feet in thickness. The crushed rock in the shear zone is not always mineralized, but generally it is more or less richly impregnated with ores, sometimes to complete replacement. In the Copper City workings, where these features are well displayed, the small ore nodules are chiefly zinc blende, with small amounts of pyrite and chalcopyrite.

One of the most important matters concerning ore bodies as they lie in the shear zone is that their longer axis usually pitches steeply to the north, so that when an ore body is struck the general position is a guide to its prospecting.

Zones in large ore bodies.—Near the surface each large ore body is naturally divided into three zones. Beginning at or near the surface with the zone of oxidation, where the material is generally known as gossan, it passes downward into the zone of enrichment, where the so-called black oxides of the miners occur, and finally at greater depths into the zone of the original sulphides. These zones are often extremely irregular, but are generally well defined.

Zone of oxidation.—The gossan of the Bully Hill ore bodies is, in the main, porous limonite, occasionally with small caves containing beautiful stalactites of the same mineral. It results from the alteration of the pyritous ores, from which nearly everything but the iron has been carried away by percolating waters, leaving the iron in the form of a hydrous oxide—limonite. The gossan usually contains also a larger portion of the gold of the original ores, but the copper is mostly carried down to form rich sulphides in the next zone. It may combine with carbon dioxide and give rise to the green and blue carbonates of copper, or be reduced and native copper result. All of these ores and also native silver occur locally in the lower part of the gossan or upon the borders of the Bully Hill ore bodies at greater depths. The red oxide (cuprite) rarely occurs at Bully Hill, but, according to Mr. Oxam, the mine superintendent, a mass several feet in diameter was found in clay 6 feet from the ore body at a depth of 151 feet. The bottom of the gossan is very irregular, extending far down into the ore bodies along fissures favoring oxidation. On gentle slopes it usually extends 70 or 80 feet below the surface, and sometimes much deeper, but upon steep slopes the gossan may be nearly all washed away and the original sulphides be near the surface. The gold from the gossan washed away in past ages accumulated in Town Creek and afforded the rich placer mines of the early days.

Zone of enrichment.—Next below the gossan occur the dark ores which the miners usually designate "black oxide," but in reality they appear to be chiefly dark sulphides, chalcocite, and sphalerite, generally mixed with pyrite, chalcopyrite, and barite. In some places there is only a thin film of this material between the gossan and the yellow sulphides, but generally in the Bully Hill district it extends for 10 feet or more to the predominantly yellowish sulphides. Chalcocite is most abundant near the borders of the pyritous ore mass, and small nodules of it are found in the adjacent fissile clays at much greater depths. Bornite occurs locally near the gossan with black sulphides; also at greater depths with chalcopyrite, pyrite, and sphalerite. While its secondary origin in the enriched zone not far beneath the gossan is evident, that at greater depths is more doubtful.

Fresh chalcopyrite was found in the zone of enrichment incrusting secondary chalcocite; hence it is evident that some of the chalcopyrite must be secondary. The lower limit of the zone of enrichment is not sharply defined, and it will be discovered only by detailed investigations.

Zone of primary sulphides.—The workings in the Bully Hill mine in October, 1902, had attained a depth of about 512 feet, which is considerably below the lowest level where the writer saw any of the secondary ores.

However, some of the miners report local "black oxides" at that depth. The ore in this zone is chiefly pyrite, with some chalcopyrite and a varying amount of sphalerite.

Gangue.—The gangue mineral of a large part of the Bully Hill ore is barite. It is rarely abundant, and often is so finely disseminated as to be invisible in the ore, yet greatly increases its weight. The source of the barite is most likely to be found in the metarhyolite, whose feldspar appears to contain a notable amount of barium.

Selvage.—On the east wall there is generally a white selvage-like material which ranges from a mere film to 12 feet in thickness. A chemical examination by George Steiger shows it to contain Na_2O 20, K_2O 3.28, and H_2O 11.87, from which it appears to be a mixture of kaolin and sericite. It affords an excellent material for lining the converters. This white selvage is sometimes found on both sides of the ore, and, combining, cuts off the ore. The selvage may be wholly absent, in which case the ore is directly attached to the wall rock. The wall rock of metarhyolite on the west side is usually much fresher than that opposite, and shows the hard, knotted, flinty character of the surface.

Prospecting.—It is evident that gossan, and to some extent also the peculiar knotted or brecciated metarhyolite, is to be the main guide in prospecting about Bully Hill and the great volcanic belt extending north to Bollibokka Mountain. Prominent limonite deposits from iron springs strongly suggesting gossan beneath were seen at several points a short distance northeast of Bully Hill, on the area of Triassic slates. The slates along the contact with the volcanics are in places richly impregnated with pyrite, but thus far no mines have been opened. This field is well worthy of careful prospecting and is now receiving attention, for recently much work has been done on some claims near Bollibokka Mountain.

BLACK DIAMOND DISTRICT.

The Black Diamond mine, which was practically closed in 1902 except for a small amount of prospecting, is about 20 miles northeast of Redding. It furnishes an excellent example of ore deposits on or near the contact between limestone and diabase. The relations of the deposits in this district differ widely from those of the other districts. The limestone and associated sediments are well characterized by fossils of Carboniferous age.

Small masses of pyrrhotite[a] and chalcopyrite occur, also pyrite and magnetite with limonite and other secondary minerals. The ore is associated with coarsely crystalline green fibrous pyroxene and garnet, whose relations are not so easily perceived in the mine workings underground, but upon the surface are illustrated at many points in the neighborhood along contacts of diabase dikes which cut the limestone. The best exposures are upon the crest of the limestone ridge, where it is crosscut by a number of diabase dikes running east and west and ranging from 5 to 100 feet in width. Along the edges of these dikes in contact with the limestone at many points pits have been dug into the iron-stained fibrous masses of pyroxene mixed occasionally with garnet, serpentine, and traces of ores. The fibers of pyroxene several inches in length are perpendicular to the contact and are conspicuous. Numerous open cuts and tunnels have been made in connection with the Black Diamond and Roseman group of mines. All were not examined, but as far as seen the relations were all essentially the same as described above.

The dike rock in question, here designated diabase, is composed largely of calcic feldspar, which generally has the ophitic arrangement characteristic of diabase, and incloses chlorite, epidote, magnetite, and quartz resulting from the alteration of feldspar and pyroxenes. The amount of quartz varies, and in some cases it seems a primary constituent.

These contact deposits have been exploited chiefly about Grey Rock, and to a less extent north of Pit River, where work is now progressing in an open cut, iron ore being taken out for flux at the Bully Hill smelter. The mass of magnetite incrusted by limonite is

[a] The pyrrhotite was examined for nickel, but there is none present.

large, and what it may lead to below is an interesting question. Associated with the magnetite are streaks of yellowish-green garnet and possibly also some pyroxenes, indicating that this mass of magnetite is a contact phenomenon.

IRON MOUNTAIN DISTRICT.

The largest and most important district of the copper region, as far as known at present, lies west of the Sacramento River and extends from Iron Mountain northeast for about 25 miles to the Summit mine northwest of Kennett. Only one mine in the district, that of the Mountain Copper Company at Iron Mountain, is productive, although there are a number of others—for example, the Shasta King and the Mammoth—that are not only extensively developed, but rapidly approaching the productive stage.

Iron Mountain mine.—The Iron Mountain ore bodies are marked upon the surface by the most prominent gossan of that region. It is chiefly limonite, which in the early days was mined for gold and silver. In places the porous gossan extends to a depth of over 100 feet, changing abruptly from the oxides to the sulphides, but upon the steep slopes bordering the canyons the gossan has been denuded and the bodies of sulphides lie near the surface.

In the Iron Mountain vicinity there are two principal bodies of ore; one, the Iron Mountain, which has been largely mined, is said to have been about 800 feet long, 100 to 400 feet wide, and traced to a depth of 600 feet. The other ore body, the Hornet, has a greater length, but less width, and has been thoroughly prospected.

The wall rock on both sides is metarhyolite, which, according to Dr. W. F. Hillebrand's partial analysis, contains 5.16 per cent Na_2O and only 0.40 per cent K_2O, with 0.015 per cent BaO and 74.52 per cent SiO_2. It is somewhat remarkable for containing so much more soda than potash, and appears to be related to the soda rhyolites described by Dr. Palache near Berkeley, Cal.

The shear zones containing the ores strike nearly northeast and southwest, dipping vertically or steeply to the northwest. The ore bodies are elongated, flattened, lenticular in shape, and at least in some cases pitch in the shear zone to the northeast.

The ores where seen in the Hornet were wholly sulphides, with the copper as chalcopyrite intimately mixed with pyrite. Chalcocite, so common in the dark ore at Bully Hill, was not seen in the Hornet body. Sphalerite is present and occasionally forms streaks through the pyritous ores, giving the mass a decidedly schistose structure. Whether this structure is derived from the schist which the ore is supposed to have replaced, or originated in the ore during or after its deposition, could not be determined without more detailed investigation. Wherever the schistose structure was observed it was generally parallel to that of the adjacent schistose igneous rock, but some of the small nodules inclosed in well-defined schistose structure show no trace of it internally. Quartz is often present in the ore, but barite, so common at Bully Hill, is absent in the Iron Mountain district.

The ore bodies usually separate easily from the wall rock, and at many points there are considerable masses of sericite selvage, but none so large as in the Bully Hill mine. The ore bodies are cut by small transverse faults, and, as pointed out by Mr. Lewis T. Wright, the general manager of the Mountain Copper Company, the sides of the ore bodies are occasionally polished by movement since the ore was deposited.

Balaklala and Shasta King.—Northeast of Iron Mountain, in the same district, there are many claims more or less extensively prospected, among which may be mentioned the Sugar Loaf, King Copper, Spread Eagle, and Balaklala; but it is not until Shasta King, on Squaw Creek, is reached that extensive activity is found. The Trinity Copper Company, Mr. A. H. Brown, general manager, controls the Shasta King, Uncle Sam, and numerous other claims in the neighborhood, and is cautiously developing them. The ores at the northern end of the district are in general not so rich as those of Iron Mountain and need to be handled under the most favorable conditions.

Shasta King is north of and below Balaklala, which is on the opposite side of Squaw Creek, and it seems probable that their ore bodies lie in the same shear zone. The country rocks in both places may be most appropriately designated metarhyolite. At Balaklala a large pyritous body of ore lies a short distance beneath the slope. It has the general strike of the district and dips to the northwest nearly parallel to the slope. Although much gossan occurs in the region, the slopes are usually so steep that it has been removed, and the dark sulphides form a very thin layer between the gossan and the pyritous ore.

In the Shasta King the ore body lies nearly flat and at its western end above is firmly united—"frozen"—to the country rock. This is exceptional in the copper region and even about the same ore body, for along its eastern border it has a well-defined selvage ranging from a mere film to a foot in thickness.

Beyond Squaw Creek the Mammoth mine and the Summit, on Little Backbone Creek, are near the northern limit of the district.

Detailed maps on a larger scale than that of the folio publication, which is only 2 miles to the inch, are now being made, preparatory to a special detailed study of these mining districts.

COPPER DEPOSITS AT CLIFTON, ARIZ.

By Waldemar Lindgren.

FIELD WORK.

The study of the copper deposits at Clifton was begun in October, 1901, and finished five months later, in May, 1902. During the examination I was assisted by Mr. J. M. Boutwell. The results of the investigation are expected to be published in the form of a professional paper. As yet, however, the necessary office work, including the examination of the ores and minerals, is not finished, and the following résumé is therefore to be considered only as a preliminary statement, which may be modified in some respects in the final report.

PRODUCTION AND DEVELOPMENT.

The Clifton mines were discovered in 1872, but owing to adverse conditions, principally the absence of railroad communication, the district did not attain prominence for a number of years. During late years the production has been increasing steadily and rapidly, due principally to the discovery of very large bodies of low-grade ore adapted to concentration. During the last eight or ten years the Clifton district has, in point of production, ranked third among the copper districts of Arizona, being preceded by the United Verde and by Bisbee. The gradually increasing production amounted to 38,000,000 pounds of copper in 1901. During that year the sequence became reversed, Bisbee leading with 39,800,000 pounds, followed by Clifton with 38,000,000 and United Verde with 34,500,000 pounds. It is believed that a still further increase took place in 1902, but statistics are not yet available. It is probable, indeed, that during the year just closed the Clifton mines produced more copper than any of the other camps in Arizona.

The production of Arizona is at present a little more than one-fifth of the total production of the United States.

At the present time there are three large companies at Clifton smelting copper on an extensive scale. These are: (1) The Arizona Copper Company, having mines at Metcalf and Morenci, a few miles northwest of Clifton, and a smelter located at Clifton. The production of this company in 1901 was 20,500,000 pounds. (2) The Detroit Copper Company, having mines and smelting works at Morenci. In 1901 the production of this company was 17,500,000 pounds. (3) The Shannon Copper Company, having mines at Metcalf and smelting works a short distance below the town of Clifton. This company began operations on a large scale in 1902, and started its furnaces in the month of May of that year.

There are a number of smaller mines and prospects, but their production cuts a comparatively small figure.

Situated in the southeastern part of Arizona, on the north side of the Gila River and only a few miles from the New Mexico line, Clifton is connected with the Southern Pacific Railway by an independent road leaving the main railroad line at Lordsburg, N. Mex. From a point on the Gila River along this road a narrow-gauge railroad branches and continues to Morenci, direct communication between Clifton and Morenci being impracticable on account of the great difference in elevation.

TOPOGRAPHIC FEATURES.

On the north of the broad valley of Gila River lies, in this vicinity, an irregular mountain region with no well-defined ranges. The elevations in the Gila Valley are about 3,000 feet. The highest elevations in the mountain region adjoining the valley on the north are about 8,000 feet. Rising gradually from the Gila River to the base of the mountains is a broad terrace of detrital material, attaining at that point elevations of about 4,500 feet. From this line, where the older rocks emerge from the old alluvium of the Gila Valley, a steeper slope begins, furrowed by sharply incised ravines and gulches. The Gila River in this vicinity receives two tributaries—Eagle Creek and the San Francisco River, both flowing southward and heading on the high volcanic plateaus near the boundary line between Arizona and New Mexico. These streams flow in moderately deep and sharply incised canyons, and are evenly graded throughout their whole course, which is generally bordered by a strip of bottom land, the width of which rarely exceeds a few hundred feet. In their upper courses these rivers flow through canyons cut in Tertiary lavas or older rocks, while the lower part of the San Francisco River, at least, is cut to a depth of about 600 feet in the old Pleistocene terraces mentioned above as adjoining the Gila River on the north. Clifton is situated on the San Francisco River, near the point where the older rocks emerge from the Pleistocene terraces, and has an elevation of 3,465 feet. At Clifton the San Francisco River is joined from the west by Chase Creek, a water course 10 miles in length and flowing in a south-southeast direction, most of the way through a deeply cut canyon. An irregular and high complex of mountains rises between San Francisco River and Chase Creek, the most prominent of which is Copper King Mountain, attaining 6,825 feet. On the west side of Chase Creek the high ridges attain elevations up to 7,400 feet, the highest point being the flat-topped mass of Coronado Mountain. The town of Metcalf is situated on Chase Creek, 6 miles north-northwest of Clifton, while Morenci is 4 miles distant in a northwesterly direction from the same place, but located high up in the hills, 1,000 feet above Chase Creek.

GEOLOGICAL FEATURES.

The old Pleistocene gravel plateau extending northward from Gila River to near Clifton and Morenci has already been mentioned. The older rocks rising above this plateau are to a very large extent of volcanic origin and of Tertiary age. The whole region north of the Gila River for a distance of at least 100 miles, and probably much more, is covered with very heavy flows of basalt and rhyolite. It is, in fact, the southern edge of the great volcanic plateau of eastern Arizona.

Near Clifton original high elevation and extensive subsequent erosion have combined in forming an exposure of pre-Tertiary rocks consisting of granite, porphyry, quartzite, and limestone. The Clifton area of older rocks may be considered as a small isolated mass, perhaps 12 miles long from east to west and 8 miles broad from north to south, appearing like an island in the surrounding vast lava flows.

The oldest rock and that which occupies the largest area is granite, evidently of pre-Cambrian age. It forms the great mass of Coronado Mountain and the larger part of the precipitous complex of mountains between Chase Creek and San Francisco River.

On the somewhat irregular surface of this granite rests a sedimentary series of Paleozoic age, the lower part consisting of 200 feet of quartzite. Immediately overlying the granite is coarse quartzite conglomerate, in places reaching a thickness of 50 feet. This quartzite, in which no fossils have been found, is probably of Cambrian age.

The quartzite is covered by 800 feet of limestone, the lower part of which belongs to the Silurian system, the middle part to the Devonian, and the upper hundred feet to the Lower Carboniferous series. Beginning from the base, the limestones gradually become purer, and the top stratum, well exposed at Morenci, is almost entirely pure carbonate of lime. Within the Devonian portion about 100 feet of clay shale is intercalated in the limestones.

A large mass of porphyry, running out at various points into complicated dike systems, has been intruded into these rocks, granites as well as quartzites and limestones, and this porphyry seems most intimately connected with the origin of the ore. Its character varies somewhat. The prevailing rock near Morenci is intermediate between a granite-porphyry and a diorite-porphyry, but at some points diorite-porphyries of typical character also occur. The porphyry at Metcalf is more acidic and contains large quartz crystals. It may more closely approach a granite-porphyry, but is, geologically, probably the same body as the Morenci porphyry.

At the Coronado mine and other places in that vicinity small dikes of diabase occur.

Southwest of Morenci a sedimentary series has been found which appears to unconformably cover the Paleozoic rocks. At one place fossils, indicating a Cretaceous age, were obtained. These rocks, however, are only of secondary importance as far as the ore deposits are concerned.

GEOLOGICAL STRUCTURE.

The geological structure of the pre-Tertiary rocks is rendered very complicated by extensive faulting. In few places does this faulting affect the covering basalt and rhyolite, from which it is to be concluded that the main epoch of disturbance antedates the volcanic eruptions of the Tertiary period. The Paleozoic era in this region was evidently one of quiescence and deposition, and it is believed that undisturbed deposition continued through the larger part of the Cretaceous period. The intrusion of porphyry took place during the late Cretaceous or the earliest Tertiary, for we find bodies of that rock intruded into Cretaceous sediments as well as into older rocks. In many places this intrusion was accompanied by very great disturbance, causing a fracturing and shattering of the sedimentary series into which it was intruded. The important ore deposits were formed during and a short time after this intrusion of porphyry. Alteration, gradually changing and often enriching these ore deposits, has, however, continued from their deposition to the present time.

The deposition of the ores was followed by very extensive fracturing and faulting, affecting, as already mentioned, all of the rocks in the district except the younger lavas.

From the form of the remaining patches of quartzite it would seem as if the surface of the granite and the whole overlying series had been buckled, perhaps elevated in dome-like shape, and then fractured extensively. The geological map will show the complicated nature of this faulting. The main faults extend in an east-west or northeast-southwest direction. Faults having a throw of over 1,000 feet are common, and in the Paleozoic series, where conditions are favorable for deciphering the structure, as for instance near Morenci, the complication is particularly apparent. Among more important faults may be mentioned that at the Coronado mine, where the south side is dropped 1,000 feet, and that cutting across Chase Creek east of Morenci, where again the Paleozoic series has been dropped 1,500 feet or more.

An extensive erosion, resulting in very irregular surface forms, followed these disturbances. Then, probably in the latter part of the Tertiary period, the whole region was flooded by rhyolites and basalts. Following this, probably in the early part of the Pleistocene, the level of the Gila River became greatly raised by accumulations of detrital material, and the foothills of the mountain complex were buried, up to an elevation of 4,500 feet.

The last phase in the geological history is the present period of erosion, which has removed large masses of these early Pleistocene gravels and deepened the canyons and gulches to the level which they had attained before the volcanic eruptions.

ORE DEPOSITS.

Contact-metamorphic deposits.—There is no evidence of ore deposits having been formed in this region before the intrusion of porphyry. This event appears to be in most intimate connection with the origin of all the copper deposits in the region. Wherever the porphyry came into contact with the granite or the quartzite, little alteration is observed; but wherever we find the porphyry adjoining the limestones or the shales of the Paleozoic series, very extensive contact metamorphism is noted, resulting in the formation of large masses of garnet and epidote. This alteration is particularly observable at Morenci. The whole Paleozoic series is affected, but more particularly the pure limestone of the Lower Carboniferous, which, for a distance of several hundred feet from the contact, has been converted into an almost solid mass of garnet. The shales have suffered less from this metamorphism, but near the porphyry are apt to contain epidote and other minerals. This metamorphism appears not only at the contact of the main mass of porphyry forming the southern slope of Copper Mountain, but also in the hills between Morenci and the Longfellow mine, in which dikes have produced contact-metamorphic minerals along their sides. Wherever alteration has not masked the phenomena, magnetite, pyrite, chalcopyrite, and zinc blende accompany in various proportions the contact-metamorphic minerals, and are intergrown with them in such a way that the contact-metamorphic origin of these ores appears beyond doubt. In many places the ores have accumulated along certain horizons in the sedimentary series, evidently more suitable than others to the processes of alteration which produced the deposits. The origin of these contact-metamorphic deposits is conceived to be in the water and metallic substances which were originally contained in the magma of the porphyry, and which were released by decreasing pressure at the time of the intrusion of the rock into higher levels of the earth's crust. We may thus speak of these deposits as contemporaneous with the cooling and solidification of the prophyry.

As to form, the ore deposits in limestone are often irregular, but more frequently, perhaps, assume a tabular shape, due to the accumulation of the minerals along certain planes of stratification.

Oxidizing waters have very greatly altered the deposits in limestone. The sulphides have been converted into carbonates, and malachite and azurite are the most common ores. Cuprite also occurs extensively, and seems to form by preference in the shale forming part of the Devonian system. Chalcocite and other sulphides are almost entirely absent. The zinc blende has been carried away as sulphate of zinc, which is frequently found in efflorescence on the walls of the tunnels. The magnetite and the garnet which originally formed a part of these deposits have also undergone decomposition, the resulting minerals being silica and limonite.

The celebrated Longfellow mine is worked on one of these deposits occurring as, roughly speaking, a funnel-shaped mass in the Lower Silurian limestone, between two large porphyry dikes. Going farther west along the main porphyry contact, the Montezuma is encountered, and farther on the Detroit and the Manganese Blue mines. Both of the latter mines were worked on several tabular ore bodies, three or more in number, occurring in horizons varying from Silurian to the Lower Carboniferous. All of these deposits are now largely exhausted. They contained a large quantity of very rich carbonate and oxide ore. The extent of these ore bodies was, however, much smaller than the large masses of chalcocite ore which now forms the main support of the camp.

At Metcalf the Shannon mine contains several ore bodies of similar origin. A fragment of the Paleozoic series outcrops on Shannon Hill, and is cut by an extensive system of porphyry dikes, which in the lower part of the mountain join the main part of a large intrusive body of porphyry. In several horizons the limestones are greatly altered, the final product generally being copper carbonates and limonite, with some quartz. In some places the ore bodies are less affected by oxidation, and their original character of garnet, epidote, magnetite, and sulphides may be plainly seen.

Oxidation by surface waters, as at Shannon mine, also diffused much copper as chalcocite in some of the porphyry dikes, and the Metcalf mine on a lower spur of the same hill consists chiefly of a body of extremely decomposed porphyry containing chalcocite and carbonates. Very probably this copper has migrated into the decomposing porphyry from bodies of contact-metamorphic rock at higher elevation, parts of which are probably now eroded.

Fissure veins.—At many places in the district the copper deposits consist of fissure veins, cutting alike porphyry, granite, and sedimentary rocks. From the available evidence it would seem as if these veins had been formed a short time after the consolidation of porphyry. In lower levels the veins consist of pyrite, chalcopyrite, and zinc blende, magnetite being conspicuously absent. At the surface many of the veins have been completely leached, and now show nothing but limonite and silicified porphyry. This rule is, however, not a general one, as, especially in porphyry, oxidized ores are sometimes found in the outcrops of the deposits. Between the leached croppings and the deep ores of pyrite and chalcopyrite is a more or less extensive zone of chalcocite or copper glance, deposited by secondary processes on the pyrite.

The most important vein system is that which, under the general name of the Humboldt vein, extends from northeast to southwest through Copper Mountain at Morenci. The outcrops of this vein are practically barren, but at the depth of about 200 feet the deposit becomes productive and contains chalcocite associated with pyrite. There are usually one or more central seams of massive chalcocite, some of which are fairly persistent. These seams are ordinarily adjoined by decomposed porphyry, now chiefly consisting of sericite and quartz, together with pyrite and chalcocite. These extensive impregnations of the country rock are rarely confined by distinct walls, but gradually fade into the surrounding porphyry. That these deposits are genetically connected with fissure veins can, however, not be doubted. In lower levels the ore is apt to change to pyrite and chalcopyrite. Both the Arizona Copper Company and the Detroit Copper Company are now working the low-grade bodies of chalcocite ore accompanying the veins. The reserves thus far opened assure a high production for many years to come.

Parallel veins, somewhat narrower, but similar in character, are those opened by the Arizona Central mine, also at Morenci. These veins are partly in porphyry, partly in contact metamorphosed limestone. While malachite and azurite sometimes occur, they are by no means as prominent as in the limestone deposits, and frequently the leached surface zone is immediately adjoined by the chalcocite ore.

The Coronado mine represents a different type of deposits. It is formed on a fault fissure between granite and quartzite, indicating a throw of at least 1,000 feet. The fissure is followed in places by a diabase dike, showing some effect of crushing and movement on the vein. The croppings contain copper carbonates and silicate, but these minerals change at slight depth to chalcocite, and still farther down it is believed that the ore bodies consist chiefly of pyrite and chalcopyrite.

Somewhat different again are the fissure veins on Markeen and Copper King mountains. The granite of this complex of hills is cut by a great number of porphyry dikes which generally have a northeasterly direction. Along many of these dikes movement and fissuring has taken place, and varying amounts of copper ores have been encountered. The veins contain comparatively little gangue, the copper minerals being chiefly distributed through the altered porphyry or through the granite adjoining the dike. At the surface a small amount of carbonates may be found, but they change at slight depth, sometimes only a few feet from the surface, into an ore composed of chalcocite and pyrite, which still farther down appears to change into pyrite and chalcopyrite. The most prominent deposit on this system of veins is the Copper King mine, which is situated only a few hundred feet below the summit of the mountain of the same name. The main mass of porphyry between Morenci and Metcalf shows evidence of very strong mineralization throughout. A great number of fissure veins have been encountered in it, although most of them are neither persistent nor strong. Close to the surface the ores are apt to spread through a considerable mass of rock, and in some cases important bodies of chalcocite, due to secondary deposition on pyrite from solutions containing copper, have resulted.

The granite adjoining this porphyry is sometimes also thoroughly altered and impregnated with pyrite and chalcopyrite. This may be seen in the narrow canyons of Chase Creek for a mile above Longfellow Incline. While a number of more or less well-defined veins have been opened here, the results have not been encouraging.

GOLD DEPOSITS.

The gravels lying in front of the older rocks at Morenci and Clifton are sometimes gold bearing, though ordinarily the metal occurs in very fine distribution. The bench gravels above Clifton, along the San Francisco River, contain gold, and attempts have been made to work them. The results, however, have not been encouraging. This gold is probably derived from a system of veins cropping on the Dorsey and Colorado gulch, a few miles north of Clifton on the west side of the San Francisco River. The system of dikes mentioned above as cutting Copper King Mountain continues in places still farther in a northeasterly direction, but the ore here contains less copper and more gold and silver. Attempts to mine these gold-bearing veins have not thus far been attended with much success.

Another gold-bearing district is that of Gold Gulch, 2 or 3 miles west of Morenci. The diorite-porphyry which occurs here contains many inclusions and fragments of limestone, and this complex geological formation is again cut by many faults. Native gold accompanied by limonite and other products of decomposition has been found in many small veins in this district, but the tenor of the ore seems very capricious, and the deposits have not yet been proved to be of much value.

The copper ores of Morenci and Metcalf, whether occurring as contact-metamorphic deposits or as fissure veins, contain a very small quantity of gold and silver, in most cases amounting to little more than a trace. At the Copper King mine, however, in the system of fissure veins following dikes of porphyry and granite, a notable amount of gold is found, and from here on northeasterly, as noted above, this tenor in gold increases considerably.

COPPER DEPOSITS OF THE MOUNT WRANGELL REGION, ALASKA.

By Walter C. Mendenhall and Frank C. Schrader.

GEOGRAPHY AND EXPLORATIONS.

Near the southeast corner of the mainland mass of Alaska, very near the intersection of parallel 62° north latitude and meridian 144° west longitude, stands Mount Wrangell, 14,000 feet high, an active volcano, and in many respects the most impressive, although not the highest, peak of the group to which its name is given. This group, a complex pile of volcanic material, with half a dozen or more great summits over 12,000 feet in height, occupies the angle between two diverging branches of the St. Elias Range.

The drainage of a part of its northern and of all its western and southern slopes is carried to the Pacific by the Copper River, while White River and the two main branches of the Tanana, called the Nabesna and the Chisana, rise on the north slope east of the Copper and flow by way of the Yukon into Bering Sea.

In the drainage basins of the upper portions of these streams, on both sides of the range, it has been known for many years that native copper exists. Yukon and White River Indians used it in the interior in the earlier days for knives and bullets, and Copper River natives exhibited similar specimens at the coastal trading stations long ago. Lieutenant Allen in 1885 secured specimens of bornite from Chief Nicolai at Taral, but most of the knowledge possessed by white men concerning these occurrences has been secured since 1898, when they first entered the region in force. Since then prospectors have explored rather thoroughly the southern field, which includes the basins of the Chitina and the Kotsina, large eastern branches of Copper River. As a result of this exploration, they have located many claims in this region and have done a little development work. At the same time somewhat less thorough prospecting has been carried on in the more distant and less accessible region north of the Wrangell Mountains, but thus far the search for promising copper deposits has been less successful there.

In 1891 Dr. C. Willard Hayes,[a] while en route with Lieut. Frederick Schwatka from Fort Selkirk to the coast at the mouth of Copper River, visited the Kletsan Creek deposits on the upper White River. In

[a] An expedition through the Yukon district: Nat. Geog. Mag., Vol. IV., pp. 117-162.

1899 the same locality was visited and described in some detail by Mr. Alfred H. Brooks,[a] of the Geological Survey, while en route from Pyramid Harbor to Eagle City with Mr. W. J. Peters. In addition to the Kletsan Creek occurrences Mr. Brooks gives notes on the extension of the copper belt toward the west.

In 1900 Messrs. Schrader and Spencer[b] visited the southern field and issued a comprehensive report on its geology and mineral resources, particular attention being given to the copper occurrences.

In 1902, while Mr. W. C. Mendenhall extended the earlier work of Messrs. Schrader and Spencer in the western portion of the southern field, Mr. F. C. Schrader visited the region about the head of the Copper, the Nabesna, and the Chisana rivers. The results of all these studies, with such information as can be gleaned from other sources concerning the localities which the geologists have not visited, will shortly be issued as a paper on the mineral resources of the Mount Wrangell district, and for a full account of what is at present known on the subject this report should be consulted. Only that portion of it which bears upon the copper occurrences is summarized here.

SOUTHERN DISTRICT.

This, the best known and probably the richest of the two copper belts of the region, occupies a strip nearly 100 miles long and of varying width along the southern base of the Wrangell Mountains. Throughout this zone, in the drainage basins of the Chitina, the Kotsina, and the Cheshnina there are scattered deposits of copper ores, some of them very promising.

GEOLOGY.[c]

The lowest stratigraphically, and therefore the oldest, of the economically important formations of this belt, is a great series of successive basalt flows, now somewhat altered, which has been called the Nicolai greenstone. A thickness of not less than 4,000 feet of this basalt is exposed near the western part of the area in which it is known, and its maximum may be very much greater, as the base of the formation is nowhere exposed. The thin sheets in which this fluid lava issued now lend themselves to the determination of structure in the formation almost as well as does bedding in sedimentary rocks.

After the close of the period of great volcanic activity of which the Nicolai greenstone is the record an era of sedimentation set in, apparently without any intervening erosion. The first of the sediments deposited was a massive white limestone, which is particularly prominent along the Chitistone River and has therefore been called the

[a] A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-First Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, p. 377 et seq.

[b] Geology and mineral resources of a portion of the Copper River district, Alaska. Special publication of the U. S. Geol. Survey, 1901.

[c] This account of the geology is summarized from the report of Schrader and Spencer.

Chitistone limestone. A series of interbedded thin limestones and shales which carry Triassic fossils were next laid down, and these had accumulated to a thickness of several thousand feet before the era of sedimentation was brought to a close. Within the Chitina Basin the massive Chitistone limestone does not carry fossils, but it has been correlated with similar beds beyond the Scolai Range to the north, from which Permian shells have been taken. If we accept this evidence as determining the Permian age of the Chitistone, it becomes highly probable that the greenstone beneath it, with no erosional interval intervening, falls in the Carboniferous, and perhaps in the Upper Carboniferous. A more definite conclusion than this can not be reached with the evidence at present available.

Following the outpouring of the Nicolai lavas and the deposition of the succeeding calcareous terranes a period of stresses was inaugurated. during which these rocks were everywhere thrown into a succession of open folds. Accompanying or following this folding the rocks were brought within reach of subaerial erosional agencies, and the folds were truncated; but the land was not, it is believed, reduced to a plain. On the contrary, a distinct relief remained, and when the next period of deposition began the sediments were laid down in local basins and unconformably upon the truncated edges of the folds in the older rocks. These deposits were gravels and muds, which have since consolidated into the conglomerates and shales of the Kennicott formation. They were deposited during Jura-Cretaceous time.

After the deposition of these gravel beds the region was again elevated and folded slightly, and a period of erosion began which reduced the land to a generally plane surface. This plain was elevated, dissected, and partly buried under the extravasated igneous material whose accumulations have produced the peaks of the Wrangell Mountains.

This, in brief, is the history, as at present understood, of the events which have resulted in the accumulation, burial, folding, erosion, and later partial reburial of the rocks which are economically important in the region. Of these the chief is the Nicolai greenstone. As is often true of greenstones in other parts of the world, this rock seems to have contained originally minute quantities of copper disseminated throughout its mass. During the operation of the processes to which the formation has since been subjected some of this disseminated copper has been concentrated at various points within the mass of the greenstone or the overlying limestone, and some of these accumulations are of sufficient magnitude to constitute workable copper deposits.

A plane which has seemed to be a favorite locus for these accumulations is the contact between the greenstone and the overlying limestone. Nearly all of the prominent ore bodies are on or near this plane, sometimes in the greenstone just below it, sometimes, but more rarely, in the limestone just above it, and occasionally in fissures which cross it.

The ore bodies have assumed various forms, and for convenience of discussion these forms have been divided into two general classes, vein deposits and bunch deposits.

The vein deposits are so defined as to include all tabular ore masses, whether in true fissures or along joint or fault planes or shear zones. The ores may be found only in shoots within the planes which have controlled their form, but are characteristically of indefinite extent in one or two directions.

The "bunch" deposits, on the other hand, are irregularly bounded masses of ore, from a few inches to a few feet in diameter, which usually are not obviously related to fractures or fissures or joint planes, but in form are much like basic segregations in igneous rocks—i. e., they generally have indefinite limits, grading from masses of practically pure ore at the center through leaner and leaner phases, into the entirely unmineralized inclosing country rock. These "bunches" are so numerous in certain parts of the field within the upper part of the greenstone that prospectors who have opened a number of them, 400 or 500 feet below the base of the limestone, have been led to conclude that a ledge of ore parallels the contact at this horizon.

MINES AND CLAIMS.

In order to give an idea of the different types of deposits and the conditions of development, some of the best-known occurrences will now be described.

Nicolai mine.—The Nicolai mine is located near the eastern part of the Chitina copper district, on Nicolai Creek, a few miles west of the Nizina River. The vein, a fissure with definite walls, is in the greenstone not more than 50 feet below the base of the limestone. It trends about N. 50° E. and dips 75° SE., and a displacement of not more than 50 feet has taken place along it. The main fissure, which may be traced for several thousand feet, although it shows no ore except near the place of discovery, is paralleled at distances of 90 and 140 feet by two other fissures, which also contain copper minerals. In the vicinity of a shaft which has been sunk in the process of development, the vein has a width of from 8 to 12 feet and is about equally divided by a horse of greenstone 3 or 4 feet across. The ore on either side of this horse is practically pure bornite with only a small amount of quartz associated in an irregular way. Locally there is a band of chalcopyrite lying next the hanging wall.

In 1900, when the shaft had been sunk to a depth of 30 feet, ore from 2 to 4 feet in thickness was exposed throughout this depth.

Bonanza claim.—This claim is located upon a high ridge between Kennicott Glacier and McCarthy Creek, and is about 8 miles west of the Nicolai mine. This vein also is a fissure, which cuts across the contact between the greenstone and the limestone, although for some distance below the contact the vein is barren. It is irregular in width, varying between 2 and 7 feet, and has a strike of about N. 40° E. There is no quartz or other vein material associated with the ore, although there is sometimes a considerable amount of crushed limestone between the walls. The ore is practically pure chalcocite, or copper glance, which is exposed in solid masses 2 to 4 feet across and 15 feet or more in length. Besides the ore within the fissure there are bedded ore bodies running off into the limestone along the planes of stratification. The ore is regarded as a replacement of the limestone. A selected sample gave over 70 per cent copper and 14 ounces of silver per ton, with a trace of gold.

Louise claim, Elliott Creek.—Elliott Creek is a tributary of the Kotsina River and is near the western end of the copper area. The Louise claim is on a small branch of Elliot Creek called Rainbow Creek. Here, in a shallow open cut, a slickensided face of greenstone, forming a well-defined and, so far as exposed, regular foot wall, is revealed. This face strikes N. 10° E. and dips 70° NW. The cut does not expose an equally definite hanging wall, but adjacent to the foot wall is a crushed zone, which has an extreme width of 15 or 16 feet. Within this zone the greenstone is generally irregularly fractured, but at the present surface there exists, in the center of this crushed mass, a "horse" of solid greenstone 7 or 8 feet wide. It is probable that the slickensided foot wall is a fault plane, but since no displacement was observed in the limestone above, its throw can not be great. The mineralization within this belt consists of an impregnation of chalcopyrite and bornite, the latter mineral being superficially more abundant. The impregnation follows the fractures and partakes of their irregularity, the exposed surfaces of the greenstone fragments generally showing more or less ore.

Goodyear claim, Elliott Creek.—Across Rainbow Creek from the Louise claim and a few feet below it, an open cut in greenstone reveals a well-defined fissure vein 4 to 5 feet wide, striking N. 12° E. and dipping 45° SW. The vein can be traced 50 or 75 feet up the slope toward the limestone contact before it is buried under the talus.

The gangue minerals are quartz and calcite, entirely distinct from the perfectly definite walls of greenstone, and this gangue carries heavy bodies of bornite and a smaller quantity of chalcopyrite. While the heavy ore bodies are confined to the vein, the shattered hanging wall and the more massive foot wall are impregnated with copper sulphides for some distance above and below.

In the upper part of the open cut a slight horizontal fault has displaced the vein laterally, so that the hanging wall above the displacement is continuous with the foot wall below it.

Eleanor, Davy, and associated claims, Kotsina River.—Two thousand five hundred feet above the level of the Upper Kotsina River, near the crest of a sharp ridge separating two tributaries, Peacock

Creek and Roaring Gulch, a number of claims have been staked in that belt in the greenstone, a few hundred feet below the limestone, which seems everywhere to carry "bunches" of copper ore. No development work has been done here, but the exposures on the faces of the greenstone cliffs show small ore bodies from a few inches to 2 or 3 feet in diameter and irregular in outline. They usually have cores of nearly pure bornite or chalcocite, but marginally these copper minerals become mingled with the surrounding greenstone as though the replacement had been less complete on the borders of the mass.

In one or two instances narrow fissures from one-half inch to 1½ inches wide were noted which extend downward from ore pockets and are themselves filled with copper sulphides, but in the majority of cases no such connection between pocket and veinlet is to be seen.

The most of the copper in the district is in the form of the sulphides, bornite, chalcocite, and chalcopyrite, but native copper also is known. A bowlder of the latter weighing several tons has been found in the gravels of Nugget Gulch, a tributary of the Kuskulana River, near the western end of the area; and on the upper Kotsina River several claims in which native copper occurs associated with other ores have been staked in the greenstone 4,000 or 5,000 feet below the contact with the limestone. Two of these, the Keystone and the Copper King claims, are described here.

Keystone claim.—Two short forks, both glacial streams, unite to form Kotsina River. The southern one of these drains two glaciers, and in a little narrow post-Glacial gorge just below the foot of the northernmost of these glaciers is the Keystone claim. Here in the wall of the canyon, in the greenstone, are some compact quartz stringers and lenses, varying in width from a mere line to 5 or 6 inches. They strike east and west and are approximately vertical.

Epidote is associated with the quartz, sometimes in equal amount, as a gangue mineral in the veins. Native copper occurs in the epidote and in the quartz, but is more abundant in later irregular crevices traversing both minerals of the gangue. A small amount of chalcocite is present also, and in one prominent example it fills a narrow fissure which intersects masses of both epidote and quartz and is evidently later than either.

Copper King claim.—This prospect is situated on the north side of the Kotsina Valley about one-fourth mile west of the Keystone claim and 700 or 800 feet above the river level. It consists of an altered belt of greenstone, in part amygdaloidal, extending several feet east from a well-defined north-south vertical crevice, along which there has probably been some movement. The greenstone within this altered zone has been rendered quartzose, the quartz occurring as stringers and as a filling of the amygdules. The septa between the latter are sometimes changed to granular epidote and chlorite.

Native copper occurs here and there in the mass in grains and flakes, sometimes intimately associated with chalcocite. The latter mineral occurs with the native copper and in minute crevices which seem to be later than the general alteration and silicification.

NORTHERN DISTRICT.

North of the volcanic pile of the Wrangell Mountains, in the valleys of the Copper, of the two forks of the Tanana River, called the Nabesna and the Chisana, and of the White River, native copper has been reported from time to time, and the reports have been substantiated by prospectors and others who have brought out nuggets of the metal.

GEOLOGY.

The geologic conditions under which the copper occurs in the northern district are different from those which prevail in the Chitina Basin. Although the Nicolai greenstone, which is the great copper reservoir for the southern field, is probably present, it does not play the important part that it does south of the mountains.

A great calcareous series, which is believed to be equivalent to the Chitistone limestone, is clearly recognized over a large area. It has been affected by complex structures in the northern as in the southern district, and after its deformation and erosion Mesozoic beds have been deposited unconformably upon its edges, and the still later lavas of Mount Wrangell have buried many of its outcrops. In these respects its history is similar to that of the equivalent beds to the south. The essential difference, however, is in its relation to the basic igneous rocks. Instead of being clearly deposited conformably upon the surfaces of earlier flows, it has been extensively cut by later intrusives, and the contacts with these diabases, which are altered in many cases to greenstones, seem to be the loci for the accumulation of native copper and other copper ores. One occurrence, of no economic importance, is known in an altered mass of diorite.

OCCURRENCES OF COPPER ORE.

The evidence at present available, although incomplete, is better than that upon which earlier judgments were based. It does not indicate that these northern occurrences have much commercial value. A brief description of some of them follows:

Monte Cristo Creek and California Gulch are respectively western and eastern tributaries of the Nabesna River, which they join within 3 or 4 miles of the foot of the glacier. A mass of altered diorite occurs in this region, and along the lines of fracture in this diorite there occur sporadically films and blotches of malachite, which is probably derived from a little chalcopyrite contained in the altered rock.

In the mountains just east of California Gulch fragments of low-grade copper ore, consisting essentially of pyrrhotite and copper pyrite, are found in the gulches. These are of such size as to indicate that the ore bodies from which they came must be at least 6 inches wide. The ore is of so low grade, however, assaying but six-tenths of 1 per cent, that the deposit is without value. This ore is supposed to be related to an intrusive contact between the greenstone and the limestone about the heads of the gullies in which the ore is found.

On Camp Creek, an eastern tributary of the Nabesna, about 15 miles below the glacier and about 3 miles above the mouth of Cooper Creek, Mr. Alfred B. Iles reports a vein of chalcocite from 6 inches to 2 feet in thickness. Both the limestone and the greenstone are present in this region, and it is probable that the ore occurs in association with them.

Natives living on the Chisana (Upper Tanana) in 1902 had in their possession a number of small copper nuggets, and one mass which weighs 35 to 40 pounds. These, they say, came from a small creek which flows into the Chisana from the west at a point about 5 or 6 miles above the foot of the glacier. Occasionally the nuggets have adhering to them fragments of amygdaloidal greenstone and of calcite gangue. It is likely that they occur in the usual way, in association with the contact of the diabase and the Permian limestone.

Prospectors, among whom may be mentioned Mr. D. K. Van Cleef, report the finding of numerous copper nuggets along the north base of the Nutzotin Mountains between the Upper White and the Chisana. Mr. Van Cleef reports also the probable existence of a sulphide vein in a canyon of the middle White.

Kletsan Creek, which drains the north base of Mount Natazhat, is a southern tributary of Upper White River. Native copper in placer form has been known in this region since Dr. Hayes[a] visited it in 1891, and it was probably a source of supply for the Indians long before that. Mr. Alfred H. Brooks[b] in 1899 reported one nugget 8 or 10 pounds in weight, and numerous other smaller pieces from this locality. In a search for the origin of the nuggets, Mr. Brooks found stringers of the native metal occurring in calcite veins in dioritic greenstones near the intrusive contact of the greenstone with Permian limestone. No other minerals except a superficial staining by malachite were observed. The character of the bed-rock geology and the finding of native copper in stream gravels led Mr. Brooks to infer that conditions similar to those at Kletsan Creek are likely to be found in the region between the Upper White and the Chisana.

From these meager descriptions it will be realized that the search for valuable deposits in the field north of the Wrangell and Skolai Mountains has not thus far revealed any large ore masses, but as the search has been by no means exhaustive it is entirely possible that deposits of practical importance may be found in the future.

[a] An expedition through the Yukon district: Nat. Geog Mag., Vol. IV, pp. 117-162.

[b] A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, p. 377 et. seq.

COPPER DEPOSITS OF BISBEE, ARIZ.

By F. L. RANSOME.

INTRODUCTION.

During the autumn and winter of 1902 a detailed geological investigation was made of the Bisbee quadrangle, embracing the greater part of the Mule Mountains, by F. L. Ransome, assisted by J. Morgan Clements and Alfred M. Rock. The geology of the quadrangle was mapped on a scale of approximately 1 mile to the inch, while an area of 8 square miles in the immediate vicinity of the principal mines was mapped geologically on a scale of 1,000 feet to the inch. The material gathered during the progress of the field work will shortly be embodied in a full report upon the geology and ore deposits of the district. In the meantime the following brief sketch includes only such salient results of the unfinished investigation as seem least likely to be modified by further study.

GEOGRAPHY.

The Warren mining district, in which occur the ore bodies that have given Bisbee its prominence, lies in the central part of the Mule Mountains, a generally northwest-southeast range, some 30 miles in length, extending from the old mining town of Tombstone down to the Mexican border. In the vicinity of Bisbee the range attains an elevation of 7,400 feet and has a width of about 12 miles; but in the neighborhood of Tombstone and near the international boundary line it is represented by clusters of comparatively low hills. On the southwest the Mule Mountains are separated by the broad valley of the San Pedro from the Huachuca Mountains, and on the northeast by the similar wide expanse of Sulphur Spring Valley from the Swisshelm and Chiricahua ranges. On the north a few low hills just southeast of Tombstone connect the Mule Mountains with the Dragoon Range. The town of Bisbee, with a population estimated at about 6,000, is crowded into a few narrow confluent ravines in the heart of the range. It is connected by the El Paso and Southwestern Railroad with El Paso, with Benson on the main line of the Southern Pacific Railway, and with Douglas and Naco on the international boundary.

GENERAL GEOLOGY.

The oldest rocks in the Mule Mountains are fine-grained sericite-schists, derived from ancient sediments. These were probably originally shales or arkose sandstones which were folded and metamorphosed into their present crystalline condition before Cambrian time. After long erosion these schists were reduced to a surface of very slight relief, which in Cambrian time was submerged beneath the sea and covered with the sands that are now represented by quartzite, from 400 to 500 feet in thickness. The submergence of the area continued, and about 750 feet of thin-bedded, cherty, fossiliferous Cambrian limestones accumulated on top of the quartzite. No record of Silurian time has been discovered in the Bisbee quadrangle. Overlying the Cambrian limestone, apparently in perfect conformity, are 340 feet of dark-colored, compact, rather thin-bedded limestones, with some intercalated shales, all carrying an abundant and characteristic Devonian fauna, consisting chiefly of brachiopods and corals.

The opening of Carboniferous time was, in this region, unmarked by any interruption of the continued subsidence. No unconformity has been detected between the Devonian and the Lower Carboniferous (Mississippian) rocks. The latter consist of white or light-gray granular limestones, often made up almost entirely of crinoid stems and containing a fairly abundant brachiopod and coral fauna. The thickness of the Lower Carboniferous limestone may be provisionally given as 700 feet. The beds are often 6 feet or more in thickness and commonly form cliffs overlooking slopes carved from the less resistant Devonian and Cambrian limestones.

There is in the Mule Mountains no discoverable stratigraphic break between the Lower and Upper Carboniferous beds. Subsidence apparently continued, and the generally thinner beds of Upper Carboniferous (Pennsylvanian) limestone accumulated to a thickness of over 3,000 feet above the Lower Carboniferous. The Upper Carboniferous limestones are usually more compact in texture than those of the Lower Carboniferous, and are more fossiliferous. They are also somewhat more variable in color, pinkish and yellowish beds being of frequent occurrence.

The local Paleozoic section from the pre-Cambrian schists very nearly to the top of the Lower Carboniferous is well exposed on the northeast face of the main ridge about 1½ miles west of Bisbee. The Upper Carboniferous beds are best seen in the hills just north of Naco Junction (5 miles southwest of Bisbee), and the relation between the lower and upper divisions is well shown near the Whitetail mine, about 2 miles due south of Bisbee.

At some time during the interval between the close of the Carboniferous and the opening of the Cretaceous the long-continued subsidence and sedimentation of the region were interrupted by extensive faulting, probably connected with uplift. Accompanying or immediately following the faulting came intrusions of granitic magma which solidified as granite, granite-porphyry, and rhyolite-porphyry. These intrusions took the form of dikes following fault fissures, of sills injected between sedimentary beds, and of irregular stock-like masses.

The dikes are well shown along the southwest face of the main ridge west of Bisbee. The larger intrusions are exemplified by the granitic mass of Juniper Flat, which is inclosed in schists, and of the smaller body of mineralized and altered porphyry forming Sacramento Hill, just southeast of Bisbee, and intrusive into schists and limestone. The latter mass is of particular significance from its connection with the principal copper deposits of the district. The intrusion of the porphyry was accompanied by little or no contact metamorphism even in the limestones.

After the intrusion of the granite-porphyry the region was eroded until the opening of Cretaceous time. It is probable that the principal mineralization of the district followed closely the eruption of the porphyry, and thus dates from early Mesozoic time.

At the beginning of the Cretaceous the region again began to subside, and a conglomerate was deposited by the advancing sea over the eroded surface of the pre-Cambrian and Paleozoic rocks, with their intruded masses of porphyry. In places this conglomerate was laid down to a uniform thickness of about 75 feet over an even surface, but elsewhere it is found filling hollows in a pre-Cretaceous hilly topography, and attains a local thickness of 500 feet. The pebbles are composed chiefly of schists, although those of limestone and granite-porphyry are not entirely absent. With the continued subsidence of the region about 1,800 feet of unfossiliferous sandstones and shales, with occasional lenses of sandy limestone, accumulated above the basal conglomerate. Conformably overlying these are about 650 feet of limestone beds containing abundant fossils belonging in the Comanche division of the Cretaceous. Most of these limestones, particularly the lower beds, are thin bedded and impure, but hard, gray, massive beds, aggregating some 40 feet in thickness, occur near the middle of the calcareous member of the local Cretaceous section, and form a cliff that is a conspicuous topographic feature of the hills north and east of Bisbee. The limestones are conformably overlain by more than 2,000 feet of sandstones and shales, much like those occurring in the lower part of the section. These upper arenaceous beds are the youngest stratified rocks exposed in the Bisbee quadrangle. As their upper surface is everywhere one of erosion, their original thickness is unknown. The foregoing Cretaceous strata were first described by Dumble, and by him called the "Bisbee beds."[a]

The Cretaceous beds of the Bisbee quadrangle have been deformed by folding and faulting. The folds are generally open, dips of more than 20° being rather exceptional. The general strike is northwest and southeast, and the prevailing dip northeast. About 7 miles southeast of Bisbee, however, where Paleozoic beds have been thrust by faulting over the Cretaceous, the latter have been turned up

[a] Trans. Am. Inst. Min. Eng., Vol. XXXI, 1902, pp. 703-706.

steeply and are in places nearly vertical. East of Bisbee the faults are normal, but southeast of Mule Pass Gulch faults of the reversed or overthrust type predominate. As Tertiary sediments are absent in the Bisbee region, this period was probably marked by the deformation of the Cretaceous and older rocks and by erosion.

The Pleistocene is represented by unconsolidated gravelly deposits flooring the broad valleys that surround the Mule Mountains on the west, south, and east. These are in the main fluviatile wash, with possibly some finer lacustrine beds at a distance from the mountains.

It is impossible without the aid of a geological map to do more than indicate very crudely the general distribution and structure of the rocks of the Bisbee quadrangle. A northwest-southeast diagonal drawn through the quadrangle will pass through the town of Bisbee and form a rough division between the Cretaceous beds on the northeast and the pre-Mesozoic rocks on the southwest. The former, although folded and faulted, exhibit simple structures and have a prevalent dip to the northeast, away from the older rocks. They undoubtedly once extended farther over the Paleozoic rocks to the southwest, but have been removed by Tertiary and Pleistocene erosion.

In contrast with the Cretaceous beds, the Paleozoic and pre-Cambrian rocks exhibit a highly complex structure, which, if we disregard the undecipherable pre-Cambrian deformation of the crystalline schists, is due to faulting, to intrusions of granite-porphyry, and to folding. In the northwestern part of the quadrangle the Paleozoic beds dip generally to the southwest, but they change near Bisbee to a southeasterly dip, which in turn swings round to a northeasterly dip a few miles southeast of the town. The pre-Cambrian schists, which are extensively exposed in the northern part of the district, pass gradually beneath the Paleozoic beds to the southwest, being less and less frequently exposed in the various fault blocks, and finally disappearing altogether toward Naco Junction.

DEVELOPMENT AND PRODUCTION.

Prior to the year 1880 Bisbee was an unimportant lead camp, a single furnace being then in operation upon cerussite mined from the Hendricks claim, close to town. The copper ore of the Copper Queen mine was discovered early in this year, and was profitably exploited until 1884. This ore was free from sulphur and had an average tenor of 23 per cent of copper. It was treated in two 36-inch furnaces, which, in spite of their small size were able, with wood as fuel, to turn out about half a million pounds a month. In 1882 the men composing the present Copper Queen Company bought the Atlanta claim near the original discovery and began prospecting.

In 1884 the Copper Queen ore body, which had been worked for 300 feet down an incline, was exhausted. The outlook was gloomy and work was almost abandoned, when a second ore body was simultaneously discovered from the original Copper Queen incline and from the Atlanta workings. In order to avoid legal complications the two companies combined as the Copper Queen Consolidated Mining Company, which gradually absorbed the neighboring properties by purchase. In 1886 the old smelting plant became inadequate and was rebuilt. Greater economy was necessary, as the average tenor of the ore had fallen to about 8 per cent and the price of copper had notably declined.

Shortly after 1890 the completely oxidized ores showed signs of failing, but in 1893 the works were remodeled by the introduction of converters, and sulphide and oxide ores have since that time been successfully worked together by the matte process. The introduction of these converters was due to Dr. James Douglas, and marked the beginning of a new epoch in the smelting of copper ores in Arizona.

Up to the end of 1902 practically all of the copper from Bisbee was the product of the connected group of mines owned by the Copper Queen Company. Recently, however, extensive ore bodies have been opened up in the Calumet and Arizona mine, and in the latter part of December, 1902, this company was turning out from 30 to 40 tons of copper a day from its new smelter at Douglas.

This town, situated in the middle of Sulphur Spring Valley, on the international boundary, has sprung up with remarkable rapidity during the last year. Its growth is due to the erection here of the new smelters for the Copper Queen and the Calumet and Arizona companies, and to the fact that it is the junction point of the newly completed El Paso and Southwestern Railroad with the Nacosari Railroad into Mexico. It will undoubtedly become an important smelting point, not only for the Bisbee ores but for those from Mexico.

From August, 1880, to the end of 1902 the total output of the Copper Queen Company was over 378,000,000 pounds of copper. The production of all the other mines within this period was probably something less than 2,000,000 pounds, so that the total production of the district may be given, in round numbers, as 380,000,000 pounds of copper. The maximum output was in 1901, when the Copper Queen mines produced 39,781,333 pounds of copper.

THE ORES.

General occurrence of the ores.—The principal bodies of copper ore lie south of the town of Bisbee, within a radius of a mile. They occur in Carboniferous limestone, on the southwest side of a great fault, and closely associated with an intrusive mass of granite-porphyry. In the absence of the geological map and sections the structural relations may perhaps be most clearly presented by a homely illustration. If half of a broken saucer be placed on a table with the fractured edge lying about west-northwest, and if the back of a book be laid against this edge, we shall have a rough illustration of the geological structure near the town of Bisbee. The saucer represents the synclinal attitude of the Paleozoic beds from the Upper Carboniferous limestone down to and including the Cambrian quartzite. The broken edge of the saucer is the great fault, while the book is pre-Cambrian schist, against which Upper Carboniferous limestone has been dropped by this fault with a throw of more than 1,500 feet.

The town of Bisbee lies on the fault line. The hills northeast of town are composed of pre-Cambrian schists; those just south of it are Upper Carboniferous limestone, with Lower Carboniferous, Devonian, and Cambrian beds coming successively to the surface along the fault to the northwest.

A little less than half a mile southeast of the center of town the fault encounters a mass of altered granite-porphyry and as a simple fracture disappears. This porphyry, which forms Sacramento Hill, a well-known local landmark, is a very irregular mass about a mile in diameter. It has invaded the pre-Cambrian schists on the northeast and the Upper Carboniferous (probably also the deeper-lying, older Paleozoic beds) on the southwest. The available evidence indicates that the intrusion of this porphyry took place after the dislocation of the invaded rocks by the great fault. The latter probably continues to the southeast of the porphyry mass, but it is concealed in this direction by the younger Cretaceous beds. The Paleozoic beds forming the faulted syncline are not merely flexed, but are cut by many faults, some of them of considerable throw. These faults are, as far as seen, of the normal type.

The ore occurs very irregularly as large masses within the limestone. The horizontal extent of these bodies is usually much greater than the vertical. They are rudely tabular in form and lie generally parallel to the bedding planes of the limestone. As a rule the important ore bodies have been found within a distance of 1,000 feet of the main porphyry mass or of the great fault fissure just northwest of the porphyry. In the Czar workings of the Copper Queen mine, partly under the town of Bisbee, ore bodies have been worked from the surface down to a depth of about 400 feet, but toward the southeast the bulk of the ore occurs at increasing depths. In the Calumet and Arizona mine, about 3,500 feet south of the Czar, no large ore bodies were encountered until the shaft had penetrated about 800 feet below the level at which the first ore body was discovered on the Copper Queen claim. The ore thus occurs at increasing depths toward the center of the local synclinal basin. Detailed structure sections will probably show, however, that the upper limit of the ore increases in depth somewhat less rapidly than would be the case did it correspond to a definite stratigraphic horizon.

With the exception of the extreme western part of the Copper Queen mine, all of the productive and important workings in the vicinity of

Bisbee are in the Carboniferous limestones. It is probable that the greater number of the ore bodies occur in the granular limestones of the Lower Carboniferous, but the distinction between Upper and Lower Carboniferous beds can rarely be satisfactorily made underground. Some important ore bodies certainly occur in the lower part of the Upper Carboniferous. On the other hand, no ore bodies of consequence have yet been found in the deeper-lying Devonian and Cambrian limestones. In the Copper Queen mine local usage has distinguished an "upper lime" and a "lower lime." As far as could be seen, however, this distinction is largely imaginary and is based on no constant lithological or structural features. The "lower lime" appears to be any limestone lying underneath the known ore bodies. It is in the main Lower Carboniferous, and the ore-bearing possibility of the underlying and Devonian and Cambrian beds is yet to be ascertained by deeper prospecting.

Although the ore masses in general are what are generally termed "flat" ore bodies, dipping gently with the inclosing beds, they are related to other structures as well as bedding planes. Ore is usually found in large masses along the contact of the limestones with the main porphyry mass. This contact, however, has not been thoroughly explored, and much of the ore along it consists largely of low-grade, partly oxidized pyrite. Dikes and sills of porphyry occur in the limestones at various distances from the main intrusive mass, and these are almost invariably associated with ore in the adjacent limestone. In some cases large ore bodies, followed for a long distance in the general plane of the bedding, have been known to turn down almost vertically alongside a porphyry dike. Fissures in the limestones have also undoubtedly influenced the distribution of the ore.

While the main porphyry mass of Sacramento Hill is often heavily impregnated with pyrite, it has not been shown to contain workable ore bodies. It is possible that one or more of the oxidized ore bodies in the Copper Queen mine were formed by the mineralization of the granite-porphyry, but this is a point which the present investigation has not yet determined. It is certain that many of the porphyry dikes encountered in the workings of the Copper Queen mines show no appreciable mineralization, even when in contact with ore.

Mineralogical character of the ores.—The ores worked by the Copper Queen Company up to 1893 were oxidized ores, consisting chiefly of malachite, azurite, cuprite, and native copper. In the upper levels the malachite and azurite occurred in beautiful incrustations and stalactites, lining caves in the limestones. These "cave ores" have been exhausted, and although oxidized ore is still abundant it occurs generally as soft earthy masses, often containing cuprite and native copper, and usually associated with large amounts of limonite and kaolin. Native copper and crystalline cuprite are still abundant in the recently opened workings of the Calumet and Arizona mine.

The original sulphide ores from which the oxidized ores have been derived consist of pyrite containing variable amounts of chalcopyrite. These pyritic ores are sometimes directly in contact with oxidized ores, but it is not uncommon to find masses of chalcocite between the two. Bornite has been reported from some of the ore bodies, but arsenical or antimonial compounds are absent, so far as known.

Origin of the ores.—That the original ore deposition was genetically connected with the intrusion of the granite-porphyry is reasonably certain. The present incompleted investigation, however, has not yet established the details of this connection. As a whole, the ore bodies may be classed as typical replacement deposits in limestone.

The ore bodies that have thus far proved workable have resulted from the operation of later processes of concentration acting upon the original pyritic ores. The occurrence of the chalcocite is closely related to the general progress of oxidation, and this mineral has plainly been formed by the action of descending solutions upon lean pyritic ores. It is probable that at least a part of the chalcopyrite is ascribable to the operation of the same agency. There is an observed connection between good ore and permeability to downward-moving solutions. Such pyritic ore as proves profitable is soft and crumbling, and usually shows upon close examination interstitial sooty material that is probably amorphous chalcocite.

The lower limit of oxidation of the ores is very irregular, and is apparently uncontrolled by any constant groundwater level. In the Calumet and Arizona mine oxidized ore occurs at a depth of a thousand feet, while residual masses of sulphide ore occur in the adjoining Copper Queen mines within 150 feet of the surface. Masses of lean pyrite are sometimes inclosed in an envelope of high-grade chalcocite and oxidized ores.

FUTURE OF THE DISTRICT.

Although more or less mineralization occurs at many points in the Mule Mountains, there is little to indicate that any deposits of copper ore will ever be found to approach in importance those already known and awaiting discovery in the faulted limestone syncline about Sacramento Hill. For over twenty years the Copper Queen mine has produced an average of more than 16,000,000 pounds of copper annually. Recently the Calumet and Arizona Company has begun energetic operations in ground almost surrounded by the property of the Copper Queen. Not only is there sufficient known ore in these mines to keep them in operation for many years to come, but there is no evidence that the bottom of the ore-bearing ground has been reached in any of these extensive workings. Moreover, the statement may be ventured that the specter of the "lower lime" has hitherto had an undue influence in restricting prospecting to horizontal planes. There is certainly a reasonable hope of finding ore bodies in the Devonian and

Cambrian limestones beneath the masses that have been so profitably worked in the overlying Carboniferous beds.

But more than this, it may be pointed out that less than half of the semicircular mineralized zone about the porphyry mass of Sacramento Hill has been explored at all. Ore was first discovered at the surface on Queen Hill, at the northwest end of the zone. From this discovery developments have been pushed by underground exploration, often with little or no surface showing, to the south. There still remains, however, an extensive area of unknown but promising ground, lying just south of Sacramento Hill and extending eastward toward the southeastern continuation of the great fault, which is here concealed by the basal conglomerate of the Cretaceous series. This is the eastern half of the semicircular mineralized girdle about the intrusive mass of porphyry. Its exploration calls for no greater outlay or boldness than is already displayed in other parts of the district with less assured hope of reward.

In conclusion, it may be said that Bisbee is less likely to suffer from a lack of ore than from too rapid exhaustion of the high-grade oxidized ores which are necessary for the economic smelting by present processes of low-grade sulphides.

MINERAL RESOURCES OF THE ENCAMPMENT COPPER REGION, WYOMING.

By ARTHUR C. SPENCER.

INTRODUCTION.

The town of Encampment is situated 43 miles by wagon road south of Wolcott station on the Union Pacific Railroad, in Carbon County, Wyo., in the foothills of the Park Range, which constitutes the continental divide and is locally known as the Sierra Madre.

The Encampment Special quadrangle occupies the area between latitudes 41° and 41° 15′ north and longitudes 106° 15′ and 107° 15′ west, and includes the town of Encampment in its northeast corner. The greater portion of the area, which has an extent of about 450 square miles, lies within the State of Wyoming, but a narrow strip of Colorado is included upon the south.

In a more extended report now in preparation a statement of the several classes of ore deposits observed will be given, together with a general discussion of the conditions of ore deposition in the region.

GENERAL GEOLOGY.

The geology of the Encampment region, when studied in detail, is found to be very intricate, but the more general features can nevertheless be readily outlined and as readily perceived upon the ground.

Among the most prominent features presented by the region are certain bands of white quartzite, which the visitor first notes a few miles southwest of the town of Encampment on the road to Battle. The bands or reefs of quartzite, which cross the country in a nearly east-west direction, are separated from one another sometimes by bands of conglomerate, slate, and limestone, and in other cases by dikes of dark diorite. All of these formations have a general dip toward the south, and frequently stand at steep angles. Taken together, they occupied a narrow wedge-shaped area, extending for a distance of about 20 miles westward from its point or apex below the mouth of Purgatory Gulch on the Encampment River, a few miles south of Encampment town site. The widest part of the quartzite area is upon the west, where it becomes covered by surface formations in the drainage of Big Sandstone Creek and of Savery River. With the exception of the diorite, all the rocks mentioned are of sedimentary origin, having been originally deposited as horizontal beds or strata, and afterwards thrown into east-west folds by comprehensive forces acting in a north-south direction.

The diorites are igneous rocks which were intruded into the sedimentary series in a molten state after the greater part of the folding and compression had taken place. They occur in dikes from a few feet up to half a mile in width, frequently extending along the strike for several miles. They are of almost universal occurrence throughout the quartzite belt, and are also found cutting the granites, gneisses, and schists which occur both to the north and to the south of the quartzite area.

The schists of the region are mostly hornblende-schists, which may be seen in typical development upon the north slopes of the continental divide in the heads of Jack Creek and North Spring Creek, and also in the region of Huston Park. The other rocks of the mineral belt may be classed under the general names of granite and granite-gneiss, and all of these appear to have been formed since the hornblende-schists, though they are probably older than quartzites and associated formations. The formations represented in the Sierra Madre are of pre-Cambrian age and belong to the most ancient series known within the Rocky Mountain province. In general, the formations are well exposed and easily accessible for examination, though locally they are covered by overwash or by glacial débris.

The topography of the region is more than ordinarily smooth for a mountainous country reaching elevations above 10,000 feet, a fact which allows the building of wagon roads to almost any desired locality at comparatively slight expense.

ECONOMIC GEOLOGY.

The ore deposits of the Encampment region have not, as a rule, been developed to a sufficient depth to afford opportunity for an exhaustive study. Hence, while those of the few mines in the district which have been opened to a considerable depth have been carefully studied, the information obtained with regard to the occurrence of economic deposits as a whole is largely based upon general geological relations ascertained from surface examinations.

Ores.—Copper is the predominant metal of value in the ores of the district, though there are a few deposits carrying values in silver, and gold occurs alone in quartz veins, or in variable but always small amounts accompanying the copper ores. The ores of copper comprise the sulphides, chalcopyrite, chalcocite, bornite, and covellite and their usual alteration products, malachite, azurite, chrysocolla, and the oxides. The silver-bearing ores are argentiferous galena, occurring with sphalerite and pyrite in fissures with a gangue of quartz, together with calcite, or the carbonate of iron, siderite.

The copper deposits.—Considered in the most general way, the deposits of copper in the region fall into two classes. The first class includes all where the mineral is chalcopyrite or copper-bearing pyrite unaccompanied by oxides, carbonates of copper, or rich sulphides, except very superficially where the former minerals have been oxidized by surface weathering. Deposits of this sort, which occur invariably inclosed in undecomposed or "live" rock, are regarded as original ores. Their distribution is almost universal, and they are found in all sorts of rocks, frequently without any recognizable vein material, but sometimes accompanying masses of quartz with a small amount of feldspar, calcite, or siderite (carbonate of iron). In those cases where little vein matter is present the ore occurs, as a rule, in pockets or lenticular masses following the schistose or platy structure of the country rock, and more or less mixed with the inclosing material. No instances were observed where bodies of this character gave promise of sufficient size or permanence to warrant the expectation that they will lead to important masses of ore.

As an exception to deposits of the above type where there is no well-defined lead traceable for any considerable distance upon the surface, there are others, still without associated quartz, occurring in strong leads traceable for long distances upon the surface. A typical example of this variety of deposit is the Verde or Hinton property. The Verde lead is a zone along which intense metamorphism has taken place, involving hornblende-schists, a band of limestone, and some thin strata of quartzite. The lead seems to follow the limestone, which in turn appears to lie parallel to the general schistosity of the region. There is every reason to anticipate that metamorphic zones of this kind will persist in depth, though the extent to which copper has been deposited in them must be proved by exploration.

In a third type of original ores the copper pyrites occur in a matrix of quartz accompanied by calcite and siderite or by feldspar. The sulphide here occurs in bunches throughout the mass of the gangue, and the value of such veins is dependent upon their persistence. Some veins of this nature are lenticular bodies lying with their longest surface dimensions parallel with the platy structure of the inclosing rock. Certain of such masses of quartz reach a width of 50 feet or more, showing in outcrop a length of from twice to several times this figure, but these seldom show any considerable amount of copper, though they are reported to carry a small amount of gold. They can hardly prove to be permanent in depth. In other cases the quartz occurs in a disconnected series of thinner lenses, extending along the same general trend in the schistose rocks. Sometimes these interrupted veins carry chalcopyrite in promising amounts. Their probable downward extent and regularity may be closely ascertained by a study of their persistence along their strike. If they are irregular and interrupted upon the surface, they are likely to be discontinuous in depth, but where strong and persistent in outcrop they may be expected to continue in depth. This type includes such deposits as the Continental in Cow Creek, the Cascade, and the Kurtz-Chatterton, in each of which it is anticipated that active development in progress should settle the question of permanence and extent of mineralization.

In the ores of the two properties last named there has been some secondary deposition of ore, but the sulphides are regarded as mainly primary.

The second class of copper deposits includes all those where the principal copper minerals are rich sulphides, such as chalcocite or copper glance, covellite, and bornite, with or without high-grade copper pyrites. In the surface portion of such deposits large amounts of oxide and carbonate ore are found, and they are commonly capped at the outcrop with strong gossan. Also the inclosing country rock is often to a greater or less extent decomposed.

Ores of this character are regarded as due to secondary concentration or enrichment of ore bodies originally of low grade, through processes similar to those which have produced bonanza deposits in many other copper camps.

The secondary deposits of the Encampment district have been thus far the only ones supporting productive mines. The ores of the Charter Oak, Doane-Rambler, and Ferris-Haggarty mines are of this nature. At the Charter Oak, where the country rock is granite and diorite, the deposit appears to have been extremely irregular, but in the other mines mentioned the deposits show considerable regularity in their occurrence. The ore bodies, inclosed in quartzite of sedimentary origin, occur in zones of shattered rock which follow the bedding of the quartzite. Courses of easy circulation for underground water have been afforded by local shattering of the rock, which doubtless determined the position of original deposition, and later allowed of concentration to the form in which the ores are now found.

In both the Doane-Rambler and the Ferris-Haggarty the secondary ores have been opened to a depth of more than 300 feet, though in neither instance has the lowest level of the workings penetrated more than a short distance below the beds of the gulches adjacent.

The question of the permanence in depth of these rich secondary ores need not be discussed here, since it is a subject which will soon be settled in a practical way by the developments now in progress. Thus far there seems to be no sufficient reason for supposing that the bottom of the zone of enrichment has been closely approached in either mine.

From the present study of the region it appears that the future of the district must depend very largely upon the discovery of additional deposits of the secondary class or type. That such deposits exist it seems fair to anticipate, but the best method for their discovery must be based upon a recognition of their character as distinct from the primary ores.

Secondary ores will not be found where the inclosing rocks are tight and impervious to the circulation of atmospheric waters. They require loose formations due to brecciation or crushing of the country rock, as in the cases mentioned, and in some cases it is to be expected that the country rock will be greatly decomposed. Several locations were noted by the writer where gossan was present in encouraging amount, but where no adequate work had been done to prove the condition of the inclosing country rock or the significance of the gossan. Other properties show the presence of rich sulphides in crushed and decomposed diorite, and it is believed that these are worthy of careful investigation.

RECONNAISSANCE EXAMINATION OF THE COPPER DEPOSITS AT PEARL, COLO.

By Arthur C. Spencer.

DESCRIPTION OF THE REGION.

Pearl, Colo., has been a post-office for several years, but only within the last three years has it become known as a mining camp. It is located in Larimer County, near the northern boundary of Colorado, about 20 miles southeast of Encampment, Wyo., and an equal distance south of the New Rambler copper mine.

The area contiguous to Pearl over which active prospecting has been carried on for the last three years is drained by a tributary of the North Platte River, now known as Big Creek, but represented on the maps of the Fortieth Parallel Survey as Grange Creek. The region is mountainous, lying as it does in the heart of the Sierra Madre, or northern end of the Park Range, which forms the westernmost of the three elevated zones which compose the Rocky Mountains in this latitude. The crest of the Sierra Madre, from 10 to 25 miles south and west of Pearl, forms the continental divide separating the waters of Big Creek from the head of Elk River, which flows to the Yampa and thus to the Green River.

Eastward from Pearl there is an easy line of travel to North Park, and toward the west the old Government road leading from Laramie to Hahns Peak gives a route to the head of Encampment River.

The town itself is picturesquely situated in a broad basin near the junction of several wide valleys, which give access to all parts of the adjacent mountains. The elevation of this basin is about 8,000 feet, but within a distance of 10 miles there are mountains which rise to an altitude of from 10,000 to 12,000 feet.

The surrounding slopes are covered by a dense growth of pine and spruce, while the valley bottoms, which were originally covered by a luxuriant growth of wild grass, are now devoted to the cultivation of timothy and other grasses for hay.

GENERAL GEOLOGY.

The geology of the region is similar to that of a portion of the Encampment district, though the pre-Cambrian quartzite, which is a noticeable and important feature of that district, is not found. The country rock over large areas is a generally coarse though variable granite of a red or gray color, frequently cut by small dikes of pegmatite. Minor areas are covered by diorite of a variable character. Though usually massive, as observed in limited outcrops, both the granite and the diorite, when considered in a broad way, show banded structures, due to a more or less evident parallel arrangement of the constituent minerals, and to the separation of light and dark minerals into narrow plates. These variations are most noticeable in areas where the granite preponderates, and in this rock the variations range from light-colored siliceous phases to very dark-colored basic types containing a large amount of mica and hornblende. Certain of the dark bands intimately connected with the granite can be distinguished only with difficulty from the diorites which occur in larger independent masses. The structure of these massive diorites is typically gneissic, and outcrops which are not banded are rarely observed.

DEVELOPMENTS.

Nine prospects showing the presence of copper minerals in encouraging quantities were visited. These have been developed by from 50 to 200 feet of workings. Two days were devoted to a rapid examination of the phenomena presented, and these observations form a basis for the notes which follow.

In every case where limonite or iron oxide was found at the surface this material has proved to be only a shallow capping; and the zone carrying oxides and carbonates of copper beneath it, when present at all, has been unimportant. In no instance did any property visited fail to show unaltered pyrite and chalcopyrite at a moderate depth from the surface, but there are as yet no thoroughly developed deposits, though on every hand intelligent efforts were being made to prove the value of the various discoveries.

Big Creek shaft.—The property of the Big Creek Mining Company lies northwest of Pearl at a distance of about 2½ miles. The general character of the country rock in the vicinity is granite-gneiss, but there are frequent bands of diorite which vary from gray to almost black, with changing proportions of hornblende and feldspar. The granite normally contains mica, but locally this mineral disappears and certain fine granular streaks in the granite have the appearance of being quartzite, though in fact they are made up of quartz and feldspar. The country rock at the shaft is a granite-gneiss which contains more than the usual amount of mica. The workings were filled with water and therefore not accessible, but from the direction of the shaft the course of the vein seems to be about N. 60° W. The vein is said to stand nearly vertical for a distance of 100 feet from the surface, and then to dip about 70° S. to the bottom of the shaft, which is 145 feet deep. From the material found on the dump the ore is seen to be chalcopyrite occurring with ferruginous zinc blende in a segregation vein composed mostly of hornblende, but carrying a small amount of calcite. The country rock is very platy or schistose, but the vein material seems to be massive. The relations of the sulphides to the hornblende and calcite show that they are contemporaneous minerals. Unfortunately the vein does not afford a visible outcrop, so that its relations to the country rock can not be studied in detail.

Sierra Madre shaft.—This property is located near the State line and about 1½ miles north of Pearl. A mineralized zone about 7 feet in width, having a course N. 60° E., occurs in dark micaceous gneiss. This zone, which is parallel to the structure of the gneiss, may be divided into two portions, one of which is made up of entirely massive hornblende, free from banding and carrying pyrite, chalcopyrite, and zinc blende, with a small amount of galena; the other portion is a light-colored banded rock resembling the sugary granite mentioned as occurring near the Big Creek shaft. This portion of the vein carries zinc blende and a small amount of pyrite, in bands parallel with the course of the mineralized zone. The hornblende vein presents no sharp walls against the inclosing gneiss or against the siliceous portion of the mineralized zone, and it seems to have been formed by segregation accompanying the general metamorphism which produced the banding of the country rocks.

The zinc blende occurring in the siliceous gneiss possibly replaces the dark-colored minerals which it originally contained, and was probably introduced at the time the hornblende vein was formed.

Lizzie and Tully claims.—These are contiguous properties lying less than half a mile north of Pearl. In this region there are rapid alternations of granite and diorite in many varieties. The mineralized zones seem to conform to the structure of the gneiss, which has a course about N. 50° E. The two shafts appear to be located upon different zones, and still other zones are present upon the claims. In both shafts bornite and chalcocite have been found, but these minerals are confined to the upper portions of the workings.

Swede or Hawkeye group.—These claims lie about 2 miles southeast of the town. In general the occurrence of the ores seems to be similar to that in the Big Creek and Sierra Madre claims. Granite is the usual country rock, but bands of diorite are also present, and the immediate walls of the ore-bearing material are of an intermediate type of rock. At the Copper Crown shaft, which is the principal opening, the course of the vein is N. 10° W. The vein matter is considerably weathered, but consists of pyrite, chalcopyrite, and zinc blende, occurring in a gangue of calcite and serpentine. Occasional specimens show that the serpentine has been derived from the alteration of hornblende or pyroxene, which indicates that the deposit is of the same nature as the Sierra Madre.

Wolverine claims.—This property, owned by the Cold Water Mining Company, is located about $2\frac{1}{2}$ miles south of Pearl. The country rock is extremely variable, showing all gradations from black diorite to pink granite, and the granites are in part hornblende-granites related to the diorites. The ore in the discovery shaft is chalcocite containing disseminated specks of chalcopyrite and zinc blende. This ore is of a very friable nature, and on exposure crumbles to a sand. An examination of the material thrown out and of the neighboring outcrops shows that the ore has resulted from the replacement of biotite in a rock originally composed of quartz, biotite, and garnet. Of these three minerals the quartz alone remains in the form of a granular gangue surrounded by the sulphides of copper. The extent of this ore and the shape of the ore body have not been ascertained, but surface outcrops are sufficient to show that the mass of the rock in which it occurs is rather limited, having the shape of a wedge which disappears toward the southeast.

The shaft where the work is now being done is situated a few feet north of the point of the wedge of granite, and through its top there passes a vein having a course N. 40° W. This shaft is in pink granite, but diorite is present on both sides. The general trend of the banded structure is N. 80° E. The various rocks near the mouth of the shaft are cut in an intricate manner by small dikes of pegmatite, and certain coarse phases of granite in the vicinity contain red oxide of iron, which has been derived probably from magnetite. Some good specimens of chalcopyrite have been taken from the shaft, but no regular deposit of the mineral has been proved thus far.

Mount Zirkel shaft.—The shaft on the property of the Mount Zirkel Company is located about 2,500 feet northeast of the Wolverine shaft, and while the general nature of the country rock is identical, the ore here occurs in a different manner, namely, in granite pegmatite and in a broken or brecciated gneiss adjacent.

The shaft has been sunk to a depth of 185 feet, and drifts started at 71 and 155 feet. The pegmatite is extremely coarse grained, and is composed of quartz and cream-colored feldspar, with occasional flakes of mica. This material has been fractured and chalcopyrite has been deposited in the openings thus formed, sometimes as a filling of brecciated bands, and at other times occurring along cracks which pass from the feldspar into the quartz. As shown in the workings, the pegmatite has a course approximately N. 80° E. For the first 35 feet there is a dip of 70° S., then for 90 feet the vein stands nearly vertical, and below 125 feet it dips perhaps 75° N. The pegmatite is inclosed in a much broken gneiss of variable composition. On the north side of the vein diorite and granite seem to be intricately mixed, and here local pockets of chalcopyrite are found in the 155-foot level, and also in the discovery shaft at the surface, where there is a well-defined streak of iron oxide stained with green copper mineral, evidently due to surface weathering of sulphide ores. The ores in the pegmatite are not accompanied by any contemporaneous quartz, but this mineral is present in small amount in the ores which occur in the country rock. The occurrence of ore, both in the pegmatite and in the inclosing rock, is very irregular, and seems to depend upon the fracturing which the rocks have undergone. There are two systems of joints, which, taken together with the gneissic structure, and with frequent rifts of low inclination, result in the production of angular blocks, by which the size and form of ore masses are often limited. The ore occurs, in some instances, as a probable replacement of country rock, and in other cases as a deposit between adjacent blocks. The relations observed tend to show that the ores have been introduced in a manner independent of the formation of the pegmatite and subsequent to it.

Gold King claims.—The workings of this property are located between 3,000 and 4,000 feet east of the Mount Zirkel shaft. The shallow openings which were visited seemed to have been located on carbonate stains occuring along a sheared zone in red granite. The heaviest stains amount almost to impregnation, and these occur at the intersection of closely spaced joints. In the granite near by there are certain bands which are very coarsely crystallized, and which carry red oxide of iron, probably derived from magnetite. Besides the large amount of granite there are also outcrops of diorite near the workings.

Round Top, Copper Queen, and Big Horn.—These claims are located in close proximity to one another, and distant about 3 miles from Pearl in a southerly direction. The surface openings which constitute the development of the Round Top property show the presence of yellow sulphides and of zinc blende in a siliceous vein-like segregation following the banding of the gneiss, which forms the country rock. It seems probable that the sulphides have been introduced in the form of replacements of hornblende grains in the streaks in which they occur.

On the Copper Queen claim, about 400 feet southeast of the last, the developments consist of a shaft about 30 feet in depth. The materials thrown out show the presence of a mass of hornblende rock in the form of a vein-like segregation in diorite-gneiss, which forms the country rock. Upon the immediate walls of the vein the diorite looks like hornblende-schist, but the microscope shows that its platy structure is due to recrystallization and not to crushing. It is therefore concluded that the vein matter and wall rock are of the same age and origin. The vein matter is entirely granular and massive, in which respect it corresponds with other occurrences that have been mentioned. Along with the hornblende there is some quartz, and this mineral is largely confined to coarse portions of the vein, where calcite is also found. The metallic minerals are chalcopyrite, iron-bearing zinc blende or black jack, and pyrrhotite. The latter mineral was tested for nickel and cobalt, neither of which was found to be present.

The Big Horn shaft is located about 600 feet from the Copper Queen opening, in a direction S. 20° E. The country rocks are a schistose diorite, which breaks up into pencils or rod-like pieces instead of platy fragments and ordinary schist. The pencil structure is produced by cleavage in two directions—N. 80° E. and N. 10° W.—the former being somewhat the more prominent. A nearly horizontal rifting is noticeable both in the surface outcrops and in the mine workings. At the 65-foot level a drift 25 feet in length, running toward the southeast, shows a vein of hornblende gangue, carrying chalcopyrite in varying amounts.

The width of the vein varies from 18 to 36 inches, but it is not continuous toward the northwest, and it appears to be a lenticular segregation conformable to the structure of the country rock, which strikes N. 80° W. at the end of the drift, with a nearly vertical dip. The vein matter sometimes incloses fragments of the country rock, and while the ore occurs largely intercrystallized with the hornblende, it also impregnates the country rock to a distance of 2 or 3 feet. At the bottom of the shaft a mass of quartz occurs, about 30 inches across, which appears to cross the trend of the country rock. The formation of this quartz is probably distinct from that of the hornblende, since the latter contains little or no quartz.

Grand Republic.—This property is located about 3 miles southeast of the Big Horn. Here the country rock is made up of alternating zones of granite and diorite, each of varying composition. The location seems to have been made on a 3-foot vein of vitreous quartz carrying some fresh chalcopyrite. This vein follows the direction of the bands in the gneiss, or about N. 30° E, and dips 20° SW. A short distance east of the vein there is a metamorphosed zone in the diorite, in which a great deal of massive epidote has been developed. Though in a very different rock, this zone recalls the metamorphosed volcanic rocks occurring at the Verde mine in the Encampment region.

The variations in the country rock at this place are extreme. Certain light-colored bands are so siliceous that upon first sight they have the appearance of quartzites, while other bands of diorite are nearly black and contain only a very small amount of light-colored minerals. Between these two extremes all intermediate types occur.

The development shaft, which has been sunk to a depth of 80 feet, penetrates a band of black hornblende rock, but though the quartz vein which has been mentioned dips toward the shaft, it has not yet been encountered. A small amount of chalcopyrite was found in the shaft in a massive segregation of hornblende, and a specimen taken at the bottom shows a small lens of glassy quartz surrounded by dark-green hornblende, with chalcopyrite disseminated throughout the latter, together with a small amount of zinc blende, revealed by the microscope.

Other prospects.—At the time the region was visited many other prospects, apparently similar in character to those mentioned, had been located, and upon some of them about the same amount of development had been done. The ores of copper encountered were in most cases chalcopyrite, as in the properties described, though in one case large masses of richer sulphides, said to have come from an open cut about 12 feet in depth, were seen.

PROBABLE VALUE OF REGION.

The rapid examination of a few properties in the vicinty of Pearl made by the writer can not with fairness be made the basis of any opinion, favorable or otherwise, concerning the probable future of the mining industry of the region. All the properties visited are in the development stage, but the work in progress should soon determine in a practical way the important questions whether any of the ore bodies are of sufficient size and permanence to afford commercially important deposits.

ORE DEPOSITS AT BUTTE, MONT.

By Walter Harvey Weed.

INTRODUCTION.

The geology of the Butte district and its ore deposits formed the subject of a report published by the Geological Survey as a geologic folio in 1897.[a] Subsequent development in the copper mines of the district, partly as a result of the greatly increased output of the properties, but mainly because of the very large amount of work done to prove structural conditions, ore connections, and other evidence for use in the many lawsuits begun since 1896, has afforded opportunity to greatly extend the earlier work and to modify conclusions based upon the earlier incomplete data. A reexamination of the district, with a special study of the copper deposits, was therefore begun in 1901. Owing to the necessity of completing other work for publication, and to the intricate nature of the study, involving a close and detailed examination of over a hundred miles of underground workings, the field work was not completed until the autumn of 1902. The later workings show that the structural conditions are far more complex than was formerly supposed. The original veins are displaced by great faults, and these later fractures are themselves mineralized and again displaced. The working out of this structure has been difficult because the deposits occur in a body of very homogeneous granite, the rock alone affording no clue to the amount or direction of displacement. Nevertheless, the correlation of displaced areas is fairly satisfactory, based as it is upon a study of the quartz-porphyry and aplite intrusions in the granite and of the structural and mineralogic variations of individual veins.

SITUATION OF THE DISTRICT.

The Butte district is situated in southwestern Montana, in the central part of the Rocky Mountain region. The city which is built about and over the mines is the largest settlement of the State, while the neighboring city of Anaconda, 20 miles distant, is a dependent,

[a] Geologic Atlas U. S., folio 38, Butte Special, Mont., 1897.

having been built for and supported by the reduction of the Butte ores. Smelting the Butte ores is also the largest industry of the city of Great Falls. Three transcontinental railways run to Butte, and its traffic surpasses that of all the other cities of the State combined.

Originally named Summit Valley district, a name which is still retained in official records, and which is significant of its situation almost upon the transcontinental divide, where the waters of the Pacific and Atlantic separate, it is now universally known as Butte, a name derived from a sharply conical hill that rises abruptly above the barren hillside on the edge of the city and forms a prominent landmark. The area comprising the district is a now barren hillside on the northern side of a flat valley bottom. This level valley is inclosed by an abrupt mountain range forming the continental divide on the east and the snow-capped peaks of the Highland Mountains on the south. To the westward a low plateau, now cut through by Silver Bow Creek, separates this valley from the great lake-bed area of the Deer Lodge Valley.

DEVELOPMENT OF THE REGION.

The Butte district of Montana is to-day the most important copper-producing area in the world, the product aggregating 2,841,791,572 pounds to the close of 1901, with a total value of $381,209,650. The discovery of the copper veins of Butte was not made until after the district had acquired some prominence for its gold placers, and subsequently as a silver camp. The placer gold was first worked in 1863, the date of greatest activity being in 1867, since which period the production of placer gold has become quite insignificant.

In 1864 the first lode location was made, upon a vein now known as the Travona. This was the beginning of a period of very prosperous silver mining, and the district became the center of energetic operations, large mills being erected, with a considerable output of silver as a result. This period of active silver mining continued until 1892, when in common with other silver camps of the country the Butte district suffered a crushing blow. The climax of the production of silver ore was reached in 1887, when the different mills treated about 400 tons of ore per day and the smelters an aggregate of about 100 tons per day, the average yield being about $25 per ton in gold and silver.

In the year 1881 the Dexter mill was leased by Marcus Daly, for the newly organized Anaconda Silver Mining Company, and 8,000 tons of oxidized silver ore, from the Anaconda ledge, was treated in this mill, yielding about 30 ounces of silver to the ton. The ore contained just enough copper to make it unnecessary to add bluestone in the raw amalgamation, but the resulting bullion was very base, sometimes running only 400 fine. In working the vein a drift running northeast at a depth of 100 feet ran into a seam of copper glance a few inches wide. Mr. George Hearst, visiting the district about 1882, selected the site of the present Anaconda shaft as the most suitable place for future development. At a depth of 300 feet a crosscut run from the shaft encountered 5 feet of copper glance, and the ore was extracted and shipped to Swansea. During these early years the copper ores showing on the surface of several of the claims were receiving attention, and in 1867 an effort was made to smelt some of the ore from the Parrot lode.

To Senator W. A. Clark is due the first successful development of the copper veins of the district. In 1872 and the succeeding two years he began development work on the original Colusa, Mining Chief, and Gambetta claims. The ore extracted was shipped 400 miles in wagons to Corrine, Utah, thence by rail to the East, some of it going to Swansea, Wales.

One of the purchasers was the Boston and Colorado Smelting Company, located at Black Hawk, Colo., and in 1879, at Mr. Clark's suggestion, this company formed the Colorado and Montana Smelting Company and erected reduction works on the present site of the Colorado Smelter, thus furnishing a local market for the copper as well as the silver ore of the district. This smelter gave a great impetus to copper mining in the district, as previously shipments containing 35 per cent of copper from the Green Mountain claim gave no profit to the shipper after the cost was paid, although the gross value of the ore was $130 per ton in copper, the average price of that ore being 18⅝ cents per pound. In silver the ore carried not less than $50 per ton, but the works charged a high price for treatment, owing to the presence of arsenic, which made the metal brittle.

Soon after the erection of the Colorado Smelter the Parrot, Montana Copper, Clark's Colusa, and the Bell Company began smelting operations. The matte produced by these works was shipped to Eastern markets for refining. In 1884 the Anaconda Smelter began operations, followed rapidly by the formation of the Butte Reduction Works, Boston and Montana, Butte and Boston, and Montana Ore Purchasing companies. The completion of the Utah Northern Railway from Ogden to Butte in December, 1881, and the connection of this railroad with the Northern Pacific at Garrison in 1893, and the coming of the Montana Central, part of the Great Northern system, in 1888, and of the local branch of the Northern Pacific in 1889—all added to the prosperity of the camp.

In the history of Butte the metallurgical advance in the treatment of the ores has been very steady; the free-milling silver plants gave place to chlorination and roasting, and these in turn to other improvements, so that the ores which could be profitably treated became lower and lower in grade. With the great decline in silver of 1892–93 the silver-mining industry of the district became less and less important, until in 1896 all the large plants were closed down, and since that time the mining of silver ores has been of relatively slight importance and has been carried on chiefly by leasers working in the old properties. The importance of Butte as a producer of silver and gold at the present time is due to the fact that the copper produced contains 0.0375 ounce of silver and $0.0025 in gold for each pound of copper produced, or approximately 2¼ cents in the precious metals for each pound of copper. On this basis the Butte copper mines yielded in 1891 8,550,000 ounces of silver, which, at 55 cents per ounce, amounted to $4,702,500, together with $570,000 in gold, or a total of $5,272,500 in precious metals. Thus we see that in the production of precious metals the Butte district ranks among the great producers of the world. The total of 2,841,791,572 pounds of copper has been produced from a tonnage which may be safely estimated as at least 100 pounds per ton of ore, and on this basis over 28,000,000 tons of copper ore have been mined in the Butte district down to the close of 1901.

ROCKS OF THE DISTRICT.

The rocks of the ore-bearing area are all igneous, the district forming part of an extensive region of Tertiary igneous activity. The prevailing rock, and the one in which all the veins occur, is a dark basic granite, technically known as quartz-monzonite, which is a part of a great mass of granitic rock extending from the snow-capped Highland Peaks, seen 20 miles south of Butte, northward to Helena. This great mass of intrusive igneous granite is surrounded by altered limestone and other sedimentary rocks, and is in part covered by dark-colored andesite (both massive and fragmental varieties) of earlier age. Neither sedimentaries nor andesite occur in the district. Throughout the Butte mining district the granite is remarkably uniform in color, texture, and composition, and the name Butte granite has been applied to it. This rock is cut by dikes and irregular intrusions of the Bluebird granite, a white aplite[a] composed of quartz and feldspar, with a little mica. This rock, though intrusive in the granite, is supposed to have separated from the same magmas as the Butte granite and to have penetrated fissures in the latter while it was still hot, as the aplite is found in all sorts of small veins and masses which do not show any chilling along the contact. The rock is found frequently, but in relatively small masses. In the copper-bearing area the Modoc porphyry appears in lenticular dikes, traversing both varieties of granite in very irregular fissures. It is a light-colored rock, carrying large and distinct crystals of feldspar and quartz in a dense groundmass, and is technically designated rhyolite-porphyry or quartz-porphyry. After the intrusion of the Modoc porphyry extensive fracturing occurred, with vein formation, the veins cutting the porphyry in many instances. After the formation of these earlier veins, renewed

[a] Called "granulite" by some writers—a name applied by German geologists to a variety of schist, but by French petrographers to aplite.

and very violent volcanic activity began, resulting in the intrusion and eruption of rhyolite, forming dikes cutting across the veins, and also great sheets and masses of fragmental material.

The Big Butte is formed of rhyolite, both fragmental and massive, and this rock occurs in dikes cutting both the granite and veins in the silver area, while the fragmental form covers a large extent of country west of the mines. These rocks are the product of volcanic action, and the Butte is the eroded remnant of a small volcano.

The granites are of Tertiary age, for at the borders of the batholith late Cretaceous strata are cut by the intrusion, and, moreover, included fragments of the early Tertiary andesites occur in the granite. The rock is cut by rhyolite dikes, and as rhyolite ash-showers form lake beds containing Miocene vertebrate remains, the granite and the veins are of earlier age, probably Eocene or early Tertiary. West of the district the lake beds appear, formed in a great Tertiary lake that filled a long and relatively narrow valley extending from south of Dillon in southern Montana to Garrison, a valley which was warped by later earth movements that drained it and carried the continental divide across its floor.

STRUCTURAL FEATURES.

The Butte Flat, a level valley bottom south of the city, contains no lake beds; it was formerly a normal erosion valley formed by the convergence of streams from east, west, and south of Butte, and was subsequently depressed by faulting along the base of the mountains east of Butte, which reversed its principal tributary and resulted in the filling of the valley by torrential débris and wash from the adjacent slopes. This faulting altered the ground-water level of the ore-bearing area and played an important part in concentrating the ores. The district is thus shown to be one of deep-seated igneous rocks, subjected to fracturing at various periods, the resulting fractures being in part filled by dikes, in part by veins, and in part displacing the veins; it is a region of continued and continuing crustal adjustment.

The veins occur in an area showing few outcrops, the rocks being altered by decomposition and disintegration and forming smooth slopes; only rarely do the granite bowlders characteristic of the western part of the district show in the copper area. A few of the copper veins outcrop, but most of them, even the largest, are recognizable at the surface only by inconspicuous débris or do not show at all, a fact which has led to many lawsuits to determine ownership of ore bodies.

The district embraces a well-defined area of copper lodes surrounded by silver veins with transition ores at the borders. Though the veins of these two areas present a strong contrast in mineralization and character, the vein systems appear to be similar, so that the area may be described as a whole.

The rocks of the entire district are traversed by a multiplicity of joints and fractures. These belong to three well-defined systems, as may be seen in excavations in the city or, more clearly still, in the great bowlder outcrops to the northeast where the veins are seen to be merely mineralized fissures, the exceptional instances in which the fractures have been channels for mineralizing solution. In the copper area the rocks are intersected by a multitude of fissures, which near the surface are filled by quartz and iron oxide, with rotted or disintegrated granite between, soft enough to yield to the pick. In depth the lesser fractures are not filled and are therefore less conspicuous.

The veins of the district, both copper and silver veins, belong to three distinct systems. The oldest lodes have a general east-west course, the Parrot, Anaconda, and Syndicate lodes being examples. Another set of fractures has a northwest-southeast course, and has displaced the earlier veins. A still later set has a northeast course and has displaced both the earlier systems of veins. The first two systems are heavily mineralized; the last shows a little endogenous ore, but the material mined is mainly the ore broken off from earlier deposits and included in the fault débris. This discrimination of the different vein systems and the recognition of the faulting of one set by the other and of the resulting mineralization is the result of the study of the district made since the Butte folio was published. It has been made possible by the enormous development work expressly made to develop the structure and continuity of veins for the various lawsuits between the mining companies.

The silver veins surround the copper lodes on the north, west, and southwest. Their course and geologic relations are very similar to those of the copper veins, but their structure and mineralogic character are different. The silver veins contain sulphide of silver, blende, pyrite, and a little galena, and commonly contain no copper save near the border of the copper area, where, though occasional bunches of copper ore occur, it consists of chalcopyrite and more rarely still tetrahedrite, minerals which occur rarely and very sparingly in the copper lodes. The gangue consists of quartz with rhodonite and rhodochrosite, and shows marked banding and crustification, in strong contrast to the structure of the copper veins. These silver veins form very prominent outcrops, the quartz being stained black by manganese oxide. The veins are largely due to the filling of open fissures, and show but slight alteration of wall rock. They are displaced by and traversed by faults with friction breccias and alteration clays like those in the copper area.

THE COPPER VEINS AND MINERALS.

Several of the copper veins were, as is well known, at first worked as silver veins. The upper portion of the veins consisted of quartz somewhat stained by iron, but not like the great iron gossan caps of other regions. This extends to a variable distance below the surface, 200 to 400 feet in some instances, where it is replaced by partly oxidized and decomposed copper ores that form the upper limit of the remarkable glance, enargite, and bornite ore bodies of the district. Carbonates and oxides are rare.

The copper minerals occur in quartz-pyrite veins of remarkable width and extent. The Anaconda ledge is frequently 100 feet wide and will average half that width, as will also the Syndicate lode.

The copper minerals of the Butte ores consist chiefly of chalcocite (copper glance), bornite (peacock copper), enargite (sulpharsenide of copper), and cupriferous pyrite. Covellite (cupric sulphide) occurred in considerable amount in one or two mines, but forms an insignificant percentage of the total output. Tetrahedrite (gray copper) and chalcopyrite (copper pyrite) are even rarer than the last-named mineral. Until 1900 copper glance constituted the most important ore mineral of the veins, but it is now nearly equaled in quantity by enargite. In the great ore bodies of the upper levels of the Anaconda veins glance occurred in masses of nearly pure lead-like mineral 20 feet or more wide. In depth the mineral shows a more crystalline structure, and it is found in all the mines in greater or less abundance and purity, but in the great bulk of the ores it forms small grains scattered through the ores.

Bornite is less common than glance, and is practically restricted in occurrence to the veins in the western part of the copper area, where, however, it occurs in great abundance, forming the chief ore of the Original and Parrot mines.

The gangue of all the veins is largely quartz, though there is also a large amount of altered granite with veinlets and bunches of ore. The vein walls are often defined by clay selvage, but these prove almost invariably to be due to post-mineral fracturing. More frequently there is a fading of ore into country rock, a feature characteristic of replacement deposits.

THE ORES AND THEIR DEPOSITION.

Character of the ores.—The copper ores average 55 per cent silica and 16 per cent iron. About 15 per cent of the tonnage mined is first-class ore, averaging 12 per cent copper; the remaining 85 per cent carries 4.8 per cent copper, and is treated in concentrating mills, the resulting product containing but 15 to 20 per cent of silica, while the copper is increased to 18 per cent.

The ores contain gold to the extent of about 2¼ cents to each pound of copper, with 0.0375 ounce of silver. Native gold has been found upon crystallized glance, but with this exception no gold or silver minerals are recognizable in the copper ores. It is estimated that the total production of copper ore has been about 31,000,000 tons, averaging 5 per cent copper. The amount of arsenic (and antimony) present is very large, it being estimated that over 32,000 pounds a year pass off in smelter fumes. Tellurium is present in very small quantity in the ores, amounting to $2\frac{1}{3}$ ounces, or 0.008 per cent, in the crude copper upon the converters. It is recovered in electrolytic refining.

Ore deposition.—Three distinct periods of ore deposition are recognizable in the deposits of Butte. As many of the ore bodies are of composite character and derive their contents in part from each one of these periods, a careful study is necessary to discriminate the evidence and results of each period. In general it is necessary to differentiate primary deposits, or those formed of material brought to and deposited in the veins from outside sources, and the so-called "secondary" deposits of transposed and redeposited material. The former constitute the normal vein filling, the latter both the bodies of rich ore that have made the district famous and masses of low-grade, concentrating ores. As a general statement, it may be said that the deposits of copper glance are secondary.

The original source of the metallic contents of the primary deposits is still an unsolved question. It has been inferred by Mr. Emmons that, in the lack of direct evidence, "It is probable that circulating waters have somewhere in the depths extracted the metals from parts of the granite mass." To the writer the mineralogic evidence and the intimate connection between periods of ore deposition and igneous activity indicate a possible derivation from magmatic emanations—so-called mineralizing agents in waters partly of magmatic origin, mingled perhaps with predominating meteoric waters.

In general it may be stated that the original mineral-bearing solutions were probably hot and ascended through fractures in the granite. The copper deposits are almost entirely replacement deposits formed by waters ascending through mere cracks and attacking and replacing, particle by particle, the adjacent rock. The silver veins, on the contrary, are in large part due to the filling of open fissures, though replacement deposits also occur. In the replacement deposits there is a general lack of definition between country rock and ore, a wide zone of altered decomposed granite alongside of the vein, and commonly an impregnation of the rock between the individual veins of a lode with ore minerals. This is especially noticeable in the eastern part of the copper area, in Leonard, Rarus, and adjacent mines. In the former an ore body is stoped out for 135 feet in width, consisting of altered granite, sheeted and intersected by a multitude of small veins crushed by later movements and impregnated by primary minerals in part replaced by secondary glance.

In the central part of the copper area fresh unaltered granite is uncommon. There has been local development of intense thermal activity. The rocks are closely fissured as a result of several periods of fracturing, and the mineralizing solutions have penetrated and altered the rock between the fissures, converting and changing the rock to what is conveniently called pyritized granite, since the hornblende and mica are altered to pyrite.

The deep development work of many of the mines shows a decided change in the amount of mineralization of the fractures. There is an increasing number of small veins of quartz and pyrite separated by altered granite. Some of the large lodes whose entire width is workable pass downward into a cluster of small veins of quartz and pyrite separated by altered granite. In other words, the replacement of inter-vein material by ore decreases with depth. There is also a decided increase in the number of small fissures devoid of ore and filled by friction breccia, but showing trifling displacement. This is particularly noticeable in the levels 1,600 feet or more below the surface. On the other hand, some of the newer fault veins that show little or no ore in the upper levels contain pay ore below, because the open nature of the fault material permitted a deeper seepage than usual of descending waters.

Secondary enrichment.—The enormous bodies of copper glance which have made the Butte district famous are probably the largest and best examples of secondary enrichment known. The fracturing of the veins has permitted the access of meteoric waters, which, dissolving the copper from the lean ores of the oxidized zone, deposit it, by reaction with pyrite, in the depths. These deposits were greatest in the upper level of the mines and have gradually lessened with depth. In some of the veins the lower limit of enrichment has been reached, in others the deepest workings still show these enrichments.

In general there is a marked association of faulting of the veins with bodies of rich ore, and these faulted areas are wet, so that the miners say: "A dry and tight vein is barren; a wet and crushed one is rich." This is particularly marked where the veins contain much pyrite, though the glance is more conspicuous in white quartz. In the deeper levels newly deposited quartz occurs with the glance. In the deepest levels, 2,000 feet or more below the surface, rounded masses of glance 2 and 3 feet across occur in crushed quartz containing relatively little pyrite.

Change of character of mineralization with depth.—The most notable change in mineralization with increasing depth is the greater abundance of enargite. In the eastern part of the copper area, in the Rarus Hill and its vicinity, this ore extends upward to the oxidized zone, sometimes very nearly to the surface. West of here there is a notable increase of enargite in depth, the mineral occurring for the first time in the very deep level of some mines (i. e., 1,800 to 2,200 feet), an association that also prevails in some of the later veins, such as the Blue, as well as in the older ones.

Influence of country rock.—There is a distinct association of the copper deposits with the Modoc porphyry occurrence, since the most productive lodes occur in the area penetrated by this rock. The veins cross the porphyry, however, even the earliest ones, and hence the vein fractures are of later occurrence.

There is also a distinct genetic relation between ore and country rock, as a result of the deposition of the ore by metasomatic replacement. Thus the Anaconda ledge is low grade where it crosses either the Bluebird granite or the Modoc porphyry, a feature explainable by the lack of easily replaceable, dark-colored, ferromagnesian minerals in those rocks.

THE VEIN SYSTEMS.

As a result of extensive legal development work the evidence is now conclusive that the east-west veins have been faulted. The identity of the Original-Parrot and Anaconda lodes is conclusively established, the displacement being due to the Blue vein. Farther east the Anaconda ledge is again thrown to the north by the Mountain View fault, the displaced segment forming the South ledge of the Mountain View mine, terminated eastward by the Rarus fault, throwing the lode southward, so that its eastward extension appears in the Rarus mine. The same faulting has displaced the other veins of this part of the district.

Earlier veins, east-west system.—The great veins of the district, the Anaconda, Parrot, Mountain View, West Colusa, Syndicate—in fact, all the great producers—belong to this east-west system, in which the trend is remarkably uniform, considering the length of the veins. The Silver Bow vein is a marked exception. There is some evidence to show that certain southeast fractures were mineralized in the earliest vein-forming period, and some of them reopened when the later faulting occurred.

These earlier east-west veins are distinguished as lodes or compound veins. They differ in structural and mineral character from the later lodes, and, except where faulted and enriched, lack the high silver contents of the veins formed later. Fortunately they have been extensively fractured by strike faults, as well as the two other vein systems noted.

Northwest fault veins.—The northwest system of fractures faulted and displaced the east-west veins. The three largest veins of this system, the Blue vein, Mountain View vein, and Grey Rock vein, are mineralized, but not so generally as the older veins; the ore occurs in chutes and is quite high grade and shows enrichment. The Blue vein has been developed for over a mile, and to a depth of 1,000 feet, proving a heavy producer in several mines. It is cut and displaced by a northeast fracture in the Parrot workings.

Northeast fault veins.—The veins of both the east-west and the northwest systems are cut and displaced by those of the northeast system. The largest and best-known example of this is the Rarus fault, and the ownership of immensely valuable ore bodies has hinged upon the geological conditions in the Rarus and adjoining claims. A careful and prolonged examination of all the accessible workings of these mines, including stopes, has resulted in the establishment of the following facts:

The Rarus faults have cut and displaced all the veins. The cut-off is as sharp as if made by a knife, and high-grade ore abuts against fault breccia. The veins displaced are so close together that on certain levels the cut-off ends of different veins are opposite. The fault is compound, consisting of two fissures, the easterly with a dip of 45°, the westerly with a dip of 30°, and these fissures differ somewhat in strike. The interfault block is crushed and the included vein segments are broken and their orientation is disturbed by a tilting of the block. The actual fault fissures are marked by attrition clay containing rock and mineral fragments. When indurated by infiltrating solutions this resembles the quartz-porphyry. As the interfault material contains workable ore bodies, stoping is sometimes continuous from one vein across the fault to another. Whatever the legal construction may be, there is no geological continuity. There has been some ore deposited in the fault fissure, but not sufficient to form a new north-south vein along the fault, being confined to the proximity of older ore, upon and about which it was precipitated.

The Rarus fissure has now been developed to a depth of 1,600 feet and its existence established for a distance of 1¼ miles. Other fissures belonging to the Rarus system exist in many parts of the district, notably at the Original, Diamond, and Leonard mines, in which extensive mineralization has taken place.

COPPER DEPOSITS OF THE APPALACHIAN STATES.

By Walter Harvey Weed.

INTRODUCTION.

Copper deposits occur at intervals along the Appalachian Mountains and the Piedmont Plateau to the east, extending from Canada to Alabama. The earliest known copper mines of the continent are included in this region, and many interesting historical facts are associated with them. The geology of so extensive a region is necessarily varied. The rocks are in most cases metamorphosed and of the types known as chloritic schists and hornblende-schists; but their true nature is disclosed when the methods of modern petrographic research are applied to them, and in most cases the original nature and origin of the rock can be made out. It would be surprising that these deposits have not been studied in the light of our newer knowledge, both of petrology and of ore deposits, were it not for the fact that for many years past they have been of but little or no economic importance, and their workings have been filled by water and inaccessible.

While engaged in the collection of data to support or disprove the theory of secondary deposition and enrichment, a number of these old and formerly well-known mines were examined, as well as several newer properties whose development was inspired by the remarkably high price of copper in 1900–1901. The result of these examinations, necessarily brief and made primarily for the object stated, has been in part already published, but, the subject appearing attractive and the investigation timely, it was decided to extend the work and, from time to time, as opportunity offers, to examine and study all the known copper deposits of the Eastern, Middle, and Southern States.

Early in this work it was recognized that, while many deposits are of similar character, others present marked differences in mineral contents, structural character, and association. This led to an attempt to group deposits of similar nature, so that a description of a type would answer for many. This was done in a paper entitled "Type Copper Deposits of the South."[a] Since then several copper properties in Maryland and New Jersey have been examined and found to be still different in character from those described.

[a] Trans. Am. Inst. Min. Eng., 1899.

NEW JERSEY DEPOSITS.

The New Jersey copper ores occur in the eastern part of the State. They were worked more or less continuously from colonial days until some thirty years ago. Several properties have recently been reopened, and in one instance extensive development work has been carried on. The ores all occur at or near the contact between the shales and sandstones of the Newark group (the red sandstone series of Triassic age), and the trap rocks. These traps all occur tilted at gentle angles, commonly conformable with the shale beds. Orange Mountain, and the second and third mountains back of it, collectively known as the Watchung Mountains, are formed by these trap sheets, the sandstones forming the intervening valleys and foot slopes. These traps are lava flows contemporaneous in age with the shales, while all the other trap sheets of the State have proved to be intruded bodies. The copper ores occur above and below these trap rocks.

In Watchung or First Mountain, back of Plainfield, and the continuation of the mountain south and west to Boundbrook and beyond, the trap is underlain by a stratum of altered shale that is almost continuously copper bearing. This constitutes the most important copper deposit of the State, one that has been worked at fully 30 different places in former years. The most important development has been near Somerville, at the American copper mine. The workings at this place follow down the ore stratum for a distance of 1,350 feet from the surface, the bed being inclined at an angle of about 10°, dipping into the mountain. The ore occurs in a well-defined bed, 16 inches to 3 feet thick, lying immediately beneath the trap rock, the latter rock being also occasionally ore bearing for a few inches next the contact.

For a distance of nearly 15 miles along the mountain front this contact stratum has proved copper bearing. The ores consist of the red oxide of copper with green carbonate and silicate, sheets of native copper, and rarely peacock copper and glance. In the American mine the workings pass through the upper oxidized part of the bed, characterized by the ores just mentioned, into a lower zone in which they are wanting and in which native copper occurs in small masses scattered through the ore bed, together with a very little finely disseminated glance, associated with calcite. The native copper occurs in grains and irregular nodules in bunches of white or grayish-colored ore irregularly scattered through the purple rock. As no average sampling was attempted, it may be stated that the systematic sampling of the company's representative is said to have yielded 2¼ per cent copper, a figure which if sustained by mill work will permit of the profitable working of the property.

At Arlington and many of the other localities of the State the ore consists of oxide, carbonate, and glance, filling cracks and crevices in the sandstones above the trap sheets. Reduction works have been erected at the Arlington property, bordering the Newark meadows, and at the American mine near Somerville.[a]

MARYLAND.

The Maryland properties are chiefly of historic interest, as the shafts and workings of most of the mines are now filled and inaccessible. The Liberty mine is a noteworthy exception, and is particularly interesting because it appears to be representative of many, if not all, of the abandoned properties, and of many undeveloped prospects of the region.

The deposits all occur in an open, gently rolling region underlain by so-called chloritic schists, whose true nature remains to be determined. Near the copper deposits thus far examined these rocks appear to be altered volcanic rocks, probably rhyolites, and resemble those of South Mountain, Pennsylvania, where copper deposits also occur. The Maryland ores impregnate these rocks but slightly, the main ore bodies occurring in what appear to be isolated blocks of limestone, or rather marble. The ores consist of bornite or peacock copper, with some chalcopyrite and associated calcite and rhodochrosite, and it occurs filling crevices, fracture planes, and cementing together the fragments of a crush-breccia of marble.

VIRGINIA.

Native copper occurs exposed at many localities along the Blue Ridge region of this State, but no workable mines have been developed on such properties. Copper sulphides occur, usually with large quantities of pyrite, in southwestern Virginia, in Carroll and Randolph counties; and also in connection with pyrite and native gold in the old gold mines of the State. Copper ores also occur in the now vigorously exploited Virgilina field in Halifax County, though the greater part of this field lies across the line in North Carolina.

The deposits of native copper and associated oxide and carbonate ores of the Blue Ridge region prove to be of limited extent, and to have been derived from the metamorphosed and schistose basaltic rocks of that region. They have been designated the Catoctin type. The native metal often occurs in masses of several ounces or even a pound in weight, and is associated with epidote, quartz, and calcite, filling small irregular crevices along shear zones in the metamorphosed igneous rock. Though often traceable for miles by outcrops and scattered ore masses, the deposits so far explored do not go down more than 20 to 30 feet from the surface.

The sulphide ores of southwestern Virginia occur beneath iron

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[a] Weed, W. H., Copper deposits of New Jersey: Ann. Rept. State Geologist of New Jersey for 1902, Trenton, N. J., 1903.

ore or croppings, constituting what has been called the great Gossan lode of Virginia, the deposits extending in the same general direction into North Carolina (Ashe County). These deposits have not yet been visited, but published descriptions indicate their close resemblance to the well-known deposits at Ducktown, Tenn.

The Virgilina deposits consist of native copper in quartz-filled fissure veins traversing andesitic porphyries altered to metamorphic schists. The ores consist principally of glance occurring in small bunches and thin lenses and rarely in large ore shoots. Some bornite also occurs, and this forms the chief ore mineral in the calcite gangue at the Blue Wing mine, North Carolina. These minerals in decomposing have produced the usual green carbonate, silicate, etc., near the surface of the ground. The character of the quartz indicates that it is the filling of an open fissure, but the veins show the lenticular thinning and thickening characteristic of veins in schistose rock. In some cases they cross the schistosity at a sharp angle and send short spurs off into the parting planes. Dikes of massive diabase occur that are later in age than the schists. These dikes narrow and impoverish the veins, but do not interrupt them. The ores are extremely siliceous, owing to the quartz gangue, hence careful sorting and concentrating is necessary before shipment.

NORTH CAROLINA.

This State is rich in copper deposits, though few have been commercially developed. The larger part of the Virgilina field, whose veins have just been described, occurs in this State and includes the Holloway, Bluewing, Durgee, and Person mines, the first named being a successful producer for many years, the ores going to Norfolk, where they are smelted with ores brought from Capelton, Quebec.

The most extensive development is, however, at Gold Hill, 12 miles from Salisbury, N. C. The chief output is from the mine of the Union Copper Company. The veins show ore shoots of dark gray and white quartz, carrying chalcopyrite and having a characteristic gneissoid structure. The veins generally consist of altered schists, and the inclosing rocks have been classed as Cambrian. These deposits are closely allied to the pyritic gold deposits of the Carolinas, which occur for many miles along the border of a large area of eruptive granite. The Gold Hill district has been the largest gold-producing district of the South, the gold occuring in the gossan of the copper lodes. The veins are lenticular in character, and thicken and thin rapidly. Although a large amount of money has been spent on these properties in the last three years and the veins have been opened for several hundred feet in depth, no definite assurance of their probable future value can be gotten from the data at hand. An expensive milling and reduction plant has been erected and is in operation, but the ore proves difficult to dress and very siliceous in character.

TENNESSEE.

The only copper deposits in Tennessee are the well-known Ducktown mines, situated in the extreme southeast corner of the State. These properties were famous for their rich secondary ores half a century ago, were worked at intervals for thirty years, and are now in successful operation. The deposits are very large lenticular bodies of pyrrhotite or pyrite in mica-schists, shown by Kemp to be metamorphosed shales. No igneous rocks are known near by, and the rocks are probably Algonkian. The schists have been broken by dislocations, along which the ores have been deposited, the ore bodies usually conforming very closely in course and dip to the inclosing schists. There are two main and parallel lines of fracture. The ore bodies are huge lenticular masses of sulphides, several of them 100 feet or more thick. The common ore is a mixture of pyrrhotite and chalcopyrite, with calcite, quartz, zoisite, garnet, and in some cases much actinolite. In some ore bodies pyrite replaces the pyrrhotite wholly or in part. Much of the ore is shattered and sometimes brecciated, the chalcopyrite filling the cracks. A second period of shattering was followed by the formation of coarsely crystalline pyrrhotite, copper pyrite, and blende. These ore bodies are covered by a gossan of porous-textured iron ore, consisting of hematite and limonite, produced by the oxidation of the sulphides, which is mined in large quantities for iron furnaces. Beneath this gossan occurred the rich "oxysulphuret" ore, a loosely textured mass of amorphous copper glance, 6 to 10 feet thick, lying above the unaltered sulphide ore. This secondary ore is, however, now all extracted, and the copper contents of the ore bodies being worked averages about 3.5 per cent.

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LEAD AND ZINC.

Extensive investigations in the principal lead- and zinc-mining districts of the country have been carried on recently by the United States Geological Survey. The papers here presented include preliminary reports covering several of these districts. Other references to lead will be found in several papers in the section on gold and silver, as all reports on districts in which silver-lead ores were prominent were included under the precious metals.

ZINC AND LEAD DEPOSITS OF NORTHERN ARKANSAS.

By George I. Adams.

INTRODUCTION.

During the summer of 1902 a party consisting of George I. Adams, of the United States Geological Survey, assisted by A. H. Purdue, of the University of Arkansas, and Ernest F. Burchard, was engaged in the study of the zinc and lead deposits of northern Arkansas. An extensive report on this field is now in preparation. The following statement of results and conclusions is made in advance of the final publication, which will be accompanied by detailed geologic maps and other illustrations.

POSITION OF THE FIELD.

The lead and zinc deposits of northern Arkansas are in Marion County and adjacent portions of Boone, Baxter, Newton, and Searcy counties. Outside of this area there are a few scattered mines, notably in Sharp and Lawrence counties. The mining development is north of the Boston Mountains, in what is known as the Ozark Plateau. The country has a broken surface, as a result of dissection by streams, and there are numerous exposures of the mineral-bearing horizons in the valley slopes. This has greatly facilitated prospecting for the ores.

HISTORY OF THE FIELD.

Lead ore was discovered in northern Arkansas by the early explorers and pioneers, and at first was utilized for rifle bullets. Later it attracted considerable attention, and in the fifties was smelted in the vicinity of Lead Hill. There was a revival of the industry during the seventies, but the cost of transportation was so great that it was practically abandoned.

Zinc ores at first attracted little attention, probably because they were not so well understood. Before the civil war, however, some zinc was smelted. In the eighties prospecting for it was carried on generally throughout the field, and resulted in finding it at so many places and so readily accessible that about 1899 there was what might be called a rush into the field.

PRODUCTION.

From the information contained in published reports and gathered by inquiry, it has been estimated that the output of the northern Arkansas district up to and including the year 1900 was 1,500 tons of zinc ore and 500 tons of lead. In 1901 about 500 tons of zinc were marketed, and in 1902 about 1,000 tons, or double the amount of the previous year. The production of lead during 1901 and 1902 was unimportant. There is considerable ore now stored in the bins awaiting transportation facilities, and the production of the district promises to increase during the coming year.

PRESENT DEVELOPMENT.

The condition of the mining industry in northern Arkansas has been largely governed by transportation facilities. Until recently no railroad entered the field. In 1901 the St. Louis and North Arkansas Railroad was built to Harrison, and since that time has been extended to Buffalo River. It is proposed to extend it southeastward, by way of Marshall, in the direction of Little Rock. The Missouri Pacific is now building a line in White River Valley from Batesville to Buffalo City, and it is proposed to extend this line northwestward, by way of Yellville, into Missouri. The completion of the railroads will afford facilities for shipping, and mines which have suspended operations will resume, and others which have attempted no development beyond prospecting are already erecting mills or determining more definitely the character of the ground preparatory to doing so.

PROSPECTIVE DEVELOPMENT.

What has been done thus far in the way of mining is not a satisfactory test of the field. Some companies which have been organized have been promoted by men inexperienced in the production of zinc and lead. The expenditure of money in erecting mills and bringing in machinery and the failure to market ore at a profit because of the long wagon hauls have usually resulted in the suspension of operations. The ore deposits of northern Arkansas are not such as mining men generally are familiar with, and some have been misled by the results of the prospecting. The mixed character of the ores found in surface workings has made it difficult to produce clean concentrates. With the continuance of deeper workings and the following of the ore bodies into the hillsides the sulphides are found to predominate, and this difficulty largely disappears. While it is impossible to predict with certainty the future of the field, there are mines now opened which are capable of large output, and many of the prospects are promising and well warrant fuller exploitation. With the completion of the railroads the northern Arkansas district promises to assume its true commercial importance.

GEOLOGY.

The ores are found in two formations, the lower being the Ordovician dolomites, and the upper the Mississippian limestones. The Ordovician rocks occur extensively in Baxter County and in the northeastern part of Marion county, and in the other portions of the field, along the valleys of the streams, where erosion has cut down to them. The Mississippian limestones lie to the south and southwest, forming an irregularly fringed and dissected belt, lying somewhat higher and extending to the base of the Boston escarpment. The Mississippian limestones formerly extended farther to the north and northeast and overlaid the Ordovician, but they have been removed by the wearing away of the land surface through the action of atmospheric agencies. In addition to these formations, which are the principal ore-bearing rocks, there are some thin formations found between the two in certain parts of the field, but for the immediate discussion of the problems connected with the ore deposits they need not be described. The Saccharoidal sandstone, however, which lies above the Ordovician dolomites, and accordingly separates the lower from the upper ore-bearing rocks, should be mentioned, since it is a convenient datum in this field. It is known locally as the "sand ledge," and is referred to in determining the horizons of the mines and prospects which occur below it in the Ordovician. To the south, lying upon the Mississippian limestones, and accordingly higher in the geologic column, are the shales and sandstones, which are extensively developed in the Boston Mountains.

STRUCTURE.

An examination of the mines of the district shows that the ore bodies are related to two classes of structure, viz, simple fractures and breccias. The rocks, considered broadly, are found to be nearly horizontal. Locally, however, they are undulating, and occasionally have well-marked dips. There are well-defined normal faults, which are later than the fracturing and brecciation above mentioned, but, except in certain instances where fault breccias have been developed, there is only a minor amount of mineralization along the fault planes or in the material filling the normal fault fissures.

The fracturing of the Ordovician rocks was produced by compressive forces, and in certain zones has a considerable vertical extent. A second and equally important result was brecciation, which was produced by the differential movement of the strata. The variation in the structure of the dolomite series, which is in places massively bedded and in other places thin bedded, laminated, and even shaly, resulted in the lateral movement being taken up in varying degree by the individual beds, so that the motion was such as is produced by forces acting in couples. The brecciation is due to the tendency of the pieces resulting from the breaking of certain brittle strata to shear past each other, or to rotate with the horizontal movements of the adjacent beds, so that the fragments are relatively displaced.

In the Mississippian limestone the compression produced principally fracturing and fissuring. The walls of the fissures not infrequently exhibit slickensiding, which has been produced by the rocks moving past each other horizontally. The Mississippian limestones do not exhibit brecciation, excepting in fracture zones or where they have been crushed by the dragging of the beds along normal faults, which in most cases are due to a later adjustment of the rocks of the area.

The fracturing and brecciation above mentioned are probably due to stresses induced at the time of the folding in the Ouachita Mountain and Arkansas Valley regions. At the close of the Carboniferous period the thick sediments which had accumulated in what is now central Arkansas and western Indian Territory were folded in a manner which suggests that they were thrust to the north. In the Ouachita Mountains there are close folding and thrust faulting; in the Arkansas Valley region open folds. In the southern border of the Ozark region, and particularly in the area here under discussion, the generally horizontal position of the rocks was retained, but there was considerable movement of individual beds. This movement was one of accommodation, and resulted in fracturing without marked displacement. It took place largely along the bedding planes and resulted in brecciation of the beds. The normal faulting in this area is of later date, and is probably due to the readjustment following the crushing, or to subsequent oscillations of level.

Geologic conditions influencing circulation of ground water.—The rocks which constitute the Ordovician system and the Mississippian limestones of the northern Arkansas district may be considered as relatively quite permeable. There are local beds of shale in the Ordovician through which water would not readily pass, and the Devonian, which has a very limited extent in the southern part of the field, is of about the same character and importance in controlling the path of the ground water. The shales do not have a wide influence, since they do not form persistent horizons. Where they occur they probably diverted the solutions laterally, but no localization of ore deposits seems to be directly due to them.

The shales lying above the Mississippian limestones, on the contrary, have sufficient thickness to make them an important factor in determining the movement of ground water. Formerly they extended from their present boundary, near the base of the Boston Mountains, northward into Missouri, and covered a considerable part of the Ozark Plateau. Before they were removed they acted as a confining or limiting horizon. Water entering the Ordovician dolomites and Mississippian limestones where they outcropped, and moving southward in the direction of the dip, was under a hydrostatic pressure beneath these shales. There may have been a first concentration of the ores, due to this circulation, and, if so, it could have taken place at some point between the upper portion of the Mississippian limestones which were below these shales and the bottom of the Ordovician. This reasoning may be appealed to in accounting for the ore bodies now found in the Mississippian limestones near the base of the Boston Mountains, where these rocks have recently been uncovered by erosion. It is possible, however, that the concentration could have occurred through the agency of lateral circulation adjacent to the fractures in which the ore bodies are found, without appealing to causes which are of such wide influence.

As erosion progressed the shales and other formations lying above the Mississippian limestones were speedily removed from the more central portion of the Ozark region, so that the conditions which at first existed, as above outlined, were not long maintained. The main streams of the region, such as White River and its tributaries, soon cut through these formations, so that water which may have formerly been under hydrostatic pressure found issuance in their valleys. At the present time there are no upper confining shales in the northern part of the field, and this condition has prevailed for a long period. The surface water has been free to descend into the Mississippian limestones and Ordovician rocks, or through the Mississippian limestones into the Ordovician, and the point of issuance of such portions as have reappeared in the surface flow has been in the valleys of the larger streams. There, no doubt, has been lateral movement along bedding planes and through the more permeable strata and open and brecciated beds and along the surfaces of local shale beds. The Saccharoidal sandstone, which is a conspicuous formation and one which is relatively porous, has probably been a horizon of lateral movement, assisting in the transfer of the ground water to places where it could find its way into the adjacent beds.

Relations of belt of weathering and belt of cementation.—Under the action of atmospheric agencies the rocks at and near the surface suffer loss of their materials and waste away. This process may be described as weathering. Deeper in the earth the materials derived from the upper rocks are largely redeposited. This process is one of cementation. The belt of weathering and the belt of cementation are not separated by a sharp line, and, moreover, with the processes of erosion the lower limit of the activity of the atmospheric agencies has constantly migrated downward. These belts are related to the topography of the country, the plane separating them being higher in the hills than in the valleys. Consequently, during the long period which has been required for the removal of the stratified rocks to their present limits, there has been a shifting downward and southward, as the streams have cut their valleys deeper and the escarpments have retreated southward. In the northern part of the field the belt of weathering which was formerly in the Mississippian limestones has, since the removal of these beds, reached the Ordovician rocks. To the south, as a result of the rugged topography, it lies partly in the Ordovician and partly in the Mississippian. At the base of the Boston Mountains, where the the shales and sandstones have been but recently removed, it has descended but a short distance into the upper portion of the Mississippian limestones. The rocks in the northern portion of the zinc and lead district of northern Arkansas may accordingly be considered as exhibiting the more advanced stages of the process of weathering and erosion.

ORE DEPOSITS.

Source of the ores.—It is generally accepted that the zinc and lead deposits of this region have been accumulated by the action of circulating waters which have dissolved the ores which were first broadly disseminated in the limestones of the region. Water has dissolved and carried them in solution to certain places where the conditions were favorable for their redeposition. Stating it differently, they have been derived from the belt of weathering and the belt of cementation, and largely deposited in the belt of cementation. A study of the nature of the ores and their gangue materials and of the geologic history of the region makes it apparent that at least the latest concentration of the ores in the Ordovician has been largely the result of downward and lateral movements. The metallic sulphides may have been mainly derived from the Mississippian limestones, which formerly had a wider distribution, from the Ordovician, or from both formations. An examination of the Mississippian rocks shows that they have been leached by surface waters. Where they are exposed in railway cuts they exhibit decay to considerable depths, and within the area of their outcrop there are numerous sink holes in which the water disappears into underground channels. The surface cherts which have been derived from the weathering of these rocks are frequently porous and spongy, thus indicating the loss of silica. In the Ordovician secondary silica is not infrequently a gangue of the ores. The Mississippian limestones contain notable deposits of zinc and lead at many localities in the Ozark region, and where there is ore in the Ordovician the Mississippian limestones have formerly overlain the area. The mines of southwestern Missouri around Joplin are in the Mississippian limestones, and in northern Arkansas, as has already been stated, prospecting has shown that in the portion of the district where they have been but recently exposed to the action of surface waters, probably as a result of a first concentration, they carry considerable lead and zinc.

Classification of ore deposits.—The most important deposits of the district are the sulphide ores of lead and zinc, or, as they are commonly called, galena and blende. In the Ordovician dolomites there are two principal classes of these deposits, which are characterized by the gangue material. One class is distinguished by the presence of secondary chert, which occurs as a siliceous replacement of the dolomites, or filling fractures in these rocks; in the other there is associated with the ore a large amount of dolomite spar, which forms a cementing material in the breccias. In certain of the mines there is, in addition to these main ore bodies, accessory ore which replaces the country rock to some extent adjacent to the main ore body without the development of secondary chert or spar.

In the Mississippian limestones the primary ore deposits are accompanied by secondary chert and calcite. They are related to fractures, and in some instances to fault planes. In the latter case they usually occupy breccias. Accessory ore replacing the country rock is sometimes present with these deposits.

The northern Arkansas field contains important deposits of oxidized ores. These are the carbonates and silicates. They are derived from the primary sulphides, and are due to the alteration of the sulphides by the action of surface waters. In discussing the genesis of the ores the important problem is the origin of the sulphide deposits, the relation of the oxidized deposits to the sulphide deposits being evident.

Processes of primary deposition of sulphide ores.—The action of ground waters in the belt of weathering, and to a considerable extent in the belt of cementation, resulted in the solution and transportation of the ores. As the water percolated downward and moved laterally, and perhaps later upward, it reached a place where deposition took place. In the early part of the journey of the waters, through the action of the carbon dioxide and the humic acids, silica was taken into solution, and the waters accordingly contained it in notable quantities, along with the ores in solution. In the later part of the journey these waters caused the solution of lime and magnesium carbonate and the deposition of silica and sulphides, the resulting ores supposedly having been transported as sulphates. The reduction of the metals to sulphides was probably accomplished through the agency of organic matter and pyrite in the rocks, directly or indirectly, and deposition of the sulphides occurred along with the formation of the secondary chert and spar.

The superposition of the original cherts in the Mississippian limestones and the occurrence of the secondary cherts and spar in the dolomites are entirely in accordance with this theory.

Processes of deposition of oxidized ores.—The oxidized ores of northern Arkansas are the carbonates and silicates, which have been derived from the sulphide ore bodies. They are, accordingly, relatively later, and have been produced since erosion has brought the sulphides into the zone of weathering. The descending waters carrying carbon dioxide have transformed the blende and galena. In some cases redeposition has taken place immediately, and not infrequently oxidized ores are found as incrustations on the sulphides. In other cases they are found along water channels or in the open spaces and on the surfaces of the country rock. In the exposed faces of ore-bearing beds and in the upper portions of workings secondary ores often predominate. When mining operations are carried into the rocks that are under cover or have been protected from the action of ground waters, the carbonates and silicates decrease, and galena and blende are found to be the predominating ores.

Secondary deposition of sulphides.—The sulphide ores which were dissolved by descending waters have not all been redeposited within the belt of weathering. Such portions as were retained in solution upon reaching the belt of cementation were redeposited as sulphides, the processes in this case being the same as in the primary deposition and the ore bodies belonging to a second generation. In the lower horizons of the Ordovician dolomites considerable zinc ore is found which occurs as bright, clean crystals associated with drusy quartz or in openings formed by fracture. Such deposits are usually lean, and thus far no workable body of ore of this nature has been discovered.

Observations have not shown that there is a criterion for clearly distinguishing the secondary sulphide ores, which may have originated by migration from the primary deposits, since it is not improbable that the solutions at the time of the first concentration may have deposited most of their ore in the upper horizons, in which case the deeper deposits would have the characteristics above described and assigned to the ores of the second generation.

Sulphide deposits associated with secondary chert.—Where chert is the principal gangue of the blende and galena, deposition in the Ordovician has taken place by the replacement of the dolomites and the filling of fracture spaces and cementation of breccias. Secondary chert when freshly exposed usually has a bluish color. It may be distinguished from the other country rocks by means of its hardness, since it can not be scratched with a knife. It frequently has a banded or bedded appearance, which corresponds to the bedding of the original dolomite, and crystals of ore usually well formed and distinct occur within the mass. In case some of the sulphides have been leached out, molds of the blende are seen, which give the chert a honeycombed appearance. The richer deposits appear to be related to fracture zones, and occur along the fissures and replacing the adjacent rocks. The path of the ore-bearing solutions in descending has apparently been along fractures and laterally along the bedding planes, and the mineralization decreases away from the fracture zone.

Sulphide deposits in bedded breccias.—In the brecciated beds of the Ordovician dolomites the open spaces between the fragments have afforded channels for the ore-bearing solutions, and the precipitation of the sulphides and dolomite or pink spar has usually taken place without the dissolving of the country rock to any appreciable extent. The pink spar is not always accompanied by ore. The sulphides have been deposited in a somewhat local way, many factors being concerned. Not infrequently, in prospecting, breccias containing pink spar and but little ore are found; and, where the breccias are ore bearing, when they are followed for a considerable distance they usually show a decrease in the amount of ore.

Sulphide deposits in fissures.—In the Mississippian limestones most of the mines and prospects are related to fissures, the ore occurring in material filling the fissures or in the fissure and the openings adjacent to it. These deposits differ from those in the fractured dolomites in being more clearly defined. The gangue is usually secondary chert and calcite. The walls of the fissures exhibit slickensiding, as a result of the movement of beds, and frequently indicate displacement in a horizontal direction.

Sulphide deposits in fault breccias.—Where the Mississippian limestones have been displaced by normal faulting and the rocks have been dragged, they not infrequently exhibit brecciation. The angular fragments are largely primary chert, and the ore occurs associated with a calcareous and siliceous matrix which cements the breccia.

Sulphide ore in country rock.—In many of the mines and prospects the country rock has not been mineralized. In other cases, for a short distance adjacent to fissures, fractures, and water channels, the ore-bearing solutions have formed what is here called accessory ore. The action in this case has been one of replacement. The country rock exhibits recrystallization and carries small crystals of ore. Where accessory ore is found the main ore body is usually rich, and there is a suggestion that deposition in the country rock resulted because of the large amount of ore in solution at these places. In the northern Arkansas district the scattered crystals of blende in the country rock are spoken of as disseminated ore. This term, unfortunately, is not quite appropriate, and, accordingly, the word accessory is suggested, since it does not imply the mode of deposition usually ascribed to disseminated ores. Accessory ore, inasmuch as it is usually found associated with rich ore bodies, is looked upon by the prospectors as a favorable indication. The ore in secondary chert is not included under this head.

Ore associated with quartz druses.—Not infrequently, in the Ordovician dolomites, the lower ore horizons exhibit quartz druses and surfaces covered with minute quartz crystals. The ore in these rocks occurs as clean, bright crystals deposited on the quartz. It seldom is found in large masses, but is generally distributed through the rocks. The probability is that it represents a migration from the higher horizons, but it is possible that it was deposited from the depleted solutions at the time of primary deposition.

Opinions of previous writers.[a]—In the previous reports on the northern Arkansas field certain ideas have been advanced which are not accepted by the writer. These largely pertain to theoretical considerations, although some of them deal with the geologic facts. There is no opportunity in this article for a discussion of the differences of opinion which have arisen, but it is thought best to mention certain points which are obvious from a review of the literature.

The writer has argued that the bedded breccias were produced by the movement of strata past one another, as a result of compressive forces. Mr. Branner, in speaking of the breccias, states that the bedded breccias were not formed on fractures, but along ancient underground water courses. The breccia deposits which Mr. Bain described were considered by him to have been formed along zones of pressure. He speaks of limestone conglomerates, which, in the opinion of the present writer, are in reality breccias. The relation of these so-called conglomerates to the brecciated beds, and the extensive brecciation due to differential horizontal movement, do not seem to have been recognized by Mr. Bain.

In regard to the faulting of the region, the writer presents an interpretation which is decidedly opposed to that of Mr. Branner. He considers certain of the most important faults, some of which were described and figured by Mr. Branner as thrust faults, to be normal faults.

In regard to the theory of ore deposition, all the differences can not be here pointed out. However, Mr. Branner described bedded deposits contemporaneous with the rocks in which they occur. Such ore bodies are believed by the writer to be the result of secondary alteration and replacement. Mr. Bain has given considerable prominence to what he calls disseminated ores in compact limestone and unbroken conglomerate. This description does not seem to be a correct characterization of any of the main ore bodies of the district.

[a] Branner, J. C., Zinc and lead deposits of northern Arkansas: Ann. Rept. Arkansas Geol. Survey for 1892 (published in 1900), Vol. V; also Trans. Am. Inst. Min. Engrs., Vol. XXXI, p. 572. Bain, H. F., Preliminary report on the lead and zinc deposits of the Ozark region: Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. II, 1902, pp. 195–202. Van Hise, C. R., and Bain, H. F., Lead and zinc deposits of the Mississippi Valley, read before the Institution of Mining Engineers at the general meeting at London, May 29, 1902: Excerpt from Trans. Inst. Min. Engrs., pp. 34, 35.

LEAD AND ZINC DEPOSITS OF THE JOPLIN DISTRICT, MISSOURI-KANSAS.[a]

By W. S. TANGIER SMITH.

INTRODUCTION.

The lead and zinc deposits of the Mississippi Valley have been divided into three groups, those of (1) the Ozark region, (2) the Upper Mississippi Valley, (3) outlying districts. Of these the most important is the Ozark region, which extends from the Arkansas River on the south to the Missouri River on the north and from eastern Kansas on the west to the Mississippi River on the east. It contains four districts, (1) the Southeastern Missouri district, (2) the Central Missouri district, (3) the Missouri-Kansas or Southwestern Missouri district, (4) the Northern Arkansas district.

LOCATION AND TOPOGRAPHY.

The Joplin subdistrict, as considered in this paper, includes that part of the Missouri-Kansas district lying along its western margin and between 94° 15′ and 94° 45′ west longitude and 37° and 37° 15′ north latitude. While thus embracing an area of only 476 square miles, it produces more zinc than all the other districts of the Mississippi Valley combined, and is in fact the most important zinc-producing district of the United States. In addition to the zinc, it produces a smaller though still considerable amount of lead. In the year 1902 the lead production of the district was about 12 per cent of its zinc production, the latter being 223,337 tons.

About three-fourths of the Joplin district is in Missouri, and includes among its larger towns Joplin, Webb City, Carterville, and Carthage. The remaining one-fourth (except for a fraction of a square mile falling in Indian Territory) is in Kansas, and its largest towns are Galena, Empire, and Baxter Springs.

The Joplin district lies on the western margin of the Ozark uplift, and its upland surface is almost flat, with a low general slope to the northwest. These level uplands are cut by numerous stream valleys, for the most part open and rather shallow. The courses of many of

[a] A more extended article, of which this paper is an abstract, is in course of preparation for Survey publication.

the smaller streams are determined by lines of shale deposits, along zones of faulting and consequently lines of weakness. As the shales are the softest rocks of the region, there is thus a double reason for the correspondence of the valleys with these lines, and probably the same facts explain the general limitation of mining to the valleys and their slopes.

GEOLOGY.

Stratigraphy.—The geology of the district is simple. The rocks are wholly sedimentary, and those exposed on the surface are all of Carboniferous age, both Upper and Lower Carboniferous being represented. The Lower Carboniferous rocks consist of about 350 feet of cherts and limestones in varying proportions. This is the ore-bearing formation of the district, the ore occurring especially in the more cherty portions. The limestone is generally nonmagnesian, but a comparatively small amount of dolomite occurs, mainly as the result of alteration of the limestone at the time of the deposition of the ores. The limestone generally contains a considerable amount of organic matter, evidenced by the vaseline-like odor which is characteristic of the rock when broken; and occurrences of bitumen are common, especially in association with the mineral deposits. Not far from the top of the series is a thin but persistent bed of oolite, outcrops of which occur over the entire district. Some distance below is a heavy bed of chert, about 50 feet thick, known as the Grand Falls chert.

The Lower Carboniferous rocks are exposed over the greater part of the Joplin district. Above them, when not eroded, lie the Upper Carboniferous Coal Measure shales and sandstones. The shales, which constitute the greater part of the Coal Measure exposures of the quadrangle, are frequently associated with thin beds of coal. The sandstone occurring with these shales is sometimes changed to a quartzite through the infiltration of secondary silica. There is a considerable area of these shales and sandstones in the northwest corner of the quadrangle, in addition to small patches of shale over the entire district. These smaller occurrences in some cases represent outlying hills left on the removal of the Coal Measure rocks; in other cases their persistence is due to their occurrence in pre-Coal Measure erosion basins, or in later basins formed by the folding of the rocks, while in still others they are the result of faulting.

Beneath the Lower Carboniferous limestones and cherts is the Devono-Carboniferous shale. The occurrence of this formation in the Joplin district has not been proved, though it is believed to be present as a thin bed of shaly limestone having an average thickness of only a few feet. The Cambro-Silurian rocks beneath the Devono-Carboniferous shale consist of a series of magnesian limestones, dolomites, and sandstones. As none of the rocks below the Lower Carboniferous are exposed in this district, their occurrence can be determined only from deep borings.

Structure.—The rocks of the district have a low general dip to the northwest at an angle somewhat greater than the general inclination of the surface. Open folding is common, both on a large and small scale. Noticeable faulting is not common over the quadrangle as a whole, though small slips occur here and there. In those parts of the district, however, where ore deposits occur, faulting and folding are both of more importance, but even here the amount of faulting, as a rule, is not great. Both normal and reversed faults are found, both being the result of readjustment due to compression stresses. Where cherts predominate, brecciation has developed as a result of the faulting and folding. The individual faults are not known to continue for any considerable distance, but they occur (as do the folds also) mainly in zones. The ore deposits follow these zones of faulting and folding, and frequently come in and die out with the faults with which they are associated. The occurrence of cross folding and faulting, at an angle with the main lines, tends to make the zones of brecciated rocks more complex. As a result the deposits are, on the whole, extremely irregular. In at least one part of the district there is well-defined evidence of two periods of movement accompanied by fracturing and faulting of the rocks, both periods having been followed by ore deposition.

In connection with the phenomena of folding and faulting, shear zones and joints of compression and tension have been extensively developed, mainly in the cherts. Adjustments of small amount, also, have taken place along the bedding planes. The effects of these different movements vary with the rocks. The shales have yielded to stresses by folding or by faulting; the limestones by folding and faulting with occasional complex fracturing. Stresses in the cherts, which are generally extremely brittle, are nearly always relieved by fracturing, more or less complex, and by brecciation, though occasionally by flexure. Many of the cherts are so brittle that only a slight amount of movement is necessary to cause complete brecciation, simple folding being frequently sufficient. The brecciated cherts are often more or less firmly recemented, sometimes by a black secondary chert frequently containing disseminated sphalerite; sometimes by free sphalerite or calcite, or by both. In many cases the cherts are thoroughly crushed, while still showing their original bedding planes. Examples have been noted of heavy-bedded cherts which have been cut by joint planes in several directions, the loosening of the mass by slight faulting or other cause giving rise to "bowldery ground" such as is characteristic of many of the mines. It is probable also that, during folding, arching of the cherts occurred in some places, and that later, in many instances after the spaces had been filled with the material which now appears as the black secondary chert, the arches were broken down. It is mainly in the brecciated cherts that the ore bodies occur.

ORE DEPOSITS.

Minerals.—The principal minerals of the Joplin district are sphalerite (locally called "jack"), galena ("lead"), calcite ("tiff"), dolomite ("spar"), marcasite and pyrite, mainly the former (both called "mundic"), chalcopyrite ("copper"), cerussite and anglesite (both known as "dry-bone"), calamine ("silicate"), and smithsonite. Calamine and smithsonite have generally been confused in this district, and most of the smithsonite, which in reality occurs more frequently than has been heretofore supposed, has been mined as "silicate."

Distribution of ores and minerals.—Of the lead and zinc ores the sulphides, sphalerite and galena, occur for the most part below the level of underground water; the sulphate and carbonate of lead and the carbonate and silicate of zinc, being all oxidation products of the sulphide ores, occur mainly above that level, together with the more or less oxidized gangue and country rock. The deposits below groundwater level represent the concentrated ores, both those of first concentration and those of secondary enrichment. They are frequently associated with more or less marcasite or pyrite, though these are as a rule inconsiderable in amount. In these deposits the galena is usually found at the upper levels (except in sheet ground, described hereafter) filling fractures in broken or brecciated cherts, and usually associated with more or less sphalerite. Only sphalerite (frequently with some iron sulphide) is found at the lower levels. It occurs (1) as a cement in chert breccia; and (2) disseminated in a black, secondary chert which cements the brecciated cherts and also occurs in lenticular bodies along the bedding planes in sheet ground. Sphalerite is also found in small quantities disseminated in shale, in selvage, in mud, in limestone, or in dolomite.

To sum up, the vertical distribution of the ores shows:

First. Above underground water level, galena and occasionally some sphalerite; also the oxidation products, the carbonate and sulphate of lead and the carbonate and silicate of zinc.

Second. Below underground water level, the sulphide zone. Sometimes, but not always, galena dominates in the upper part of this zone, with sphalerite dominant in the lower and greater part of the zone. This succession does not always hold, and some mines have yielded mainly galena throughout, while mines yielding sphalerite with little or no galena are common. In the typical sheet ground galena and sphalerite usually occur together and associated with marcasite.

Forms of ore deposits.—In considering the forms assumed by the ore deposits, the ore bodies in the mines of this district may be roughly divided into two classes, (1) horizontal or nearly horizontal deposits; and (2) vertical or inclined deposits. The first class includes the tabular bodies of ore known as blanket veins or sheet ground. Deposits belonging to this class are mainly limited in occurrence to a belt extending from the town of Duenweg northwesterly between Webb City and Carterville to Oronogo. They reach their greatest development south and southeast of Carterville. The rocks in which the ore occurs are bedded cherts, horizontal or nearly so. The ore is found mainly along the bedding planes, though it also occurs in seams in the somewhat broken beds. Much of that occurring along the bedding planes is disseminated in a dark secondary chert which appears to fill cavities left by the removal through solution of limestone lenses. The ore is mainly sphalerite, with a minor proportion of galena, and a still smaller amount of marcasite. Deposits of this form are always near ore bodies belonging to the second class.

The latter may be divided into (1) linear deposits (runs), (2) circular or elliptical deposits, and (3) irregular deposits. The linear deposits consist of comparatively narrow bodies of ore, either vertical or inclined, following a roughly uniform direction. The ore is as a rule mainly or wholly sphalerite; where it is associated with galena the latter occurs usually in the upper part of the deposit. The sphalerite is found both disseminated, for the most part in a dark secondary chert matrix or in selvage, and cementing chert breccia or lining interstices of the breccia or solution cavities in limestone or dolomite. It is often associated with calcite and pink dolomite. The rocks in which the ore occurs are generally brecciated cherts which have been recemented to a greater or less extent, either with black secondary chert or with calcite, sphalerite, dolomite, or galena, either separately or in combinations of two or more. In the vicinity of Joplin this breccia with its ore occurs almost without exception against a barren wall of chert and limestone, the latter altered to a coarse-grained gray dolomite, apparently closely connected with the deposition of the sphalerite. In these same deposits galena, where it occurs, is usually found filling cracks in the fractured cherts, near the upper limits of the sphalerite and for the most part near its outer margin, i. e., away from the dolomite.

The chert breccias in which the linear deposits occur are due largely to faulting, though to a minor extent developed by folding. Breccias produced by folding may be associated with those resulting from faulting. The ores in the former occur, as a rule, along the flanks of the folds. Where two faults meeting at an angle have developed at the same time, the brecciation, with its accompanying deposit, formed along one fault, instead of crossing the other fault at the point of meeting, may take the direction of the intersecting fault, thus forming one continuous deposit; and the two faults, instead of meeting at an angle, may be joined by a curve. Such deposits are closely related in manner of formation to the deposits of the following type.

Circular or elliptical deposits are a modification of the linear deposit. A horizontal section of these ore bodies would have the form of a roughly circular or elliptical ring, inclosing a central barren "core."

The deposit as a whole has roughly the form of either a truncated cone or a dome, both types being commonly associated with an irregularly circular or elliptical area of shale at the surface, over this central portion. The ores of the circles are similar in character to those described under linear deposits. In all the important cases studied, the circle has been formed by the intersection of faults. Small circular deposits are sometimes developed on the flanks of a dome produced by folding. In all the circular deposits near the city of Joplin which were examined, the inner walls were of the dolomitized limestone with chert.

The vertical extent of the ore body, in both linear and circular deposits, may be limited to a few feet or it may continue for a hundred feet or more. The occurrence of the ore is not confined to a particular horizon, but it may be met at any level where the conditions were favorable for its deposition, and it may be found at several levels, one above another, with barren or nearly barren ground between.

Under the head of irregular deposits may be included all such ore bodies as do not correspond to any of the foregoing types. They are formed in breccias due either to complex folding or faulting, or to folding combined with faulting, and have no definite form. They may in most cases be considered as combinations of types already described.

Individual runs of ore, associated with one or more faults or folds, may have a horizontal extent ranging from a few feet to one-fourth mile or more. Although there are areas in which no systematic arrangement of the individual ore bodies can be discerned, in most cases they can be grouped along a zone of faulting or folding, within which they may or may not show a general linear or parallel arrangement; or the main lines parallel to the general direction of the zone may be associated with minor lines at an angle with it. Such zones usually have the same general trend as the main system of faulting for the part of the district in which they occur. There are several important systems of faults and folds in the Joplin district which vary somewhat in direction from place to place, and of which the most prominent throughout the district has a general northerly or northwesterly trend. A second important system having a general easterly or northeasterly direction sometimes predominates, though it is usually associated with the other and subordinate to it.

The principal structural disturbances of the Joplin district appear to have been concentrated along certain lines or belts having the same general trend as the more pronounced zones of ore deposits, which group themselves roughly along these belts. The three main belts of the district are (1) the Joplin belt, including the zones immediately around Joplin and northward to Tuckahoe, with the outlying groups southward to Shoal Creek and northwesterly to Carl Junction; (2) the Galena belt, including the deposits around Galena and just north and south of it; (3) the Webb City belt, including the mining zones from south of Duenweg northwesterly between Webb City and Carterville to Oronogo and beyond. Of these the Joplin belt is characterized by the common association of the sphalerite with dolomitized limestone (as already noted), while in the Galena and Webb City belts dolomite is of comparatively rare occurrence. The latter belt is characterized by extensive sheet deposits which are either entirely absent or unimportant in the other belts. Around Joplin itself the breccias on the east side of the town are cemented mainly with calcite, and black secondary chert is not common, while on the west side of the city black chert is common, and in places forms the far larger proportion of the cement of the brecciated cherts.

Deposition of ores.—In this district as elsewhere, the conditions governing ore deposition are partly physical and partly chemical. The physical conditions are those governing the circulation of underground waters in general; the chemical conditions are more complex, and as yet are only partly understood. Lead and zinc sulphides are known to be widely distributed in minute quantities in both the Carboniferous and Cambro-Silurian rocks. The underground circulation probably takes lead and zinc sulphide from all the rocks where conditions are favorable to oxidation and solution, tending to concentrate the ores as sulphides wherever favorable conditions for this process are met. The lead- and zinc-bearing waters come from both the Carboniferous and Cambro-Silurian rocks, and entering at the surface east of the Joplin district, they have flowed and still flow down the dip of the rocks. Reaching the Joplin district they meet conditions favorable to primary concentration, and the ores are deposited. It is believed that such deposition is still taking place, as it has done in the past.

As the waters which give rise to the primary concentration flow down the dip of the rocks their motion is partly descending until the Joplin district is reached. There the waters coming from the Carboniferous rocks have, on the whole, a lateral motion, while those bringing lead and zinc from the Cambro-Silurian into the Carboniferous rocks are, on the whole, ascending. The direction of flow of the underground waters is not in general a fixed factor in ore deposition, but solution and redeposition of ores may take place in waters having either an ascending, descending, or lateral motion, provided other conditions are favorable to oxidation and solution at one point and to reduction and precipitation at another.

Although this process of primary concentration is still effective, it was far more important when the entire district was covered with the comparatively impervious Coal Measure shales, and the conditions were more favorable than now to an artesian circulation. When erosion had largely removed this covering from the district, and had brought many of the ore deposits near or quite to the surface, within the reach of the downward-moving waters containing oxygen, the ores became oxidized to sulphates. The sulphate of lead (anglesite) underwent further alteration to the carbonate (cerussite). The sulphate of zinc, reacting with the limestone or with the secondary chert which contained the ores, replaced the former with smithsonite and the latter, in part at least, with calamine, which also filled small cavities in the rocks. As the galena is less easily oxidized than the sphalerite, and its oxidation products are less soluble, the oxidized lead products are generally found nearer the surface than those of zinc. The oxidized zinc ores extend generally from the surface, or close to it, downward to a short distance below ground-water level. In all observed cases the oxidized products have been deposited close to the place of original sulphide concentration, and are associated with secondary chert leached of its formerly contained sphalerite—the honeycomb rock of the miners.

During the process of oxidation, carbonation, or silicification of the ores some of the products of oxidation of the sulphides were carried in solution below the level of underground water, where they were redeposited as sulphides. Gradually, also, the oxidation products deposited above ground-water level were taken into solution by surface waters and carried downward and redeposited in the same way. These sulphides, together with those of primary concentration, form an enriched zone, which is greatest not far below the level of underground water, and decreases downward. In the Joplin district the enrichment of the sulphide ores has resulted not in a better grade of the ore already existing, but in an increase in the quantity of the ore of the enriched zone. The lead sulphide is deposited at the highest levels, together with more or less sphalerite, and decreases in amount downward, while the sphalerite increases, so that in depth the latter dominates. Pyrite and marcasite are relatively unimportant in the Joplin district, and it can not be stated definitely that they are more abundant, on the whole, at one level than at another.

Where ores of secondary enrichment have been brought near the surface by the wearing down of the land through erosion, they would be acted on in the same way as ores of primary concentration, and would be again concentrated below ground-water level. As the Joplin district, however, has been so little eroded since the removal of the Coal Measure shales, it is believed that this concentration of enriched ores is of little importance.

LEAD, ZINC, AND FLUORSPAR DEPOSITS OF WESTERN KENTUCKY.

By E. O. ULRICH and W. S. TANGIER SMITH.

GEOLOGY AND GENERAL RELATIONS.

By E. O. ULRICH.

INTRODUCTION.

During the summer and fall of 1902 a party consisting of the writer and Dr. W. S. Tangier Smith, with two field assistants, Messrs. A. F. Crider and F. Julius Fohs, was engaged in an extended investigation of the zinc, lead, and other valuable mineral deposits of western Kentucky and, in less detail, of those occurring on the northern side of the Ohio River in Pope and Hardin counties, Ill. The latter counties, together with the counties of Crittenden, Livingston, Caldwell, and adjacent portions of Christian, Trigg, and Lyon, in Kentucky, are embraced in a lead and zinc district differing in several respects from the other lead and zinc districts of the Mississippi Valley. This district differs from the others in the presence of basic igneous dikes, in the ores occurring principally along fault lines in true fissure veins, and, finally, in having the lead and zinc ores almost invariably associated with fluorite, the latter as a rule forming the most abundant gangue mineral.

The recent work in western Kentucky consisted largely in the verification and correction of the mostly unpublished results of a study of the geology of the three counties of Caldwell, Crittenden, and Livingston carried on by the writer in 1889 and 1890, while a member of the geological survey of Kentucky. The developments of the past decade permitted us to add many new observations and to advance the geologic knowledge of the district to a point where it is possible to describe the ore deposits and the systems of fractures and faults in and along which they occur as well as the geologic formations and their geographic distribution in considerable detail. The following brief statement, however, is to be viewed merely as an advance publication of results and conclusions that will be more fully described, and will be illustrated, in a report now in preparation.

DEVELOPMENT.

History.—The ore deposits of this district have been known to settlers since early in the last century. The first attempt to mine them was made by a company headed by President Andrew Jackson. The operations of this company were carried on in Crittenden County, Ky., their shaft being sunk on the Eureka vein within 100 yards of the present main shaft of the Columbia mine. Between that time and the beginning of the civil war other equally primitive attempts were made to mine the ore deposits, most of them in Livingston County, notably at the Royal mines near Smithland.

With the general resumption of mining activities in the seventies, and especially in the later years of that decade, when some excitement was evoked by the successful operations at Rosiclaire, on the Illinois side of the Ohio River, work was resumed at several of the mines in western Kentucky. Considerable activity, indeed, was shown in the development of the Columbia mines, in Crittenden County. In 1878, however, nearly all mining operations in the district ceased, because the market value of lead, which up to that time was the only mineral sought here, dropped to so low a figure that with the lack of transportation facilities mining operations became unprofitable.

The demand for American fluorspar which set in at about this time served to maintain a small degree of interest in mining in the southern portion of the district, but only for a few years, when the same lack of cheap transportation and a slight drop in the value of the product rendered the otherwise equally good Kentucky mines incapable of competing with the more fortunately situated Rosiclaire mines.

In the last five or six years interest in the district has again revived, and, for the first time in its history, the numerous veins and mines are being systematically prospected and developed.

Production.—It is impossible now to make any satisfactory statement concerning the output of the mines of the district prior to 1899, but it doubtless amounted to a thousand or more tons of lead and many times that amount of fluorspar. Estimates of the production of the Illinois mines were not secured, but those in Kentucky produced, according to statements of shippers, about as follows: Fluorspar, 1899, about 5,000 tons; 1900, 10,500 tons; 1901, 13,700 tons, and the first seven months of 1902, 12,000 tons. Zinc carbonate, 1901, 1,136 tons; first seven months of 1902, about 2,450 tons. The production of lead was insignificant, chiefly because the mines in which galena is an important or predominating ore have only recently resumed operations or are awaiting improved transportation. The present year, however, promises to see a notable increase in the production not only of lead but also of zinc, and a smaller increase in the output of fluorspar.

Prospective development.—The mining operations so far carried on in the district can not be considered as a satisfactory test of its possibilities. It seems probable, however, that a field containing mines that at various times were operated with profit for the lead ore alone, the zinc ores and fluorspar being left on the dump, should under economic and competent modern management become a producer of some importance. Two obstacles stand in the way at present. The first is a lack of a cheap and thorough method of separating the fine-grained sphalerite from the fluorspar with which it is almost invariably associated. Now that the need of such a process is emphasized, it is possible that a satisfactory method will be discovered before the second impediment—lack of transportation—can be overcome. Many men are working on the problem and already several promising if not wholly satisfactory processes have been patented. A plant to do this work has just been completed in Paducah and another is being erected in St. Louis, while a third process is being perfected at a plant near Salem, Ky.

The second difficulty in the way of the development of the district is one common to all new fields, namely, a lack of transportation facilities. The roads throughout the district are almost without exception very bad, rendering successful mining where the wagon haul exceeds 5 miles impossible. Fully two-thirds of the entire district lies more than that distance from the lines of the Illinois Central Railroad which traverse it. However, two navigable rivers, the Ohio and the Cumberland, are being used in a small way, and this cheap mode of shipment will doubtless exert a considerable influence on the development of the field.

GEOLOGY.

Stratigraphy.—The geologic formations exposed at the surface or penetrated in mining in the area under consideration are all of Carboniferous age, the lowest being the St. Louis limestone of the Mississippian series, while the highest contains the two lower coal beds of the Coal Measures and is confined to the eastern and northern edge of the district. These lower Coal Measures constitute the western border of the western Kentucky coal basin, which extends into the district from the east and north. As is proved by outliers, remaining chiefly because they crown blocks thrown down in the faulting of the region, this border once extended much beyond its present limits, the basal Coal Measures perhaps having originally covered the whole of the area. The base of the Coal Measures or Pennsylvanian series is here always formed by a coarse brown sandstone containing more or less abundant quartz pebbles. Immediately beneath this come the sandstones, shales, and limestones of the Chester group, the rapidly alternating beds of which have a total thickness of about 600 feet. Next beneath and intervening between the base of the Chester and the top of the St. Louis limestone is the Princeton limestone, 200 to 250 feet thick, which is light-gray and compact and includes more or less shale in its upper third, and more massive, oolitic, and light-gray or nearly white in its lower two-thirds. Between these two divisions of the

Princeton there is a very persistent layer of calcareous sandstone, varying from 1 to 12 feet in thickness.

The St. Louis limestone underlying the Princeton limestone has a thickness of about 500 feet. Its basal portion is also oolitic, but of a darker color than the Princeton oolites. The remainder consists of dark-gray, highly siliceous limestone, the silica of which, on the weathering and decomposition of the limestone, to which it is more readily subject than the other limestones, is concentrated into nodular masses of flinty chert varying from 2 to 8 inches in thickness. These rounded lumps often occur in great abundance and are highly characteristic of the formation. Decomposition of the St. Louis limestone is always deep, sometimes extending to a depth of 50 feet beneath the surface, so that the limestone itself is rarely seen except along rapidly eroding streams. Owing to complex faulting the areal distribution of these formations is very irregular and patchy.

Beneath the St. Louis limestone there is an even more siliceous and earthy limestone, representing the Tullahoma formation and Fort Payne chert of the south, the Keokuk and Burlington limestones of western Illinois, and the Boone chert of Missouri and Arkansas. This horizon holds most of the zinc and lead deposits of the Joplin district and some of the deposits found in northern Arkansas. Whether it is ore bearing in this district or not can only be determined by sinking on the veins to its horizon.

Structure.—The most marked structural feature of the district is an extensive series of fractures, nearly all of which are accompanied by more or less faulting. All available evidence tends to the conclusion that vein deposits of some kind occur in all the fractures where either one or both walls are limestone, excepting where the fractures are occupied by peridotite dikes. These usually are accompanied by only a slight displacement of the strata, and, with a single known, but very notable, exception, are not associated with valuable minerals. It is a fact that nearly all the mines of the district whose value has been proved by development, and nearly all the promising prospects, have either the St. Louis or the Princeton limestone on one or both sides of the fracture. As to the few exceptions where a promising prospect occurs in a Chester area, in every case known to me one of the limestone beds of that group of rocks forms either the hanging or the foot wall of the fissure. We have met with several cases in the district that might appear to be exceptions to this rule, notably the Clements mine on the Crittenden Springs property, and the easternmost shaft of the Tabb mines. Critically examined, however, the exceptions prove to be more apparent than real, since in the first of these cases one of the walls of the adjacent main fault is the Princeton limestone, and in the other the St. Louis limestone, the openings in question being driven in fissures running parallel with and sudsidiary to the main faults. These subsidiary fissures were probably formed by large slices of country rock breaking away from the hanging wall, which is usually jointed parallel with the fault plane. If this is true then the two fissures should unite at some distance beneath the surface.

There are at least 30 faults in the district, with maximum displacements of from 400 to 1,400 feet, and traceable for distances of from 2 to 20 miles or more. Since many of these are connected with a series of subsidiary fractures and faults, whose displacement rarely exceeds 200 feet, they may be distinguished as the main faults. Of the subsidiary fissures, there are probably hundreds, and it is the belief of the writer that many of them will prove more productive, for equal lengths, than the veins in the main faults.

As a rule the fault lines are practically straight, apparent slight deflections in the course being generally due chiefly to the dip of fault planes, which is usually considerable, upon the line of outcrop over the undulating surface. Occasionally, however, and perhaps oftener than the obscured surface indications now lead us to suspect, the faults are broken up into series arranged en échelon. The Tabb fault is a good example of the latter type.

When the displacement of the strata is sufficient to bring two lithologically distinct formations into juxtaposition, as, for instance, when the sandstones of the Coal Measures or Chester are thrown down to the level of the Princeton or St. Louis limestones, there is no difficulty in tracing the fault; but where the displacement is insufficient to produce this result very close stratigraphic comparisons are required to establish its presence. Indeed, the difficulties proved almost insurmountable in the cases where the faults traversed the deeply weathered areas occupied by the St. Louis limestone. In the cases where different members of the Chester formation are on the two opposite sides of the fault plane the difficulties are not so great, since the various members of the Chester formation are usually distinguishable without much trouble, and the line of the fault is very commonly marked by protruding masses of quartzose sandstone.

Taken as a whole, the fractures fall into at least two (and probably four) well-defined systems, one trending northeast, the other northwest. The northeasterly system is the more prominent and its fractures perhaps more generally mineralized than those of the other systems. When platted on a map this system of faults, on the Kentucky side of the river, presents an obscure fan-shaped arrangement, radiating and diverging eastwardly from the region between Salem and Pinckneyville, in Livingston County. The ribs of the fan pass through Crittenden County, and its successive lines become more and more easterly as we approach the southern boundary of that county and enter Caldwell, where they strike from a little north of east to a few degrees south. It is to be understood that the fan-shaped arrangement of the main fractures of this system has no known genetic relation to the dikes of the district. No igneous rocks are known to occur within 6 miles of the imaginary converging point, while the trend of all the dikes sufficiently known to permit a statement concerning their directions is essentially at right angles to these fractures, being northwest instead of northeast.

A well-defined northwest system of fractures, to which probably all the known dikes of the district belong, finds its best expression in the western half of Crittenden County. Here the trend of the dikes and faults belonging to the system varies between N. 30° W. and N. 37° W. The fractures of this system usually caused only a very limited displacement, but they contain some of the largest mineral deposits of the district, notably at the Eureka, Old Jim, and Holly mines.

The northeast faults found in the northern and eastern parts of Livingston seem to indicate a distinct third system, extending across the Ohio from Hardin and Pope counties, Ill. Similarly, the northwest fractures occurring in the northern parts of Crittenden and Livingston counties, having a direction varying but a few degrees either way from N. 20° W., probably belong to a fourth system, which, like the other, has its strongest development in the Illinois counties mentioned.

The fractures, whether mineralized or not, frequently furnish channels for descending underground waters, as is evidenced by the corrosion of the walls, forming in the case of some of the apparently unmineralized fractures open fissures or crevices filled with red clay. Sink holes are common along some of the fractures, and caverns are known to follow them for short distances.

The formation of the mica-peridotite dikes, of which seven or eight are known in Crittenden County, and one in Pope County, Ill., is believed to have taken place prior to the extensive faulting of the region. They were probably produced by an accumulation of molten matter within this portion of the crust of the earth, causing its elevation and fracturing and subsequent intrusion of the igneous masses. The strain on the continuity of the strata produced by their elevation caused the relatively brittle limestone to part along certain lines and form fissures. The more pliable shales and sandstones of the Chester, however, frequently accommodated themselves to the strain, so that the intruded mass failed to pass through them, but spread itself horizontally in sheets between the bedding planes. The fissures occupied by the dikes are generally very nearly vertical and quite straight in their courses, and although narrow, varying from about 2 feet to nearly 25 feet in width, some of them have been traced for miles.

THE VEINS AND VEIN MINERALS.

By W. S. Tangier Smith.

The well-defined veins of this district almost without exception fill fissures due to faulting. They are found in the Princeton, St. Louis, and Chester formations; mainly in the first two. Where two of the formations have been faulted into juxtaposition, veins frequently occur along the fault or in a fissure not far from and parallel to the fault. Veins have been occasionally noted in groups of two or more, either parallel or arranged en échelon. Their width is variable; the maximum thus far recorded—in the case of well-defined veins—is nearly 15 feet. Most of the important veins, however, do not exceed 6 or 8 feet in width. The veins all dip at a high angle.

Most of the veins show distinct evidence of movement either in the displacement of the beds on the opposite sides of the fissure or in shearing with or without well-defined slickensiding. The shearing occurs both in the vein itself—especially near the walls—and in the country rock, where it may extend as much as 50 feet from the veins.

The walls of the veins are usually, though not always, well defined, and are frequently marked by pronounced slickensiding. One or both walls are often fractured where the vein is in limestone, and are frequently much seamed with minute veins of calcite or fluorite. This seaming also frequently accompanies ordinary fracturing of the limestone where no vein has been formed. The shear planes are sometimes marked by thin, clayey partings, especially in the Chester sandstone. Also, where the veins are adjacent to this formation, dragged-in shales along the walls are not uncommon. These sandstones, where intersected by fissures, whether the latter are filled with vein matter or not, or where they have been filled with igneous rock, have been as a rule silicified, to a greater or less extent, to a hard quartzite. This quartzite, being resistant to erosion, appears in dike-like forms above the surrounding rocks, the shearing giving the effect of vertical or highly inclined bedding.

The principal minerals of the district are galena and its oxidation products; sphalerite ("blende") and its oxidation products, smithsonite ("carbonate"), and hydrozincite; pyrite (or marcasite), greenockite, fluorite ("fluorspar"), barite, calcite ("calc spar"), quartz, and ankerite. Nearly all of these occur either in the veins or in connection with them. In addition, bitumen is occasionally found in the veins.

Fluorite.—Fluorite is by far the most important of the vein minerals, composing, as a rule, the greater part of the vein, the remainder being made up of a varying proportion of other minerals, with dragged-in country rock. In some cases the vein is composed almost wholly of fluorite; in others the proportion of other substances is so large as to make it unprofitable to work the deposit. The associated minerals and rock fragments may be found throughout the vein, but in general they are most abundant toward the margins. The fluorite veins frequently show a pronounced banding, due either to shearing or to a variation in the grain of the fluorite in bands parallel to the walls of the fissure.

In the Chester sandstone fracturing has frequently resulted in brecciation rather than in a well-defined fissure, and the breccia may be more or less completely cemented with fluorite. Barite may occur under similar conditions, and both are found replacing sandstone to a greater or less extent.

The usual mode of occurrence of fluorite is massive and granular. It is also found as cubic crystals in vugs or coating the walls of small fractures in the country rock; but well-crystallized occurrences are comparatively rare. It is generally translucent, though rarely transparent; its color is usually white, sometimes purple, and occasionally yellow.

Calcite and barite.—Of the minerals associated with the fluorite calcite is the most abundant. It occurs as white crystals or coarsely granular masses scattered through the veins. Barite is next in amount, though it is not found in most of the veins. Where it occurs with the fluorite it is apparently intergrown with it. There are also in both the St. Louis and the Princeton limestones veins of fine-grained barite occurring either alone or with a minor proportion of fluorite; but so far, except in one instance, this mineral has not been found in sufficient quantity to pay for mining.

Galena.—Galena occurs in many of the fluorite veins, sometimes in quantities large enough to make it profitable as a by-product, though in most cases it is insignificant in amount. It usually occurs in grains and crystals of varying size, though generally small, disseminated in the fluorite, for the most part near the walls of the veins, and frequently concentrated in lines parallel to the walls. Occasionally it is met in elongated columnar forms, due to shearing in the veins.

Sphalerite.—Fragments of the wall rock, whether quartzite or limestone, are common in most of the veins. They have in some cases been replaced by fluorite to a greater or less extent. Sphalerite, which is found in many of the veins, occurs mainly as minute grains disseminated in the included fragments of limestone, frequently concentrated near the contact between the fragments and the inclosing fluorite. It is also found occasionally disseminated in the fluorite and in the wall rock where this is of limestone. This fine-grained sphalerite is more abundant, on the whole, than the galena, and will prove of economic importance if a satisfactory method of separating it from the associated fluorite is found. Sphalerite is also found here and there (especially in the region southwest of Crittenden Springs) in coarser form and in greater amount.

There are a number of deposits in which sphalerite or its oxidation products have been found apparently unassociated with fluorite, notably in the Old Jim mine, where the ore (smithsonite with some hydrozincite) occurs adjacent to a dike of peridotite. Here as in other similar instances, however, mining has not been carried deep enough to show the character of the unoxidized ores.

Effects of oxidation.—Above ground-water level the oxidized and carbonated surface waters have removed from the veins much or most of the calcite which they contained, as well as the included fragments of limestone, and have altered the country rock to a greater or less extent, but they have had comparatively little effect as yet on the fluorite and barite. The galena has not been oxidized to any considerable extent, and is still found near the surface. The fine-grained sphalerite has been largely removed from the veins, having been in part altered to smithsonite (zinc carbonate), which in turn is being slowly dissolved and removed by the surface waters. At the Old Jim mine the zinc salts in solution, reacting with limestone, have replaced it here and there with zinc carbonate. The result of the leaching out of the calcite and limestone fragments has been to leave the fluorite in a more or less honeycombed condition. Where it was not originally associated with these substances it is usually found in lumps. Wherever the grains have been loosened or separated it is found in a sandy or gravelly form known as gravel spar. In all these cases it is usually associated with red clay formed as a residual product on the solution of the adjacent limestone.

The depth of oxidation along the course of the veins is variable and may be as much as 100 feet or more. In a few cases fresh, unaltered vein matter and country rock come nearly or quite to the surface. Descending surface waters have occasionally formed channels along a fissure, thus carrying oxidation and oxidized products considerably below the normal level of underground water.

Vertical distribution of vein minerals.—As far as the deposits have been developed it can not be proved that the fluorite, on the whole, actually decreases with depth, though it is said to do so in some cases. This assumed decrease may be merely comparative, since the associated calcite in many instances appears to increase with depth, although it is quite probable that in general this is due merely to the fact that it has been removed by surface waters at the higher levels. Galena, in general, appears to be most abundant near the surface, and on the whole to decrease with depth, though in many instances it is not apparently more abundant at one level than at an another. Above the level of underground water fine-grained sphalerite has been generally removed or changed to carbonate. Below this level it seems probable, from what has been observed, that it does not materially increase in amount with depth. The coarser occurrences of the sphalerite may be due to secondary enrichment, the finer-grained mineral having been oxidized and carried downward in solution below ground-water level, where it was redeposited in the coarser form. Connected with these deposits there appears to have been also some secondary concentration of the galena. No positive statement can be made on this point, as none of the mines yielding coarse sphalerite were accessible below ground-water level at the time the region was visited by the writer; but if this is the true interpretation of the facts, these deposits of coarser sphalerite will be found to be most abundant just below ground-water level, and will tend to decrease with depth till only the finer-grained ore is found, the latter representing the primary concentration.

ZINC AND MANGANESE DEPOSITS OF FRANKLIN FURNACE, N. J.[a]

By J. E. Wolff.

According to a tradition, this celebrated occurrence of zinc and manganese ore was noticed and prospected as early as 1640, but Lord Sterling, after whom Sterling Hill is named, did the first mining in 1774. About this time several tons of the red zinc oxide were shipped to London, yet the first description and analysis of this mineral were given by Dr. Bruce in 1810, and of franklinite by Berthier in 1819. The Mine Hill deposits were worked for iron ore about the beginning of the last century, but there was not much mining for zinc until after 1840. Different parts of the deposits have been worked more or less continuously since then by different companies and there has been long litigation, which has been finally settled by the consolidation of all the interests. The ores are now treated at the mines by magnetic separators, which separate the franklinite (as well as the garnet and other impurities) from the willemite and zincite, while the calcite is removed by jigging. The principal uses of the zinc ores are for metallic zinc and zinc white, and of the manganese for Bessemer steel.

The ores occur at Mine Hill (Franklin Furnace) and Sterling Hill (Ogdensburg), localities 3 miles apart, and at no other place has exploration found more than traces of the ores. The deposit is in the white Franklin limestone, and at Mine Hill, where the surface and underground workings are best developed, lies about 30 feet from the gneiss boundary on the west, along the west limb.

The ores consist of zincite, the red oxide of zinc (ZnO), containing 94 per cent zinc oxide and 6 per cent manganese oxide; willemite, silicate of zinc (Zn_2SiO_4), containing 67 to 69 per cent zinc oxide and 5 to 10 per cent manganese oxide; and franklinite (FeZnMn) O $(FeMn)_2O_3$, containing 56 to 67 per cent ferric oxide, 4 to 10 per cent manganese sesquioxide, 7 to 23 per cent zinc oxide, 10 to 16 per cent manganese oxide. The ores are usually accompanied by varying proportions of calcite. The contrast between the deep-red zincite, green willemite, lustrous black franklinite, and white calcite is very striking. The proportions of these minerals vary constantly, so that sometimes zincite is abundant, sometimes only present in traces, and

[a] From the descriptive text of the Franklin Furnace folio, Geologic Atlas of the United States—in preparation.

so with the relative proportions of the other three. The size and shape of the minerals also vary greatly. A common form is the "shot" ore in which irregular rounded franklinite, willemite, and calcite grains, with or without zincite, occur together without marked banding; at other times the ore is finely banded or foliated, and these minerals are then seen to be in small flattened lenses or elongated pod-like masses parallel to the foliation; or such forms may be due to an aggregate of several grains. At other times large round masses of zincite, 1 or 2 inches in diameter, are scattered through coarse calcite like a pudding stone, or franklinite occurs similarly in rough octahedral crystals. These four minerals have evidently been formed contemporaneously, for each is found inclosed in the others and neither in general has any distinct external crystal planes, although the franklinite has a tendency to occur in rounded octahedral grains. These structures in general simulate so closely that of the associated gneisses that they must be classed together.

GEOLOGIC OCCURRENCE.

At Mine Hill the zinc deposit is much like a bedded deposit, and forms a band which outcrops on the surface as far north as the extreme point of the gneiss band lying west of the white limestone, and runs southwest for about 2,700 feet (Trotter and other mines), when it makes a sharp curve and runs northeast about 600 feet (Buckwheat mine) as far as the trap dike, where it disappears from the surface, and has been worked underground in a northeast direction for about 600 feet on a pitch of 27° to 32°. By diamond-drill exploration the further underground continuation of this deposit to the northeast was found at depths of 1,000 feet more or less from the surface, a shaft was sunk, and extensive mining operations are carried on (Parker shaft workings).

The west limb of the deposit is known as the "front vein" and the east limb as the "back vein," while the connecting point is known as the "South chamber."

Along the west outcrop the ore body has a width toward the north end of 15 to 25 feet. It is separated from the gneiss by 30 feet of limestone and dips east at from 55° to 60°. The distance from the gneiss is remarkably constant, for the same 30 feet of limestone between the foot wall of the ore deposit and the gneiss is found at the surface, and 900 feet vertically below and 1,200 feet along the dip. The foliations of ore and limestone are conformable.

At the Trotter mine the ore body is divided by a large mass of granite, which was also found underground for a long distance. South of this mine the deposit widens considerably. It has been followed down about 500 feet along the dip from the outcrop of the west vein, widening and narrowing and with some variation in the angle of dip.

At the Buckwheat mine the ore has been worked from the outcrop down nearly 300 feet with the dip, which is very steep to the east, and at the Parker shaft workings 1,000 feet from the surface.

The comparison of the structure and extent of the workings along the west vein and those of the Parker shaft shows an evident continuity of the deposit, dipping steadily downward to the east from the outcrop for 1,300 feet, where it begins to rise again for 150 feet, when the ore terminates. In the basin thus formed, and also in the part forming the eastern edge, there is a great thickening of the ore. At the Buckwheat mine the same structure is found, a crosscut driven west to the west vein shows that the foot wall of the east vein curves around to form the hanging wall of the west vein, the width of the ore in the north slope of the Buckwheat mine is about double the normal width of the two veins (70 feet in the first, 35 or less in the second), and the limestone forms an arch over the ore, the foliation of which, and the structure of the franklinite bands in the limestone roof, conforming to the arch of the ore, which pitches downward at an angle of 27° to 32°. Putting all these facts together, the interpretation on which all observers agree is that the east and west veins are one continuous plane body of ore folded in a synclinal trough, which narrows to the south and finally spoons out at the surface in the south chamber workings; less positive is the theory that there is a sharp subordinate anticline on the east side, with the two sides compressed together and the axis pitching 27° or more to the northeast. The fact is plain that there is a thickening of the ore and that this thickened shoot pitches northeast at about the same angle as the axis of the main synclinal trough or basin. The compass direction of this axis gradually curves to take a more northerly direction in the Parker shaft workings so as to conform to the strike of the west vein. The pitch also flattens in the north workings to as low as 9°, and certain facts from the diamond-drill records show that the structure is more complicated there, but the data available are too fragmentary to permit a definite conclusion. It is noteworthy that the pitch of 27° in the Buckwheat mine is also to be seen in the gneisses lying just west, an argument for the contemporaneity in present form of the gneiss, white limestone and ore deposit.

In several places in the underground workings at Mine Hill, granite or syenite masses cut the ore. In 1898 several of these were studied in the Parker shaft workings. They run, like the surface granite outcrops, nearly parallel to the general trend of the foliation of the vein and yet cut distinctly across it in places. The granite is fine-grained for several inches from the contact, the ore is hardened for some distance, and between granite and ore there is a band of yellow (Mn) garnet (polyadelphite) mixed with rhodonite, calcite, willemite, franklinite, and a Mn. Zn. pyroxene (jeffersonite?); the granite itself also contains stringers and isolated masses of these minerals. Sometimes a coarse vein-like aggregation of these minerals separates granite from ore. A large number of the rare minerals come from these underground granite contacts, and there can be no doubt that the granite is later than the zinc bed and intrusive into it.

At Sterling Hill there is an analogous structure of east-west limbs of the ore body, outcropping on the surface in a hook and pitching under northeast at both ends, the west vein outcropping about 600 feet from the turn, and the east vein about 1,500 feet.

The west vein has only been worked down a short distance from the outcrop; the east vein in places about 650 feet at an average angle of 50° to 65°.

In the center of the canoe joining the two veins the axis pitches 50° NE. In the mines the pitch of the ore shoots is said to have been generally 65°. At the apex of the trough the limestone is filled with various silicates (diopside, jeffersonite, etc.), and was probably impregnated with franklinite and zinc ores, now mined out. A little farther north a large deposit of calamine was mined, which lay in a bowl-shaped cavity on top of the limestone, and was undoubtedly hydrated ore derived from the decomposition of the higher lying portions of the zinc deposits.

ORIGIN OF THE ZINC DEPOSITS.

The descriptions of the structure and relations of these deposits speak for their contemporaneity in present form and structure with the inclosing white limestone and associated gneisses, and therefore for a period of formation earlier than that of the intrusive granites, although the difference in time may have been small. The ore deposits are often not sharply defined from the limestone foot and hanging walls, and the latter are shot through with franklinite, willemite, etc. Horses of limestone or coarse calcite also occur in the middle of the ore deposit. It is believed that the zinc deposits acquired their present structure and mineralogical composition contemporaneously with the limestone, and that they represented originally a local segregation of the zinc manganese and iron minerals in some other form which may have been originally that of sulphides which were then oxidized to carbonates, and the latter by metamorphism, which caused the loss of carbonic acid with or without the substitution of silica, assumed the present form. Sphalerite (zinc sulphide) has been found very rarely in the ore deposits and only in small isolated masses, and the carbonates are equally rare, so that there is little positive fact upon which to base a theory.

GEOLOGICAL SURVEY PUBLICATIONS ON LEAD AND ZINC.

Many papers relating to silver-lead deposits will be found included in the list on pages 90 and 91 of this bulletin. The principal other papers on lead and zinc, published by the United States Geological Survey, are the following:

BAIN, H. F., VAN HISE, C. R., and ADAMS, G. I. Preliminary report on the lead and zinc deposits of the Ozark region [Mo., Ark.]. In Twenty-second Ann. Rep., Pt. II, pp. 23–228. 1902.

CLERC, F. L. The mining and metallurgy of lead and zinc in the United States. In Mineral Resources U. S. for 1882, pp. 358–386. 1883.

HOFMANN, H. O. Recent improvements in desilverizing lead in the United States. In Mineral Resources U. S. for 1883–84, pp. 462–473. 1885.

ILES, M. W. Lead slags. In Mineral Resources U. S. for 1883–84, pp. 440–462. 1885.

WINSLOW, A. The disseminated lead ores of southeastern Missouri. Bulletin No. 132. 31 pp. 1896.

IRON AND MANGANESE.

Reports on a number of the iron-ore fields of the country have been issued by the United States Geological Survey within the last year, and work in several important iron districts was carried on during the field season of 1902. Summaries, both of the published reports and of the unpublished results of the season's field work are presented below. A paper on the utilization of slags, prepared for the last volume of the report on Mineral Resources, United States, and separately printed, but omitted by error from the bound volume, is here republished. In addition to the papers included in the present section, the ocher deposits of Cartersville, Ga., which are closely allied to the iron deposits of the same region, will be found described on pages 427 to 432 of this bulletin. On pages 214 to 217 will be found a paper on the zinc-manganese-iron deposits of Franklin Furnace, New Jersey, which may be of interest in the present connection. A list of the principal previous publications by the Survey on iron and manganese ores and mining districts will be found on page 256.

IRON ORES OF THE REDDING QUADRANGLE, CALIFORNIA.

By J. S. Diller.

Iron ore (magnetite) occurs in the Redding quadrangle at a number of points on the contact between diabase and the Carboniferous limestone. Numerous prospects have been opened on the contact about Grey Rock, northeast of Bayha and on Pit River, as well as farther northward, opposite the United States fishery. The openings generally show limonite, but it is derived from the decomposition of ore in which magnetite and pyrrhotite play an important role, associated with pyrite, chalcopyrite, light-green fibrous pyroxene, and garnet resulting from contact metamorphism. The prospects are generally made in searching for copper ore, but at one place, about a mile southeast of the United States fishery, on McCloud River, a much more promising opening is operated, furnishing the iron flux at Bully Hill. The ore is chiefly porous magnetite, which is often coated with irridescent and stalactitic limonite, and opened to a width of 40 feet without reaching the limits. Small bands of garnet mixed with pyroxene occur, and traces of copper ores have been reported. Lying essentially upon the contact between the Carboniferous limestone and an igneous rock, the ore is believed to owe its origin largely to this relation. Its extent, however, is a matter of doubt, and the progress of the work disclosing what is underneath is watched with much interest.

Similar bodies occur along the same limestone contact farther north, upon the west side of the McCloud, and should the mass referred to above prove a large deposit it may lead to the development of an important industry in that region.

UTILIZATION OF IRON AND STEEL SLAGS.

By Edwin C. Eckel.

INTRODUCTION.

In recent years the attention of many technologists has been directed to the problem of slag utilization. Certain slags may, of course, be considered as low-grade iron ores, and have been used as such for many years. By far the greater portion of the slag annually produced by iron and steel works is not available for this use, however, and it is only in comparatively recent years that uses have been found for many of these slags. At present slag is utilized extensively in cement and slag-brick manufacture, as a fertilizer, and in the form of mineral wool; to a less extent in the manufacture of alum, paint, and glass; and a considerable quantity is disposed of less profitably for use as road metal, railroad ballast, and in land reclamation. These uses will be discussed in order.

SLAG CEMENT.

Slag cement, properly so called, is the product obtained by pulverizing, without calcination, a mixture of granulated basic blast-furnace slag and slaked lime. This product, though in reality a member of the class of pozzuolanic cements, is usually marketed as "Portland cement," in spite of the fact that it differs from a true Portland cement in method of manufacture, ultimate and rational composition, and properties. Eight plants are at present engaged in the manufacture of this material in the United States, the production for 1901 being about 400,000 barrels, while that for 1902 was in the neighborhood of 800,000 barrels. The writer has discussed the manufacture of slag cement in detail in a recent publication.[a] A brief résumé of the technology of the material in question is here given.

As to composition, the material used in the manufacture of slag cement must be basic blast-furnace slag. Tetmajer stated that the ratio $\frac{CaO}{SiO_2}$ should never be less than unity, and that the best results were obtained when the ratio $\frac{Al_2O_3}{SiO_2}$ gave a value of 0.45 to 0.50. Prost and Mahon later obtained good results from slags in which the

[a] Mineral Industry, Vol. X, pp. 84–95. See also Mineral Resources U. S. 1900, p. 747, where a description of two Alabama slag-cement plants is given.

alumina was much higher than indicated by Tetmajer's ratio, and analyses of slags used in practice are shown in the following table, with the ratios $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$ calculated for each slag:

Analyses of slags in actual use.

Constituent.	Middlesboro, England.	Bilboa, Spain.	Choindez, Switzerland.	Saulnes, France.	Chicago, Ill.
SiO_2	31.50	32.90	26.24	31.50	32.20
Al_2O_3	18.56	13.25	24.74	16.62	15.50
FeO		.46	.49	.62	
CaO	42.22	47.30	46.83	46.10	48.14
MgO	3.18	1.37	.88		2.27
CaS		3.42	.59		
$CaSO_4$			.32		
S	2.21				
SO_3	.45				
$\frac{CaO}{SiO_2}$	1.34	1.44	1.78	1.46	1.49
$\frac{Al_2O_3}{SiO_2}$	.59	.41	.93	.52	.48

Slags allowed to cool slowly are only feebly hydraulic, even if of proper chemical composition. When used in the manufacture of slag cement, therefore, the slag must be cooled as suddenly as possible. This is effected by bringing the slag, as it issues from the furnace, in contact with a jet or stream of cold water. This sudden cooling "granulates" the slag, i. e., breaks it up into porous particles, and has also two important chemical effects. One is that the slag, if of suitable chemical composition, is rendered strongly hydraulic; the other, that most of the sulphur is removed in the form of hydrogen disulphide. After granulation the slag is dried, usually in rotary driers, the Ruggles-Coles being a favorite American type.

The lime used for mixture with the slag should be low in magnesia, well burned, and carefully slaked. At Chicago, where the Whiting process is used, a small percentage of caustic soda is added to the water used for slaking, the effect being to accelerate the set of the cement. After slaking and drying, the lime is ready for mixture with the granulated and dried slag, which usually has received a preliminary reduction in a crusher, ball mill, Kent mill, or other comparatively coarse reducer. The proportions used will vary from 20 to 40 parts of lime to 100 parts of slag. The mixture and final reduction is usually accomplished, in the American plants, in tube mills. The composition of a number of American and European slag cements is shown in the following table of analyses collected from various sources:

Analyses showing composition of slag cements.

Constituent.	Choindez, Switzerland.	Donjeux, France.	Saulnes, France.	Chicago, Ill.	Ensley, Ala.
SiO_2	19.5	24.85	22.45	28.95	27.78
Al_2O_3	17.5	12.10	13.95	11.40	11.70 (Al₂O₃ and FeO)
FeO		3.85	3.30	0.54	
CaO	54.0	49.20	51.10	50.29	51.71
MgO		1.75	1.35	2.96	1.39
S		1.30		1.37	1.31
SO_3		1.35	0.35		
Loss on ignition		5.65	7.50	3.39	

The composition of good slag cements may vary within the following limits: Silica, 22 to 30 per cent; alumina and iron, 11 to 16 per cent; lime, 49 to 52 per cent; magnesia less than 4 per cent; sulphur, less than 1½ per cent. It will be noted that the lime content is lower and the alumina-iron content higher than in a cement of the Portland type. Slag cements also differ from Portland cement in being lower in specific gravity and lighter in color. Normally, they are slower setting than Portland cement, though this defect can be overcome by treatment during manufacture. They are deficient in resistance to mechanical wear, and do not set satisfactorily in dry situations. For use under water or in permanently damp ground, however, they would seem to be of service.

PORTLAND CEMENT FROM SLAG.

True Portland cements, which must be sharply distinguished from the slag (pozzuolanic) cements discussed in the preceding section of this paper, can be made from mixtures of which one element is blast-furnace slag. In this case the slag is ground, intimately mixed with powdered limestone, and the mixture calcined and reground. Two plants are engaged in the manufacture of Portland cement from slag and limestone in the United States. An analysis of the "Universal" brand of the Illinois Steel Company, a Portland cement made from these materials, follows:

Analysis of Universal brand, manufactured by the Illinois Steel Company.

	Per cent.
SiO_2	23.62
Al_2O_3	8.21
Fe_2O_3	2.71
CaO	61.92
MgO	1.78
SO_3	1.32
S	None.
Loss on ignition	0.52

Cecil von Schwarz, in a paper read before the Iron and Steel Institute of Great Britain, has recently described in detail German and Belgian practice in the manufacture of Portland cement from blast-furnace slag. The slag is granulated in order to remove sulphur and to reduce the cost of crushing. The granulated slag is dried and mixed with about an equal amount of limestone. To the mixture is added about $3\frac{1}{2}$ per cent of powdered slaked lime, and their intimate mixing and reduction are accomplished in ball mills and tube mills. About 8 per cent of water is added, and the slurry is then made into bricks, which are dried before charging into the kiln. A ring kiln is used, with coke as fuel. The clinker is moistened, stored for six weeks, and reduced in ball and tube mills.

Analyses of limestone, slag, and finished cement at a typical plant.

Constituent.	Limestone.	Slag.	Cement.
SiO_2	1.6	30 -35	23.70
Al_2O_3	1.0	10 -14	6.14
Fe_2O_3			1.80
FeO		0.2- 1.2	
MnO		3. - 4	
$CaCO_3$	97.0		
CaO		46 -49	59.08
MgO	0.5	0.5- 3.5	1.40
SO_3	0.06	0.2- 0.6	1.30
Loss on ignition			5.70

SLAG BLOCKS.

Slag, run into molds on issuing from the furnace, furnishes blocks which have been used for paving, notably in Philadelphia. These slag blocks are very durable, but objectionable because of their slipperiness. This difficulty has been overcome, in English practice, by casting the blocks in a double-sized mold, with a projection which results in a notch passing around the slag block. The two halves of the block are then split apart at this notch, and the rough fracture surface of each is laid uppermost in paving.

SLAG BRICK.

The manufacture of slag brick can hardly be considered as being more than a specialized phase of the manufacture of slag cement. Slags, approximately of the same composition as those used in cement making, are granulated, dried, and pulverized. Sufficient slaked lime is added to bring the calcium oxide content of the mixture up to about 55 per cent, the mixing being carefully and thoroughly done. During or after mixing, a small amount of water is added, and the moistened material is then fed to the brick machine. On issuing from this the bricks are placed on racks to dry. The drying takes from six to ten days, at the end of which time the bricks are ready for use.

Slag bricks are light in color, varying from light to dark gray; they weigh less than clay bricks of equal size, require less mortar in laying up, and are equal to clay bricks in crushing strength. The following analyses of slags used in slag-brick manufacture are fairly representative:

Analyses of slags used in slag-brick manufacture.

Constituent.	1.	2.	3.	4.	5.
SiO_2	22.5	25.8	27.0	33.0	35.0
Al_2O_3	14.0	17.3	19.3	18.67	15.0
FeO	3.3	1.5	1.7	1.0	1.1
MnO	.0	.0	0.1	4.25	0.3
CaO	51.0	51.4	51.5	40.0	45.0
MgO	1.4	0.4	2.5	2.33	.0
S	0.3	1.3	1.8	1.33	0.4

FERTILIZERS.

The highly phosphatic slags produced by basic Bessemer converters are valuable fertilizers, and are of great economic importance. In Germany, especially, large quantities are annually sold under the name of Thomas slag. In slags produced by this process the content of phosphoric acid usually runs from 10 to about 25 per cent.

Analyses of basic Bessemer slags.

Constituent.	1.	2.	3.	4.	5.	6.
SiO_2	7.38	7.5	5.8	5.76	5.10	2.49
Al_2O_3	2.57	2	1.5	1.43	4.01	
Fe_2O_3	8.54	4.1	15.42	2.07		8.19
FeO	13.62	9.3	2.1	12.72	12	1.23
MnO	3.79	4	3.5	3.43	5.56	} 61.02 (MnO, CaO)
CaO	41.58	49.6	45.04	47.34	45.26	}
MgO	6.14	4.7	6.42	6.01	5.90	
K_2O, Na_2O					.80	
CaS	.54			.91		
S		.5	.32			
SO_3		.2				
P_2O_5	14.36	17.5	18.1	19.19	21.37	27.35
H_2O, etc	1.29			1.19		

1. Redgrave, Jour. Soc. Arts, Vol. XXXVIII, p. 230.
2. German. Phillips, Trans. Am. Inst. Min Eng., Vol. XVII, p. 86.
3. English. Phillips, ibid., p. 86.
4. Redgrave, Jour. Soc. Arts, Vol. XXXVIII, p. 230.
5. Pottstown Iron Company, Pennsylvania. Morris, Trans. Am. Inst. Min. Eng., Vol. XXI, p. 232.
6. Bohemian. Phillips, Trans. Am. Inst. Min. Eng., Vol. XVII, p. 87.

The possible commercial value for agricultural uses of these high phosphorus slags produced by the Thomas-Gilchrist process was early recognized. At first, however, it was argued that in an untreated condition they would be useless as fertilizers; that the phosphoric acid they contained was not directly available for plants, and that the ferrous oxide would probably prove positively injurious to vegetable life. Attempts were accordingly made to dissolve out the phosphates of the slag and reprecipitate them. Fortunately this treatment was soon shown to be unnecessary, for field experiments with finely ground but otherwise untreated slags proved that they were excellent fertilizers. From this date (1882) onward the use of Thomas slag as a fertilizer has increased steadily, and it is now an important article of commerce.

Regarding the chemical composition of these slags, facts of great economic importance were brought out by the work of Hilgenstock and later investigators, and the efficiency of Thomas slags as fertilizing agents is now explained. In rock phosphates the phosphoric acid exists combined with lime as the tribasic lime phosphate ($3CaO_3P_2O_5$). In the slags above mentioned, however, the combination existing is the tetrabasic lime phosphate ($4CaO_3P_2O_5$). These two compounds differ greatly in the degree of their solubility in saline solutions, the tetrabasic phosphate being much more soluble than the tribasic. For this reason the phosphate slags are more efficient as fertilizers than the mineral phosphate. Jensch states that about $1\frac{1}{2}$ per cent of the total phosphorus of slags is present in the form of phosphide of iron, which is changed into phosphate in the soil.

Many types of crushers and mills have been experimented with in the pulverizing of Thomas slag. The ball mill, however, seems to be the only one capable of economically crushing this product to the fineness required—75 per cent through a 100-mesh sieve.

The slight development of the basic Bessemer steel industry in the United States necessarily renders the use of these phosphatic slags of less commercial importance than in Europe. During the year 1901 about 1,000 tons of phosphate slag, produced in the United States, were sold as fertilizer. This American material has been tested by the Maryland Agricultural Experiment Station, the report[a] of the results being that slag phosphate gave a greater total yield than did any of the other insoluble phosphates. The yield of corn with slag phosphate was not quite so much as with bone meal, but the yield of wheat and of grass was greater. All yields were produced at less cost with slag phosphates than with bone meal. The slag used in these experiments was a commercial sample and contained 16.32 per cent total phosphoric acid. Other commercial analyses of this fertilizer show phosphoric acid contents of 21.03 and 22.24 per cent. A complete analysis of the slag from the Pottstown, Pa., converters is given in the preceding table of analyses.

[a] Bull. Maryland Agric. Exp. Sta. No. 68, p. 28.

The slags produced in steel plants using the open-hearth process are less valuable as fertilizers than those produced by basic converters, as the former contain less phosphoric acid and more silica and lime than do the basic Bessemer slags. A two-stage modification of the open-hearth process—the Bertrand-Thiel process—gives slags higher in phosphoric acid than ordinary open-hearth slags. It is even claimed by Thiel[a] that the Bertrand-Thiel process produces a greater value of slag, if both quantity and phosphoric content be considered, per ton of finished steel than does the Thomas-Gilchrist process.

The slags resulting from processes other than those above noted are not sufficiently phosphatic for use as high-grade fertilizers. Elbers has, however, called attention[b] to the fact that highly calcareous blast-furnace slags might be profitably used as fertilizers in place of the other forms of lime (marl, shells, etc.) now used by farmers.

MINERAL WOOL.

Over half of the material marketed as "mineral wool" or "silicate cotton" is derived from slag, the remainder being manufactured from natural rocks of different types.

Originally the process was carried out at the furnaces. At present, however, the slag is bought from the furnace companies and remelted in a small cupola. From this the molten slag issues in a small stream, into which is injected steam or air under pressure. The effect is to scatter the slag, small spherules of slag being blown out from the main stream, each spherule carrying behind it a thread of slag. The fluidity and composition of the slag and the pressure of air or steam are manipulated so as to give the greatest proportion of fiber to spherules, as the spherules are commercially unavailable and must be separated from the fiber if present in much quantity.

No analyses of slags used in the manufacture of slag wool are at present available. A mineral wool made from natural rock gave on analysis the following result:

Analysis of mineral wool made from natural rock.

Silica	37.5
Alumina and iron oxide	20
Lime	30.6
Magnesia	11.8

The presence of sulphur is a defect in most mineral wools made from slag, as they must be carefully protected against moisture to prevent the oxidation of the sulphur and the consequent destruction of the pipes or other metallic surfaces on which the wool has been used.

The most important property of slag wool, from a commercial point of view, is that it is a very poor conductor of heat. This property

[a] Chem. Zeit., 1901, p. 371. [b] Eng. and Min. Jour., November 3, 1900.

renders it available for all uses for which a nonconductor is desirable, as steam-pipe coverings, safe linings, etc. In 1884, Mr. J. J. Coleman carried out a series of experiments on the heat-conducting power of various covering materials. His results[a] were as follows, the conducting power of slag wool being taken as unity:

Comparative heat-conducting power of materials.

Slag wool	1.00
Hair felt	1.17
Cotton wool	1.22
Sheep's wool	1.36
Infusorial earth	1.36
Charcoal	1.40
Sawdust	1.63
Gas-works breeze	2.30

Subseqently more elaborate experiments were made by Professor Ordway, 32 materials being tested under conditions closely approximating to those encountered in actual practice. The following results[b] have been selected by the writer from Ordway's list and rearranged and recalculated to permit the heat-conducting power of slag wool to be taken as unity:

Comparative heat-conducting power of materials.

Loose wool	0.62
Loose lampblack	.75
Hair felt	.79
Compressed lampblack	.82
Loose calcined magnesia	.95
Slag wool	1.00
Light carbonate of magnesia	1.05
Compressed carbonate of magnesia	1.18
Ground chalk	1.58
Asbestos paper	1.67
Compressed calcined magnesia	3.28
Fine asbestos	3.78
Sand	4.77

It will be noted that though Ordway's results are not so favorable to slag wool as were Coleman's, both experimenters established the fact that this material is the best of the noninflammable coverings tested.

PAINT STOCK.

In 1891 Mr. A. Sahlin described[c] a plant then in operation at Boonton, N. J., at which slag was utilized in the manufacture of paint stock. The slags used were puddle slags and reheating cinder, which, of course, can not be utilized in the manufacture of cements,

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[a] Engineering, September 5, 1884, p. 237.
[b] Trans. Am. Soc. Mech. Eng., Vol. V, p. 73.
[c] Trans. Am. Inst. Min. Eng., 1891.

fertilizers, alum, etc. Analyses of samples of these materials showed the following compositions:

Analyses of puddle slag and reheating cinder.

Constituent.	Puddle slag.	Reheating cinder.
FeO	52.43	71.29
Fe_2O_3	19.62	
MnO	6.41	.21
CaO	.81	----------
Al_2O_3	.38	7.78
SiO_2	16.39	20.06
P_2O_5	3.84	.27
S	--------	Trace.

The slag was crushed in a Blake crusher to pass a three-fourths inch screen, and finally reduced in a Cyclone pulverizer to pass 225 mesh. The finest dust was used directly as paint stock. The coarser material, after treatment with sulphuric acid, was calcined and reground. This industry has been discontinued at Boonton, and it is believed that no slag is at present used for that purpose in the United States.

ALUM.

The preparation of alum from highly aluminous slags is accomplished by means of the Lürmann process. So far the manufacture of alum by this process has not been attempted in the United States, though it has been carried out on a commercial scale in Europe. At Donjeux, France, the process has been employed in connection with the manufacture of slag cement, the gelatinous silica resulting from the alum-extraction process being used to accelerate the set of the cement.

The Lürmann process, in brief, is as follows: Slags, as high in alumina as possible, are decomposed by means of hydrochloric acid. The resulting solution of aluminum chloride is treated with lime carbonate, which serves to precipitate the alumina and any dissolved silica that may be present. In treatment with sulphuric acid the alumina is dissolved, leaving the silica. It is stated[a] that 100 kilograms of slag, containing 25 per cent of alumina, will yield 180 kilograms of alum and 31 kilograms of gelatinous silica. The silica is used in the manufacture of soluble glass and, as above noted, in the manufacture of slag cement. The process may even be profitably arrested after the first stage, as the aluminum chloride then obtained is marketable for use in certain sewage purification processes.

[a] Wagner, Chemical Technology, p. 439.

GLASS.

Small quantities of slag have been used in Europe in the manufacture of the inferior grades of glass, but this use has never attained much commercial importance. In America slag has never, to the knowledge of the writer, been so utilized.

ROAD METAL.

In addition to its use as a paving material in the form of slag bricks, discussed in preceding sections of this paper, slag has been somewhat extensively used in highway construction as macadam.

Sections of roads constructed in New Jersey with slag macadam, under State supervision, have proved entirely satisfactory. Near Buffalo, N. Y., slag has been used to some extent in highway construction, and to a greater extent in Pennsylvania and Alabama. The most extensive use of slag for this purpose is, however, probably in Maryland, where it has been utilized in highway construction in the counties of Baltimore, Howard, and Prince George.

Prof. W. B. Clark refers to the use of slag for this purpose in Maryland in the following words:[a]

> Furnace slag has been found to be, under certain conditions, a highly satisfactory road metal. It is not as valuable as the trap rocks, although its cementing properties are excellent, except in the case of some of the materials from the old furnaces. These old slags break down quickly and are readily ground into fine dust, and for these reasons are of little value in road construction.
>
> The slag from the present iron furnaces, on account of the large amount of lime contained in it, is very valuable as a highway material. It compacts easily when rolled and forms an even, smooth surface, while the fine particles unite as a hard cement that grows firmer with time. The iron furnaces at Sparrow Point afford material of this character that has already been demonstrated to be a valuable road metal.

RAILROAD BALLAST.

In several States, notably in Alabama, slag is largely used as railroad ballast. At the third annual convention of the American Railway Engineering and Maintenance-of-Way Association, a committee reported on this as follows:

> Blast-furnace slag containing a small excess of lime and being of a glassy nature will, when broken up under the track, fulfill the requirements of ballast to a very large degree, If a large excess of free lime be present the slag soon becomes too soft to hold the load, becomes concreted under the ties, and churns in wet weather. Slag-ballasted track usually requires a lift of 2 or 3 inches, and to be surfaced out of face at intervals of from two to six years, depending on the hardness of the slag and the amount of traffic. Slag composed almost exclusively of hard, glassy pieces approaches closely to the quality of rock ballast; on the other hand, slag with a large amount of free lime is inferior to reasonably good gravel.

It will be noted that the noncalcareous, glassy slags, which are thus said to be preferable for railroad ballast, are precisely the kinds that

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[a] Maryland Geological Survey, Vol. III, 1899, p. 105.

are unsuitable for use as macadam for highway construction. It is therefore evident that almost any type of slag will be of service for one of these two uses.

LAND RECLAMATION.

In the vicinity of furnaces slag is of considerable local importance as a cheap and readily transportable material for filling purposes. Large quantities are annually used for land reclamation, filling of abandoned mine workings, etc. The greater part of the slag so used is, however, given away by the furnaces, and such uses may, therefore, be regarded rather as a means of inexpensively disposing of a troublesome waste product than as a utilization of slag. Such methods of disposal are, of course, economical only when the slags are unfit for the more profitable utilizations discussed in the preceding sections of this paper.

MANGANESE ORES OF THE CARTERSVILLE DISTRICT, GEORGIA.[a]

By C. W. HAYES.

Closely associated with the Georgia deposits of iron ore (see pages 233–242) are extensive deposits of manganese. These have been quite fully described by Dr. Penrose,[b] and require only brief mention here. All the iron ore contains traces of manganese, but the main deposits of the latter ore are quite distinct from the iron. The ore occurs, like the brown hematite, embedded in a heavy mantle of residual clay, associated with chert and angular fragments of quartzite. The proportion of clay to ore is usually larger than in the deposits of brown hematite. The ore occurs as small concretions scattered through the clay, and also in the form of veins, penetrating the clay in an irregular manner. It has the appearance of having been deposited by solutions percolating through the residual mantle. The original source of the manganese was probably the Beaver limestone, although some of it may have come from the Weisner quartzite. The deposits occur with about equal frequency in the residual material derived from the two formations.

Dr. Penrose holds the view that some at least of these deposits existed in their present form in the rocks of the region before weathering, and are therefore strictly residual. While this may be true in a few cases, the writer has found no evidence of it in the field; and the manganese ores are regarded, like the iron ores with which they are associated, as purely secondary deposits, their distribution being determined chiefly by chemical and physical conditions, rather than by the outcrop of beds especially rich in manganese.

Although, in the aggregate, a large amount of ore has been mined from this district, most of the work has been done in a primitive and inefficient manner. It is probable that with modern appliances a large amount of material would pay for working which does not contain a sufficiently large proportion of ore to be profitably worked by the present methods.

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[a] Abstracted from the descriptive text of the Cartersville folio of the Geologic Atlas of the United States, in preparation.

[b] Penrose, R. A. F., jr., Manganese, its uses, ores, and deposits: Ann. Rept. Geol. Survey Arkansas, Vol. I, 1890, pp. 418–426.

IRON ORES OF THE CARTERSVILLE DISTRICT, GEORGIA.

By C. W. Hayes and E. C. Eckel.

One of the most productive iron-ore districts in the Southern Appalachians lies in the vicinity of Cartersville, Bartow County, Ga. The ore deposits of this region are so directly related to the stratigraphy and structure of the area that a brief description of the geologic features must be given before taking up the subject of the origin and position of the ore deposits.

GENERAL GEOLOGY.

Stratigraphy.—The area in question occupies the southeastern half of Bartow County, Ga. Its surface is about equally divided between the older crystalline and metamorphic rocks which occupy the Piedmont Plateau and Appalachian Mountains in the east, and the unaltered Paleozoic formations which occupy the Appalachian Valley on the west. The line of separation between these two groups of formations in the Cartersville district is located as follows: Beginning at the north, it lies about half a mile east of Fairmount post-office, and runs almost due south for about 7 miles, when it swings eastward to near Martins Mill. From this point it takes a southwest direction, passing half a mile west of Rowland Springs, and then turns southeast, crossing the Etowah near the old iron works and crossing the railroad about a mile southeast of Emerson. From the point at which it crosses the railroad the line pursues an almost southerly direction for a few miles; then turns northwest, almost reaching the Etowah at the Free Bridge, 4 miles from Cartersville, and finally turns southwest, passing about 2 miles south of Stilesboro and Taylorsville.

As noted later, this line between the two groups of formations marks, throughout most of its extent, the position of the Cartersville fault, which is the most important structural feature of the region.

The formations of the valley belt, to the west of the Cartersville fault, are, in ascending order, the Weisner quartzite, the Beaver limestone, the Rome and Conasauga shales, and the Knox dolomite. All, except the latter, belong to the Middle and Lower Cambrian; and the lower portion of the Knox dolomite should probably also be classed with the Cambrian. The principal outcrop of the Weisner quartzite forms a nearly continuous band, 15 miles in length, and generally from 1 to 3 miles in width, which occupies the central portion of the area. The formation is in contact on the east with the Cartersville fault; its base is nowhere shown. It consists chiefly of fine-grained vitreous quartzite, although it also contains some beds of fine conglomerate and, probably, considerable beds of siliceous shales. The latter, however, are usually concealed by the abundant débris from the quartzite beds, which tend to break up into angular fragments when exposed to atmospheric conditions. Two subordinate outcrops of the quartzite occur near the western margin of the area, being brought to the surface by small faults. The thickness of the formation is probably 2,000 or 3,000 feet, and may be considerably more; but it can not be accurately determined because of the intense folding which its beds have undergone, and the absence of satisfactory exposures.

West of the quartzite is a narrow belt of deep, red soil, usually forming a level valley. This is underlain by the Beaver limestone, a formation which rarely appears at the surface, its outcrops being almost everywhere covered with a deep mantle of red clay, in which occasional masses of vesicular chert are embedded, along with much angular quartzite derived from the adjacent quartzite ridges. The few natural exposures of this formation which have been observed, together with the results of drilling, indicate that it is a gray crystalline dolomitic limestone, becoming shaly in places, and containing occasional masses of chert. It is much more readily soluble than the purer blue limestone; and its impurities form an abundant residual mantle. In addition to the main belt which it forms along the western base of the quartzite ridges, it underlies a broad level valley near the western margin of the district extending southward from Grassdale to the line of the Atlantic and Western Railroad. The thickness of the Beaver limestone has not been accurately determined; but it is probably between 800 and 1,200 feet. With these two formations, the Weisner quartzite and the Beaver limestone, a majority of the ore deposits in this region are associated.

Overlying the Beaver limestone is a very great thickness of shales, constituting the Rome and Conasauga formations; and above the shales is the Knox dolomite. The latter is a massive formation from 3,000 to 5,000 feet in thickness, composed of gray crystalline dolomite, with an abundance of chert. In adjacent regions it is intimately associated with extensive deposits of iron-ore; but it is unimportant in the present connection.

The rocks on the opposite side of the Cartersville fault, occupying the eastern half of the district, present considerable variety in composition and age. A large area, extending from Stamp Creek southward across the Etowah River, to the Atlantic and Western Railroad, is occupied by the Corbin granite, which is, for the most part, a massive coarse-grained rock, containing large porphyritic crystals of feldspar (microcline), in a groundmass of plagioclase feldspar, muscovite mica, and blue quartz. Some portions of the rock have undergone considerable alteration, by which it has been converted into an augen-gneiss. This area of Corbin granite at one time probably formed an island, since it is surrounded, in part at least, by rocks derived from its waste. These are feldspathic conglomerates in which the blue quartz and the porphyritic crystals of microcline, which characterize the granite, can be readily distinguished. In some places the transition from granite to conglomerate is so gradual that it is difficult to determine the exact boundary between the two formations. The development of the gneissoid structure in the granite evidently took place after it was deeply buried by sediment, for the alteration of the latter is even more marked than that of the granite itself. Wherever the granite is not bordered by coarse conglomerate or quartzite it is in contact with black graphitic slates, which generally overlie the coarser sediments.

These conglomerates and slates associated with the granite belong to the Ocoee series, which reaches its greatest development in eastern Tennessee and western North Carolina. No fossils have yet been found in the rocks of this series, although many of them are only slightly altered. They contain limestones and slates similar to portions of the adjacent valley formations, but the latter are always found to contain more or less abundant traces of life. In the absence of fossil evidence their age can not be definitely determined, but on structural evidence, obtained chiefly in Tennessee, they are believed to be Lower Cambrian with possibly some pre-Cambrian.

The rocks of the Ocoee series generally show an increasing degree of metamorphism toward the southeast; and within a few miles of this region they pass into schists and gneisses, the original form of which, whether igneous or sedimentary, can not be readily determined. This increased metamorphism toward the southeast is due in part to the greater compression which that region has suffered, and in part to the presence of considerable bodies of various igneous rocks which have been intruded into the sedimentary beds. These intrusive rocks present considerable variety in composition, varying from extremely basic diabase to acid granites. The most common variety is a diorite, which was among the earlier intrusions, and has been subsequently converted for the most part into amphibolite-schist. Two belts of this basic schist pass across the southeastern corner of the district. Its southeastern corner is occupied by the Acworth gneiss, which, like the Corbin granite, is probably Archean in age, and formed the foundation on which the oldest sediments of the region were deposited.

Structure.—In common with other portions of the southern Appalachian region, the Cartersville district has been subjected to intense compression in a northwest-southeast direction. From evidence obtained in adjoining regions, it appears probable that this compression, and the subsequent folding, began in early Paleozoic time, and continued at intervals up to its culmination at the close of the Carboniferous. It resulted in the formation of folds and faults in the valley rocks and in the development of a slaty cleavage or schistose structure in the older rocks to the east, while the latter were thrust upward and westward relatively to the former, producing the great Cartersville fault. The region west of the Cartersville district is occupied by a broad, gentle syncline of Knox dolomite. This massive formation appears to have resisted folding, and to have transmitted the thrust in such a manner that while its own beds retained very nearly their original horizontal position, the beds coming to the surface in narrow belts on either side were intensely folded. Thus the shales which occupy the western portion of the district are highly contorted, and are doubtless intersected by numerous small faults. Also, considerable slaty cleavage has been developed in them. The Weisner quartzite likewise resisted folding to some extent, although its beds were thrown into the form of an anticline with numerous irregular minor folds. The irregularity of the anticline is shown by the character of its contact with the overlying limestones to the west. In addition to the folding which the quartzite has undergone, it is doubtless intersected by numerous faults, the evidence of which is seen in its crushed and brecciated condition at many points. Owing to the character of the outcrops, however, these faults generally can not be located or traced.

The folding referred to brought about certain mechanical and chemical conditions favorable for the deposition of mineral deposits, and hence has an important bearing on the economic geology of the district. It is frequently observed that the originally compact vitreous quartzite is converted into a rock somewhat resembling jasper. Chert from the overlying limestone, under similar conditions, is altered in the same manner; and it is often impossible to distinguish between the final products of the alteration of rocks originally wholly unlike. Portions of the quartzite have been converted into a spongy rock, containing innumerable fine cavities lined with small quartz crystals and stained with yellow ocher. This form of alteration is probably due to the circulation through the rock of thermal waters, by which the quartz was taken into solution and in part redeposited, along with more or less iron oxide.

The line marking the Cartersville fault departs in this region from its rather regular course across northwestern Georgia, making a distinct embayment to the east in passing around the belt of Lower Cambrian quartzite and limestone. On either side of this region the fault brings the soft slates of the Ocoee series in contact with Cambrian shales of a similar character. The actual plane of contact between the formations on opposite sides has been observed at many points. The older rocks above always have a well-developed slaty or schistose structure, and are but little more altered immediately at the fault than elsewhere. The underlying rocks, on the other hand, are much more intensely folded and brecciated immediately at the fault than a few feet distant. The fault plane itself is usually marked by a bed of breccia, a few inches or feet in thickness, and made up of the comminuted fragments of the formations on either side. This fault plane dips to the east, usually at angles varying between 5° and 20°, and is parallel, in a general way, with the cleavage and bedding of the rocks on either side.

The Weisner quartzite varies greatly in thickness within a short distance. It has the appearance of a delta formation rather than an evenly distributed littoral or marine deposit. North and south of its present outcrops in this region it probably becomes very much thinner, and its local thickening has doubtless influenced the structure in this region. Another factor which has been important in producing this peculiar structure is the presence of the great mass of granite to the east of the fault. This is the only point at which massive rocks of this character approach so near the fault line. They are usually separated from the western margin of the metamorphic rocks by a belt, several miles in width, of readily yielding slates and schists. It is evident that the conditions for the formation of a thrust fault of great lateral extent are much more favorable in bedded sedimentary rocks than in the massive igneous rocks, such as the Corbin granite. The latter appears to have acted like an immovable buttress against which the rocks from the west were thrust. It will readily be understood that, on account of these massive quartzites on the west and the still more massive igneous rocks on the east, this portion of the Cartersville fault differs materially from that to the north and south; and further, the reasons will be seen for the very considerable alteration, both physical and chemical, in the valley rocks adjacent to the fault.

IRON ORES.

The iron ores of the southern Appalachian region fall naturally into five distinct groups, as follows: (1) Magnetite, (2) specular hematite, (3) red hematite or fossil ore, (4) carbonate or black-band ore, and (5) brown hematite or limonite. Only two of these groups occur in the Cartersville district, namely, the specular hematite and the brown hematite or limonite, and of these, the latter is much the more important.

Specular hematite.—This variety of ore occurs at two points in the district in sufficient abundance to be mined with profit. One is about 2 miles southeast of Warford and the other between Emerson and the Etowah River. The ore occurs at both localities as a band in the quartzite, and both the ore and the inclosing quartzite have a strongly developed schistose structure. The ore passes into the quartzite by a gradual transition, and only the richest parts of the bed can be worked. The greater part of it is quite siliceous. Even the purer portions of the ore contain many inclusions of white saccharoidal quartz, generally drawn out into long, slender filaments. In some cases the iron appears as flattened oolitic grains embedded in a ground mass of white quartzite. It is evident that in these deposits the iron existed in the quartzite before the alteration of the latter. It may have been in the form of the carbonate or of the hydrous oxide, and possibly, in part at least, of the sulphide. Some portions of the ore contain what may possibly be greatly altered pseudomorphs after pyrite. The ore is not appreciably magnetic; is nearly black in color and has a bright metallic luster. It is called "gray ore" by the miners, to distinguish it from the brown hematites of the district.

The specular hematite outcrops at short intervals, along a line lying a short distance east of the Western and Atlantic Railroad, from a point about 1 mile north of Emerson station to the north side of the Etowah River. It is possible that this belt extends still farther north, so as to include the workings noted near Warford, but outcrops have not been noted in the intervening space. South of the Etowah River the specular hematite has been worked to some extent, by means of pits, open cuts, and a short tunnel, on the properties of the Roan and Etowah Iron companies. The ore from these properties ranges from 55 to 65 per cent in metallic iron, and at several of the pits it falls within the Bessemer limit for phosphorus. The ore bodies, however, do not appear to be sufficient in size to justify exploitation on a large scale. In many of the pits the silica content is high, and no cheap and simple concentrating system is available for separating the purer ores from the more siliceous portions.

Brown hematite or limonite.—Several varieties of this ore occur in the southern Appalachians, and are more or less distinct in their appearance, manner of occurrence, and mode of formation. The most important of these are (1) gossan ores, (2) Tertiary gravel ores, (3) concentration deposits, and (4) fault deposits. Only the two latter varieties occur in the Cartersville district; but all four of the classes occur in the immediate vicinity, and may be briefly characterized.

1. The best-known deposits of gossan ore occur in the Ducktown district. As is well known, copper occurs there associated with great quantities of pyrrhotite. The latter has been oxidized at the surface to limonite, and during the process of oxidation the copper has been concentrated at the bottom of the weathered zone, forming the rich deposit of "black copper" overlying the unaltered pyrrhotite. The gossan ore has a variable depth, down to 50 feet or more, and consists of soft, porous, ocher-yellow limonite.

2. During Tertiary time the valley region was reduced very nearly

to sea level, and in its lower portions, chiefly those underlain by the Chickamauga limestone (the next formation above the Knox dolomite), swamps were formed which received drainage from the adjacent regions, and in which extensive deposits of bog ore were formed. When the region was elevated, the limestone areas were again reduced more rapidly than the adjacent areas underlain by dolomite, and doubtless much of the accumulated iron ore was removed by erosion. Around the margins, however, the ore remained embedded in the residual clay. Deposits of this character are especially abundant in the Rockmart and Cedartown districts, southwest of the Cartersville area. These districts comprise a number of areas of Chickamauga limestone, surrounded by zones which contain large quantities of iron ore. This is usually in the form of gravel ore, composed of concretions from the size of shot up to a foot or more in diameter, embedded in the residual red clay, and associated with more or less chert from the underlying Knox dolomite.

3. The brown hematites of the third class, here called concentration deposits, constitute the most important deposits of the Cartersville district. They may occur wherever a limestone is underlain by an insoluble and impervious stratum, such as sandstone or quartzite. Favorable conditions for this accumulation occur in northwest Georgia and Alabama, at the contact of the Lower Carboniferous limestone with the sandstones which sometimes underlie it, and at the contact of the Beaver limestone with the underlying Weisner quartzite. The Beaver limestone is more readily soluble than the formations on either side, and hence, in the erosion of the region, it has always formed valleys. At various times these valleys have received the drainage, not only from the adjacent quartzite and limestone, but probably also from other of the valley formations, and the widely disseminated iron leached from these formations during the process of decay has been transported to the limestone valley and there concentrated upon the underlying impervious quartzite. As the surface of the limestone was lowered, chiefly by solution, upon successive elevations of the region, remnants of the ore deposits thus formed were left resting upon the underlying quartzite and marking elevations at which the surface of the limestone had remained for considerable periods. These deposits are composed in part of gravel ore and in part of masses of considerable size, in some cases reaching many feet in diameter. Where the large masses of ore preponderate, it is probable that they represent replacements of the limestone by iron-bearing solutions rather than ordinary bog-ore deposits. When the deposition was by direct replacement of limestone below the level of ground water, the iron was probably in the form of carbonate, changing to limonite as the ground-water level was gradually lowered with the progress of erosion. At a few points the limonite deposit has been traced down-

ward directly into the unchanged carbonate. This is well shown in the Sugar Hill deposits, later discussed. From the distribution of the ore banks it will be seen that a large proportion of them are located near the contact of the Beaver limestone and the Weisner quartzite. These generally belong to this class of concentration ores; and this contact is marked by a more or less continuous band of ore deposits. The red clay in which they are embedded is chiefly derived from the limestone; and the surface is generally covered with fragments of quartzite from the higher portions of the quartzite ridges.

4. As already remarked, the quartzite has been considerably folded and is doubtless also intersected by numerous faults of small throw, the evidence of the faulting being chiefly the occurrence of breccias. The latter usually consist of fine angular fragments of quartzite cemented by limonite; and associated with these breccias are often found considerable deposits of iron ore. These are sometimes irregular deposits embedded in the residual material which covers the surface, and are not sharply differentiated from the concentration deposits above described. In other cases, the ore appears to form well-defined fissure veins, with distinct walls of the inclosing formation. This is notably the case at the Wheeler bank, about 4 miles southeast of Cartersville. The vein is from 12 to 15 feet in width, with occasional offshoots. The inclosing rock is a gray siliceous schist, with some blue curly talcose slate and quartz stringers; also occasional bands of schistose feldspathic conglomerate. The vein dips east about 80° and strikes nearly north and south, parallel with the schistosity of the inclosing rock, and with the adjacent Cartersville fault. The ore appears in part to have filled an open fissure and in part to have replaced the schist, numerous fragments of which remain in the ore body. It consists for the most part of geoidal shells, containing many cavities with stalactitic and botryoidal forms, which have glazed surfaces showing brilliant iridescent colors. It generally has a fibrous structure, and further differs from the concentration deposits in the almost complete absence of residual clay associated with the ore. This ore body has evidently been deposited subsequent to the development of schistosity in the inclosing rocks, since it shows no evidence of movement in the way of brecciation or slickensides.

At no point in this district has development gone below water level. The deposits are generally worked only to a depth permitting direct drainage. Hence, the bottoms of the ore bodies are seldom reached. Of the depth to which the our classes of deposits enumerated above extend, it may be stated (1) that the gossan ores are sharply limited by water level; (2) that the Tertiary gravel ores are generally superficial, the greater part of the deposits being near the surface, below which they rarely extend more than 30 feet; (3) that the concentration deposits go considerably deeper, and, under favorable conditions, may extend to the depth of 100 feet or even more, and (4) that the deposits associated with faults and formed in fissures are undoubtedly the deepest of all. If, as appears probable, they were formed by solutions ascending from considerable depths, they may extend downward several hundred feet, although the character of the ore would doubtless be found to undergo some change with depth, the oxide being accompanied by increasing proportions of sulphide and perhaps carbonate.

The general belief among the ore miners that certain of these brown hematite deposits are stratified, occupying a definite geologic horizon, is, of course, entirely erroneous. Also, the view which has been held[a] that in this and adjoining districts the deposits of brown hematite follow the outcrops of particular beds rich in iron is almost equally erroneous. The present distribution of these deposits, as shown above, depends entirely upon the geologic structure which determined chemical and physical conditions requisite for their deposition. In all cases the iron has been transported to a greater or less distance from the beds in which it was originally disseminated. The specular hematite above described, and the red hematites which occur at various horizons in the Silurian rocks, belong to an entirely different class of deposits.

The deposits of brown hematite which are at present best exposed, and which furnish excellent examples of the type of "concentration deposits" described above, are those now worked by the Hurt Iron Company at Sugar Hill. The mines are located about 12 miles northeast of Cartersville, and 3 miles southeast from Pine Log Village. Supplies are obtained and ore is shipped over a branch road which leaves the Western and Atlantic tracks at a point about 3 miles west of Cartersville.

Occurrence of ores.—Mining is being carried on in a number of large open cuts, which, with natural exposures in the vicinity, permit a good idea of the structural relations of the deposits to be obtained. The ore deposits are associated at this point with the upper beds of the Weisner quartzite (Cambrian). In the vicinity of the mines, the quartzite beds are seen to lie in a series of low folds, cross folded so as to form a number of shallow pitching basins. The ore deposits occur as a mantle over the impervious quartzite strata, and are in turn often overlain by thin beds of talcose slates, which are commonly much decomposed. Taking the Sugar Hill group of mines as a whole, their ore deposits seem to occupy a fairly regular stratigraphic position. They appear to have originated by a replacement of the strata which originally lay between the quartzite and the talcose slates, by the deposition of iron from surface or underground waters.

[a] Spencer, J. W., Economic resources of the Paleozoic group of Georgia: Geol. Survey of Georgia, 1893.

The strata which have been thus replaced may have been thin beds of impure limestone, or other relatively soluble materials. The concentration of the iron-bearing waters at this horizon, and the consequent deposition of their iron, was favored by the solubility of this replaced bed, and the relative imperviousness of both the underlying quartzite and the overlying talcose slates. The iron-bearing waters were probably, in part, merely surface waters, coming to rest in drainage basins and there depositing their iron, under favorable conditions at points where the decay or complete removal of the talcose schists gave easy access to the soluble bed. Part of the ore deposition, however, may have taken place through the action of iron-bearing waters gaining access to the soluble and pervious replaced beds at some point where these were exposed, and following down these particular beds, which formed good channels of communication, even under the areas where they were covered by the impervious talcose slates. It will be evident that the resulting ore deposits, in the two cases, will differ somewhat in extent. If deposited entirely from surface waters, the ore deposits could not extend beyond the limits of the drainage basin in which they were laid down. If deposited from waters flowing underground, acting under the principles of artesian flow, the deposits might have a greater extent, reaching under other beds, and if the underground structure was favorable, extending beyond the surface limits of the minor drainage basin.

The ore deposits in the Sugar Hill group of mines usually vary between 5 and 10 feet in thickness, occasionally passing these limits. The ore commonly carries 50 to 55 per cent metallic iron, and about 1 per cent of phosphorus.

IRON-ORE DEPOSITS OF THE CRANBERRY DISTRICT, NORTH CAROLINA-TENNESSEE.[a]

By Arthur Keith.

MAGNETITE.

Deposits of magnetic iron oxide occur along a line passing through Cranberry in a northwest direction. The ore has long been worked at Cranberry and produces iron well known for its purity. Beginning near Old Fields on North Toe River, the magnetite has been traced with small intervals, south of Smoky Gap, through Cranberry, and on to Shell Creek in Tennessee. This line of outcrop lies in the Cranberry granite, which is in places mashed and metamorphosed so as to resemble gneiss, and it is nearly parallel to the boundary of the granite and Roan gneiss, a relation which is repeated in other districts toward the west.

At the Cranberry mines open cuts have been made at intervals over an area 900 by 300 feet and through a vertical distance of 250 feet. From these tunnels are run in for considerable distances. The ore occurs as a series of lenticular bodies of magnetite in a gangue of hornblende, pyroxene, epidote, with a little feldspar and quartz, and a few unimportant minerals. The ore and gangue occur as a series of great lenses dipping toward the southwest at angles of 45° to 50°, about parallel to the planes of schistosity in the gneiss. The ore is found in the gangue in the shape of smaller lenses, dipping southwest from 40° to 60°. These vary from 50 feet down to a few inches in thickness, and are from two to five times as long as they are thick. Sometimes the lenses have sharp limits, but usually the gangue and ore grade into each other at the contact. Considerable ore is sprinkled through the gangue, and more or less gangue is scattered through the ore bodies. The ore is very free from the objectionable elements, phosphorus and sulphur, though it is not high in iron. It yields an average of 42 to 46 per cent of iron with ordinary concentration. Considerable trouble is experienced in freeing the ore from the gangue before smelting, on account of the tough and refractory nature given to the mass by the epidote.

Because of the occurrence of the ore as a series of lenses the quan-

[a] Abstracted from descriptive text of the Cranberry Geologic Folio, now in press.

tity is rendered more or less uncertain. Each lens will be worked out in time and its place supplied by other lenses, and to what depth or distance the occurrences will go on it is quite impossible to state. The ore bodies may diminish, they may remain about the same, or they may increase. As judged by openings, tests by diamond drill, and surface outcrops, the deposit has a length of over a half mile, carrying bodies of ore throughout that distance. Large quantities of ore have been taken out, far greater quantities are now in sight, and there is every reason to expect a large output in the future.

The minerals composing the ore and gangue were deposited at a time much later than the production of the inclosing rock. They are also younger than the period of deformation which produced the schistose arrangement in the granites. The minerals of the ore deposit are only slightly crushed or rearranged, although they are the same varieties which, in adjacent formations, show the greatest metamorphism. The ore deposit, therefore, was not due to original segregation from the igneous granite, but is entirely of a secondary nature. It may have replaced a preexisting mass of rock by solution and substitution of new minerals, or it may have been deposited from solution in open spaces in the inclosing formation. This latter result is quite unlikely, on account of the great dimensions of the opening required by the size of the ore deposit. If the deposit represents a substitution of new minerals for old, the latter were either portions of the inclosing granite or a mass of a different original character. The shape of the ore deposits agrees with the general form taken by the smaller intrusive bodies in this region. The minerals composing the granite—quartz, mica, and feldspar—are among the least susceptible to chemical alterations. It is therefore probable that the rock replaced by the ore body had a less simple chemical composition. If the present minerals represent a recrystallization of those preexisting, the original rock might well have been a diabase similar to the Linville metadiabase. This rock contains almost exactly the same minerals as the ore deposit, but even the greater alteration through which it has passed has not produced anything in the nature of an ore. Accordingly, some additional or separate cause must be sought besides dynamic alteration. An agency fulfilling the conditions, and one that is everywhere at work, is water charged with mineralizing agents. This dissolved and perhaps added to the rock minerals and redeposited them in favorable places, either in the old or in new chemical combinations. In this case the deposits have not the size or shape of veins, but are discontinuous and lenticular in shape, as above stated. They are plainly controlled and directed by the schistosity of the granite in this and many other areas toward the west and southwest.

There is no indication whether or not the channels through which the solution entered corresponded with the schistosity of the granite, although such correspondence is probable. In the red feldspathic granites near Cranberry small veins and stringers of magnetite are found at many places. These may represent deposition from the mineralizing solutions, where there was no body of readily altered rock which could have been changed into an ore deposit. Also, northwest of Cranberry the gangue minerals and even magnetite are developed in the mass of the red granite along more or less mashed zones. These perhaps represent the places where alteration was most active; that is to to say, the actual channels through which the mineralizing solutions passed.

As to the cause that put into action the mineralizing solution some suggestions can be made. In many areas the heated solutions and vapors arising from bodies of intrusive rock have produced mineral alterations and deposits. As stated above, the magnetite deposits are later than the folding movements. That is also true of the Bakersville gabbro. These intrusive masses are frequent in the area of Roan gneiss west and southwest of Cranberry, and the magnetite bodies swing around their circumference. It is thus suggested that the magnetites are due to alterations begun by the gabbro intrusions. Whether true or not in this locality, this explanation does not hold for the magnetite deposits in Ashe County, for there are no recent igneous rocks in that area.

Of the source of the iron there is as little evidence. The adjacent formations, the Cranberry granite and the Roan gneiss, both carry iron chemically combined in the biotite and hornblende. Solution of either might furnish the iron. There is, however, no apparent alteration or diminution of the ferruginous minerals in the adjacent granite. From the Roan gneiss iron might more readily have been obtained on account of the extreme abundance of hornblende in that formation. That the mineralizing solutions passed through these formations at more than one epoch is clear from the existence of a band of titaniferous magnetite deposits parallel to and southeast of this band. These are as regularly titaniferous as the ores of the Cranberry band are free from that mineral. Inasmuch as the two belts are in close proximity and each is extensive without overlapping the other, their depositing solutions were probably active at different times. Still another period of mineralization left its record in the pegmatite veins and lenses so common in this region. These, however, were crushed and distorted during the folding of the strata, and thus are so much older than the magnetite deposits that they can have no origin in common.

RED HEMATITE.

This ore is found in one locality in this area, on the east side of Bull Ruffin Mountain. It occurs in the schistose metarhyolite next to a fault plane, and it is rather an impregnation of the schist with hematite than a distinct and pure deposit of ore. Little work has been done in development of the ore, and its value and amount are questionable.

SPECULAR HEMATITE.

Iron ore of this nature is found at several points along the south slope of Beech Mountain. It is found in a small vein in black schist, which occurs as a narrow band in the Cranberry granite about 2 miles long. The ore appears at several places along this line. It has not been developed beyond shallow prospecting, so that neither the depth nor the extent of the deposit is known. In association with similar black schist beds on Big Ridge, a northern spur of Beech Mountain, are a number of other veins of specular hematite. These have been examined only by test pits. In all of these localities the ores exposed are siliceous. The veins are of small or only moderate thickness, and have a steep dip. The course of the veins is nearly east and west, and is marked by scattered outcrops and fragments of ore. In the same black schist beds at various points northwest of Beech Mountain these ores are found, indicating a considerable range for the veins.

BROWN HEMATITE.

Ores of this nature are abundant in the Tennessee district, and include limonite and various combinations of the oxide and hydrate of iron. They occur as lumps and masses in the residual clays of the Watauga shale and the Shady limestone, and are most plentiful in the northeastern part of the district. Ores of the Watauga shale are siliceous and present all grades between pure limonite and pure chert. Masses in this formation attain a diameter of 6 feet. As a rule they are not available on account of the silica, and only within 2 or 3 miles of Shoun Crossroads have they been found sufficiently pure to be used. Ores of the Shady limestone are usually very pure, and were worked in the old forges for many years. The deposits form two classes, masses scattered irregularly through the limestone clay and ores lying along the fault planes. The latter usually contain considerable silica in the form of sand grains and fragments of Erwin quartzite, and they grade from good ore through ferruginous breccias into ordinary siliceous and calcareous fault breccias. The deposits in clay are very pure and have received the greatest development. Like all deposits of this nature, the amount of ore in the clay varies much. In this region, however, the ore lumps are distributed with unusual frequency and regularity. The lumps attain a size as great as 2 and 3 feet, and the deposits have been tested to a depth of 50 feet. The richest and most frequent deposits are found in the lower part of the limestone, near its junction with the Erwin quartzite. Considerable pyrite is found in the upper layers of the quartzite, and may be the source of much of the iron. The deposits of ore occupy the synclinal basins for the most part, and may be due to downward concentration toward the bottoms of the folds. This correspondence of structure and ore deposits is most striking in Shady Valley just north of the Cranberry quadrangle.

GEOLOGIC WORK IN THE LAKE SUPERIOR IRON DISTRICT DURING 1902.

By C. K. Leith.

In the early part of the year there was distributed a general paper by C. R. Van Hise on the Iron Ores of the Lake Superior Region, containing a general account of the geology of the region and of the origin of the ores, and accompanied by small scale maps of some of the districts.

There have also been sent to press during the year Monograph XLIII, on the Mesabi iron-bearing district of Minnesota, by C. K. Leith, and Monograph XLV, on the Vermilion iron-bearing district of Minnesota, by J. Morgan Clements. W. S. Bayley has spent the year in the preparation of another monograph, on the Menominee iron-bearing district of Michigan, which will be published in 1903. The work in all of these districts has been directed by C. R. Van Hise.

MESABI DISTRICT.

The Mesabi monograph (XLIII), by C. K. Leith, is a volume of 301 pages, accompanied by a general map of the range, covering the area between Birch Lake and Grand Rapids on a scale of 1 mile to the inch, and by 33 plates and 12 figures, including many detail maps and sketches.

The Mesabi iron ores have developed from the secondary alteration of a rock composed largely of green ferrous silicate granules, resembling glauconite, and so called by Spurr, but here shown not to be glauconite and called "greenalite." The greenalite granules are supposed to develop in much the same way as iron carbonates of other parts of the Lake Superior region, described by Van Hise, and to owe their occurrence in the form of granules to organic agencies. The concentration of the ores has consisted essentially in the oxidation, under weathering conditions, of the ferrous iron in the greenalite granules and the segregation of the iron and silica. The alteration of the greenalite and concentration of the ore has occurred through the agency of moving underground waters and the ore deposits have been localized in places where the circulation has been vigorous. Broad, shallow synclines in the iron formation (Upper Huronian) have exerted a primary control of the circulation of the underground waters concentrating the ores, but other factors, the cross fracturing of the formation affording trunk channels for water circulation and the ponding of water by impervious slate layers within and above the iron formation, have had strong modifying effects on the circulation and have locally been dominant. So important are these modifying factors and so complex their effect that the ore deposits have most irregular shapes and erratic distribution, and it is scarcely possible to indicate from the structure of the iron formation an area which is more likely than any other to reveal ore on exploration.

The ore deposits are shallow, seldom exceeding 350 feet in depth, but have great horizontal dimensions, sometimes a mile or more. The ore bodies come to the rock surface for most of their area, but are covered with glacial drift to a depth varying from a few feet to 100 feet. The rich ore deposits thus far discovered are confined to the central part of the district. At the east end of the district the ores are hard and magnetic and associated with amphiboles, and have not been shown to occur in bodies large enough to warrant mining. In the west end of the district some good ore has been found, but here for the most part the ores are of low grade and contain abundant chert particles resulting from the disintegration of associated chert, making it necessary to wash the ores before using them.

The iron formation is overlain to the south by a thick slate formation. Exploration has not yet shown whether or not ore will be found beneath this slate, but certain geologic facts indicate small probability. The boundary between the slate and iron formation as shown on the geologic map is, because of the heavy covering of glacial drift, only approximately correct. Much more exploration will have to be done before the true limits of the iron formation on the south can be mapped. The iron formation itself contains interbedded slate layers which closely resemble the slate overlying the iron formation, making it difficult in individual areas to determine whether the area should be mapped as iron formation or as overlying slate.

The total tonnage of high-grade ore thus far discovered in the Mesabi district has been estimated at from 500,000,000 to 700,000,000 tons, a common estimate being 600,000,000 tons, of which nearly 70 per cent is of Bessemer grade. This tonnage is over twice that of all the other Lake Superior iron districts combined. The United States Steel Corporation in 1902 owned and controlled 85 per cent or more of the Mesabi ore. Shipments from the Mesabi district first began in 1891, and in 1902 the shipments were nearly half of the total for the Lake Superior region, namely, 13,329,953 tons, and more than one-third of the total of the United States.

The ores are mined in open pits by steam shovel, or underground by either ordinary or "milling"[a] methods. In 1902 about 46 per cent

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[a] Chutes, known as mills, are run from the level of the bottom of the shaft up to the working levels. The ore is loosened and dumped into the chute, falling into cars at the bottom, being trammed to the shaft and hoisted.

of the ores was mined by open-pit steam shovel, 46 per cent by ordinary underground methods, and 7 per cent by "milling."

When first introduced Mesabi ores were considered too soft for extensive use in furnace charges, but now they constitute an average of 50 per cent of the ore burden, and individual ores may be used in percentages as high as 100 per cent.

The iron and water content of the Mesabi ores is greater than in the other ores of the Lake Superior region. The phosphorus in the ores (determining their Bessemer or non-Bessemer character) is shown to have been introduced into the ores by percolating waters during the concentration of the ore and not to be a residual product of alteration. The precipitation of phosphorus from percolating waters is believed to be connected in some way with aluminous compounds in the ores.

VERMILION DISTRICT.

The Vermilion monograph (XLV), by J. Morgan Clements, is a volume of 463 pages, accompanied by a general map of the Vermilion range covering the area from west of Tower to Gunflint Lake, an atlas of 24 detail maps, and 13 plates and 23 figures in text.

The iron ores are shown to be confined to the Basement Complex or Archean, to be closely associated with jasper and greenstone, and to have been concentrated by underground waters in steep pitching troughs formed by the folding of the greenstone. No direct evidence of the original source of the ore has been found, but it is believed that the iron has developed from an iron carbonate, in this feature resembling the old ranges of the Lake Superior region rather than the Mesabi range.

The ores are hard, blue and red hematites, and up to the present time have been found in large quantities in only two areas in the district—near Soudan and near Ely. The detail maps show iron-formation belts at many other places in the district in which exploration is warranted.

MARQUETTE, GOGEBIC, AND CRYSTAL FALLS DISTRICTS.

At the completion of work in the Mesabi district in 1902, C. K. Leith, with the direction and assistance of C. R. Van Hise, took up the revision of the published geologic maps of the Marquette, Gogebic, and Crystal Falls districts with the purpose of preparing for publication corrected editions showing the results of the vast amount of recent exploration, and with the further purpose of combining the geology shown on these maps in a large geologic map of the Lake Superior region, including all of the iron districts, to accompany a final monograph of Lake Superior geology to be submitted in 1904 by C. R. Van Hise, with the assistance of C. K. Leith. Many changes in the boundaries of the iron formations in the different districts were noted. Facts were collected that seemed to indicate that the phosphorus in these districts, as in the Mesabi district, is the result of the concentration of the percolating waters rather than a residual product, and that the precipitation of the phosphorus from such waters may be in some way connected with aluminous compounds in the ore, notwithstanding the fact that some of the phosphorus is now present in the ores as apatite, as shown by Prof. A. E. Seaman, of the Michigan School of Mines.

MOOSE MOUNTAIN DISTRICT.

Late in the season a visit was made to the new iron-bearing district, the Moose Mountain district, northeast of Lake Superior. Magnetite ore was observed in large quantities. This is the first district in which iron ores in large quantity have been discovered in Canada. The district in its geologic features resembles the Vermilion of Minnesota more closely than any other district, and because of this resemblance the Moose Mountain iron-bearing rocks are supposed to be of Archean age, although no structural connection of the two districts is possible. The ores are closely associated with quartzites and graywackes bearing iron pyrites, and alterations of iron pyrites to iron ore may be observed on a small scale, and these facts, together with the abundance of other sulphide ores in this area, lead us to suspect that further work may show the origin of the iron ores to be in some way connected with the iron pyrites.

MANGANESE DEPOSITS OF SANTIAGO, CUBA.[a]

By Arthur C. Spencer.

The deposits of manganese which have thus far been worked in Cuba are all located in the vicinity of the city of Santiago, in the province of the same name, which is the easternmost on the island. The first ore, shipped in 1887, was a picked lot of 50 tons, and in spite of adverse conditions in regard to facilities for transportation, the output had increased by 1890 to 21,810 tons. From this time up to 1898 the amount of ore annually mined was not so great, but various deposits were discovered and several mines were opened with varying success. As many as eight mines, which were worked previous to the revolution of 1895–1898, have been visited by the writer.

The manganese ores of the Santiago region are mixtures in various proportions of the common oxides of manganese, probably including manganite, pyrolusite, braunite, and wad. The deposits occur in a region lying back of and parallel to the Sierra Maestra, between Guantanamo on the east and Manzanillo on the west, and in general coincident with the drainage basins of the Rios Cauto and Guantanamo. The geologic structure between the latitudes of the two cities named is that of a broad synclinal fold, with an east-west axis. From Cabo Cruz on the west to Guantanamo on the east the stratified rocks which compose the northern slopes of the Sierra Maestra dip at angles of from 10° to 20° toward the depressed area of the interior occupied by the Rios Cauto, Guaninicum, and Guantanamo, while upon the north side of these drainage basins the strata rise as the mountains which occupy the country between them and the north coast are approached. The rocks exposed along the crest of the Sierra Maestra are coarse, well-stratified volcanic breccias, but upon the northern slope these soon pass beneath strata showing an alternation of marine sediments and fine-grained volcanic tuffs, which are in turn covered by flows of basalt and still other fragmental volcanic deposits.

This essentially volcanic series grades into and finally gives place to limestones and other purely marine sediments, as may be well observed along the new military road which crosses the high range of hills north of Santiago Bay, and at Cristo, where the Moroto and

[a] Report on a geological reconnoissance of Cuba, made under direction of Gen. Leonard Wood, military governor; also Eng. and Min. Jour., August 23, 1902, pp. 62–69.

Sabanilla Railway crosses the same range in a deep notch or pass. On both sides of the railroad south of this pass there are several old manganese mines in rocks belonging to the upper part of the mixed volcanic and marine series. The manganese was also formerly worked near the station of Dos Bocas, several miles west of the deposits located south of Cristo, and apparently in rocks occupying approximately the same stratigraphic position. The beds exposed in these mines are very much disintegrated, and the rock is frequently impregnated to a considerable extent by manganese ore. It is variegated in its coloring, being green with red splotches. It exhibits no gritty material, and it appears to have been made up of fragments which were originally angular in form. At the Boston mines, located between 2 and 3 miles to the east of Cristo, the country rocks are limestones and glauconitic greensands, cemented by lime, and both of these rocks are found replaced by ore. When decomposed they resemble the disintegrated beds south of Cristo.

In the deposits south of the Cristo divide, between the drainage which flows directly to the sea by way of Rio San Juan and the basin of the Rio Cauto, which finds its outlet to the west of Cabo Cruz, the strata all dip at varying angles toward the north, excepting in such instances as they are overturned, when the reversed dips are very steep toward the south. Associated with the ore there are large amounts of siliceous rock in the form of dense amorphous jasper, or bayate, as it is locally called. Traced in a broad way, the bayate may be made out to follow the stratification of the bedded rocks, along which it occurs in interrupted masses. But studied locally, the irregularity of the bayate is such that, with the poor exposures of the strata which exist, it would be impossible to say that it did not have the form of cross-cutting veins, as sometimes appear. However, the interbedded character of the siliceous rock is established with a good degree of certainty. Across the stratification the thickness of the jasper masses is found to vary from a few inches to 15 or 20 feet, while along the bedding they may have a length reaching in some cases several hundred feet.

The ore occurs principally in a very irregular way, filling spaces between the jasper and the country rock, but also in the form of veins in the masses of jasper, and disseminated through the decomposed country rock adjacent to the jasper. In the last case the ore frequently has the form of nodules arranged in the bedding planes of the parent rock, which it seems to have replaced in part. The relations of the ore and the jasper are very intimate, and specimens may be found in which veinlets of ore penetrate the jasper as though there had been molecular replacement of the latter by the former. On the other hand, cases may be observed in which the opposite condition seems to have obtained, so that the ore was replaced by siliceous material introduced after the first deposition of the metallic mineral. In general the mode of occurrence is such that both the ore and the associated jasper appear to have been introduced in a secondary way after the deposition of the strata in which they are found and the original substance of which they now replace. The jasper and the oxides of manganese are of contemporaneous origin, and for their introduction into the strata where they now occur the action of the heated water in circulation is suggested. The constitution of the greensand beds was evidently favorable for a chemical reaction between their substance and the materials held in solution by ascending hot waters, which doubtless, originating at a considerable depth, found easy channels of outlet through the more porous of the disturbed and upturned strata occurring in the region.

Other manganese mines, and in fact the only ones at present in operation, lie about 3 miles east of Cristo, and 12 miles to the northeast of the same town. The former comprise the Boston group of claims already mentioned and the Ysabellita near by, and the latter includes the Ponupo mines. Owing to the limited time at the writer's disposal it was impossible to sufficiently test the theory formed in the field that all of these deposits lie at approximately the same geologic horizon. There are, however, some facts which tend to support this idea. Perhaps the most important of these is the occurrence of a band of limestone, composed almost entirely of foraminifera belonging to the type *Orbitoides*, just above the ore horizon at four distinct and widely separated localities, namely, near the mines east of the railroad south of Cristo, at the Boston mines, at the Ponupo mines, and at San Nicolas, about 8 miles west of San Luis, where manganese ores also occur in green, disintegrated sandstones. Again, in almost all of the places where the strata in which the ores occur are exposed, they are exactly similar, being loose, disintegrated sandstones, mostly of a dark green color. At the Boston mines the green, decomposed sandstones have been uncovered at a short distance from the ore body, and here, though resembling in general appearance the sand which occurs with much of the ore, they are found to be made up in large part of the shells of a large variety of foraminifera filled with glauconite and accompanied by grains of the same mineral to which the green color of the sandstone is due. It seemed evident that these rocks and the ore-bearing beds were originally of the same nature, but that the calcareous shells of the foraminifera had been removed from the near neighborhood of the ore deposits by the solutions which deposited the silica and manganese. A similar removal of the calcareous contents may be taken to explain their absence from the other localities, where the only strata observed were those in close proximity to the ore bodies and jasper.

The rocks in the region south of Cristo were found to have been tilted toward the north, as though they were lying upon the south side of a great structural syncline. This, in fact, they do, as more general observations in Santiago province show. The structure in the immediate vicinity of the Boston and Ponupo mines is quite different. These lie well within the great syncline, where the strata have been thrown into minor folds, and it is observed that the ore deposits in both places occupy the central or axial portion of articlines or arches of the strata. The Ysabellita mine is less than a mile from the Boston, and appears to be located upon the same arch, but the structural relation between this fold and the one at the Ponupo mine is not known. Though the altitude of the strata is different, the relations of the ore, jasper, and country rock are exactly the same as at Cristo, and the deposits have been the result of metasomatic replacement of calcareous strata by manganiferous minerals and jasper. In the case of the Boston, Ysabellita, and Ponupo mines, and probably also at San Nicolas, it may be argued that the hot waters to which the replacement is attributed ascended through fissures locally developed along the axis of the folds rather than through the strata, as has been suggested for the occurrences in the vicinity of Cristo, where the stratified formations are standing on end. This would account for the local character of the deposits along the folds, as well as the presence of undissolved shells and the absence of both jasper and ore in the beds of green sand as they rest on the flanks of the arch at the Boston mines.

In both the Boston and Ysabellita mines the amount of jasper is large, and it occurs in large masses, around which the richest ore is found, with deposits in which the ore is mixed with rock, disseminated locally in the portions of the decomposed greensand or glauconitic rock adjacent to the jasper. Sometimes the ore is found to entirely surround the masses of siliceous rock along its contact with the country rock. An illustration of this is seen in the Boston mine, where a large block of jasper has been worked about on all sides and a large amount of ore extracted. Another is seen in the workings of the Ysabellita mine. Next to the large mass of jasper a bed of loose, sandy material, containing oxide of manganese in the form of small nodules arranged along the planes of stratification, extends to a distance of not less than 25 feet from the jasper, and the thickness of the ore-bearing bed is not less than 20 feet as exposed.

In this vicinity there are no less than six distinct outcrops of jasper in large masses within a radius of about 150 feet, but only one has been sufficiently developed to prove the presence of large quantities of ore.

At the Ponupo mine the conditions are quite similar to those at the two mines just mentioned. The deposit occupies the center of an anticlinal fold, and there are large amounts of jasper, with high-grade ore occurring in contact with it, and ores of lower grade, because mixed with decomposed rock lying adjacent to it. Here the ore extends up to the horizon of the foraminiferal limestone, which it has replaced in part, as was well seen upon the north side of the mine. The ores in these three mines occur about the summits and slopes of knolls which owe their elevation to the durability of the jasper against the processes of erosion. This jasper occurs in very irregular masses, between which the ore is found in equally irregular pockets, either pure, or, as has been stated, mixed with decomposed country rock. Frequently the ores are intimately veined or impregnated with streaks of jasper, when they become valueless, but as a rule the jasper occurs in well-defined nodules, which may be easily separated from the rock, which must be mined with the ore.

The mode of occurrence in all of the localities mentioned is such that very large deposits can not be expected. A yield of 100,000 tons of first-grade ore from any one mine is estimated as all that can be expected in most cases, though if the attempt now being made to concentrate the ores at the Boston mine is successful the marketable output will be greatly increased.

The Ponupo mine has been worked on a large scale since the winter of 1898. It has standard-gage tracks laid to the ore chutes. A track has also recently been completed to the Boston mine, and can readily be connected with the Ysabellita. It is from these mines that the supply of Cuban manganese will be drawn for some time, though with the completion of the Cuba Central Railway a few other mines of importance may be developed. The amount of ore which may be anticipated from any one of them will not, however, warrant the construction of special tracks of any great length to bring their product to the trunk line.

PUBLICATIONS ON IRON AND MANGANESE.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey, or by members of the Survey, are listed below:

BARUS, P. The present technical condition of the steel industry of the United States. U. S. Geol. Survey Bulletin No. 25, 85 pp. 1885. (Out of print.)

BIRKINBINE, J. American blast-furnace progress. In Mineral Resources U. S. for 1883–84, pp. 290–311. 1885.

——— The iron ores east of the Mississippi River. In Mineral Resources U. S. for 1886, pp. 39–98. 1887.

——— The production of iron ores in various parts of the world. In Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 21–218. 1894.

——— Iron ores. In Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. VI, pp. 23–63. 1898.

——— Manganese ores. In Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. VI, pp. 91–125. 1898.

CHISOLM, F. F. Iron in the Rocky Mountain division. In Mineral Resources U. S. for 1883–84, pp. 281–286. 1885.

CLEMENTS, J. M. The Vermilion iron-bearing district of Minnesota. Monograph U. S. Geol. Survey Vol. XLV, 463 pp. 1903.

CLEMENTS, J. M., SMYTH, H. L., BAYLEY, W. S., and VAN HISE, C. R. The Crystal Falls iron-bearing district of Michigan. Monograph U. S. Geol. Survey Vol. XXXVI, 512 pp. 1899.

HAYES, C. W. Geological relations of the iron ores in the Cartersville district, Georgia. In Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 403–419. 1901.

IRVING, R. D., and VAN HISE, C. R. The Penokee iron-bearing series of Michigan and Wisconsin. Monograph U. S. Geol. Survey Vol. XIX, 534 pp. 1892.

KEMP, J. F. The titaniferous iron ores of the Adirondacks [New York]. In Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 377–422. 1899.

LEITH, C. K. The Mesabi iron-bearing district of Minnesota. Monograph U. S. Geol. Survey Vol. XLIII, 316 pp. 1903.

SMITH, E. A. The iron ores of Alabama in their geological relations. In Mineral Resources U. S. for 1882, pp. 149-161. 1883.

SMITH, GEO. O., and WILLIS, B. The Clealum iron ores, Washington. In Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 356–366. 1901.

SPENCER, A. C. The iron ores of Santiago, Cuba. In Eng. and Min. Jour., Vol. LXXII, pp. 633–634. 1901.

SWANK, J. M. The American iron industry from its beginning in 1619 to 1886. In Mineral Resources U. S. for 1886, pp. 23–38. 1887.

——— Iron and steel and allied industries in all countries. In Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 219–250. 1894.

VAN HISE, C. R., BAYLEY, W. S., and SMYTH, H. L. The Marquette iron-bearing district of Michigan, with atlas. Monograph U. S. Geol. Survey Vol. XXVIII, 608 pp. 1897.

WEEKS, J. D. Manganese. In Mineral Resources U. S. for 1885, pp. 303–356. 1886.

——— Manganese. In Mineral Resources U. S. for 1887, pp. 144–167. 1888.

——— Manganese. In Mineral Resources U. S. for 1892, pp. 169–226. 1893.

YALE, C. G. Iron on the Pacific coast. In Mineral Resources U. S. for 1883–84, pp. 286–290. 1885.

In addition to the papers listed above, iron deposits of more or less importance have been described in the following geologic folios (for location and further details see pp. 11–13): Nos. 2, 4, 5, 6, 8, 10, 11, 12, 14, 18, 19, 20, 21, 22, 24, 25, 28, 32, 33, 35, 36, 37, 40, 43, 44, 55, 56, 59, 61, 62, 64, 70, 72, 78, 82, 83, 84.

COAL.

The first paper presented below is a reprint, in slightly condensed form, of the introduction to the series of special reports on the coal fields of the United States, published in 1902.[a] It is republished here to serve as a summary of the subject for this volume. Following it will be found two reports, hitherto unpublished, on the results of field work by the Survey during 1902 in the coal fields of Pennsylvania, Indiana, and Illinois, and of Alaska. Field work was also carried on by the Survey in other coal districts, but the results are not now in shape for publication.

The series of reports on United States coal fields above mentioned covered the entire coal industry of the country. Owing to the length and importance of these reports, it is impossible to present satisfactory abstracts of them in this bulletin. For detailed information in regard to the various fields it will be necessary, therefore, for the reader to consult the reports themselves.

COAL FIELDS OF THE UNITED STATES.

By C. W. Hayes.

DISTRIBUTION OF COAL IN THE UNITED STATES.

Coal occurs in commercial quantities in 27 of the 47 States and Territories of the United States and in Alaska. The following table shows the areas of coal-bearing formations in the several States and the rank of the coal-producing States in area and production:

Rank of coal fields and coal-producing States in area and production.

Coal field, and State or Territory.	Area of coal-bearing formations.	Per cent probably productive.	Rank of field and State in area.	1900. Production.	1900. Average price per ton at mine.	1900. Per cent of total production.	1900. Rank in production.
Anthracite field:	*Sq. miles.*			*Tons.*			
Colorado and New Mexico	----	----	----	98,404	----	0.04	----
Pennsylvania	484	----	26	57,367,915	$1.40	21.25	1
	----	----	X	----	----	----	----
Atlantic coast Triassic:							
Virginia	270	50	30	57,912 (Virginia and North Carolina)	1.79	.02	----
North Carolina	800	(?)	24				
Total	1,070	----	VIII	57,912	----	----	----

[a] Twenty-second Ann. Rept., Pt. III. For a list of Survey's publication on coal, see p. 294.

Rank of coal fields and coal-producing States in area and production—Cont'd.

Coal field, and State or Territory.	Area of coal-bearing formations.	Per cent probably productive.	Rank of field and State in area.	1900. Production.	Average price per ton at mine.	Per cent of total production.	Rank in production.
Northern Appalachian:	*Sq. miles.*			*Tons.*			
Pennsylvania	15,800	75	7	79,842,326	.97	29.58	1
Ohio	12,000	70	10	18,988,150	1.02	7.03	4
Maryland	510	80	25	4,024,688	.98	1.49	11
Virginia	1,850	80	22	2,353,576	.89	.87	17
West Virginia	17,280	75	6	22,647,207	.81	8.39	3
Kentucky (eastern)	10,300	70	13	2,222,867	.92	.82	18
Total	57,740		III	130,078,814			
Southern Appalachian:							
Tennessee	4,400	47	18	3,708,562	1.14	1.38	13
Georgia	167	14	31	315,557	1.17	.12	26
Alabama	8,500	44	15	8,394,275	1.17	3.11	5
Total	13,067		VI	12,418,394			
Northern Interior:							
Michigan	11,300	(?)	12	849,475	1.48	.31	25
			VII				
Eastern Interior:							
Indiana	9,300	60	13	6,484,086	1.03	2.40	6
Illinois	42,900	50	1	25,767,981	1.04	9.55	2
Kentucky (western)	5,800	65	17	3,106,097	.92	1.15	15
Total	58,000		II	35,358,164			
Western Interior:							
Iowa	20,000	50	4	5,202,939	1.38	1.93	9
Missouri	23,000	60	2	3,540,103	1.21	1.31	14
Nebraska	3,200		19				
Kansas	20,000	75	3	4,467,870	1.22	1.65	10
Total	66,200		I	13,210,912			
Southwestern:							
Indian Territory	14,848	50	8	1,922,298	1.45	.71	19
Arkansas	1,728	75	23	1,447,945	1.14	.54	21
Texas	11,300	45	11	968,373	1.63	.36	24
Total	27,876		V	4,338,616			
Rocky Mountain:							
South Dakota	120		32	129,883	1.22	.05	28
Montana	13,000		9	1,661,775	1.63	.62	20
Idaho				10	5.00		30
Wyoming	7,500	50	16	4,014,602	1.36	1.49	12
Utah	2,000	30	21	1,147,027	1.26	.42	23
Colorado	18,100	50	5	5,182,176	1.12	1.92	8
New Mexico	2,890	40	20	1,263,083	1.37	.47	22
Total	43,610		IV	13,398,556			
Pacific coast:							
Washington	450		27	2,474,093	1.90	.92	16
Oregon	320		28	58,864	3.74	.02	29
California	280		28	171,708	3.05	.07	27
Total	1,050		IX	2,704,665			

Areas of lignite-bearing formations are not included in the above table. These areas are extensive and their beds of lignite contain a vast reserve of valuable fuel, but they are not strictly comparable with the higher-grade fuels of the anthracite and bituminous fields. There are approximately 56,500 square miles of lignite-bearing formations, chiefly Cretaceous, in Montana, the Dakotas, and Wyoming. The Tertiary lignite-bearing formations of Alabama, Mississippi, Louisiana, Arkansas, and Texas constitute another area of about equal extent. The percentage of the areas of coal-bearing formations which is probably productive is fairly well known in a few of the thoroughly developed fields. In most of the fields, however, the figure given is merely an estimate based on incomplete data, while in a few the available data are of such a character that an estimate would have little if any value. The estimates given are believed to be conservative in every case. It should further be remembered that large areas which under present conditions are, for various reasons, classed as unproductive, may in the future, under changed conditions, become productive. This is the case with those fields in which the coal lies too deep to be mined with profit at the present time.

The true rank of the several coal fields and States in value of the available fuel which they contain is not indicated by the table, since area of coal-bearing formations and percentage of productive area are only two of the factors which determine that value. Other factors are the number and thickness of the workable beds of coal, its quality as fuel, and the ease with which it can be mined. The data are not at present available for bringing these factors into the problem.

It will be noted that the rank of the States in production is quite different from their rank in area of coal-bearing formations. Thus the Northern Appalachian field, which ranks third in area, ranks first in tonnage and value of product, while the Western Interior field, which ranks first in area, is fourth in production. This result is due to several causes, among the most important of which are (1) proximity to markets, (2) suitability of the coal to the fuel requirements, (3) relative quantity of workable coal per square mile of productive area.

GEOLOGIC RELATIONS OF THE COAL FIELDS.

The coal-bearing formations of the United States range in age from Carboniferous to Tertiary. The Carboniferous coals are confined to the region east of the one hundredth meridian and the Triassic coals to the Atlantic coast. Most of the Cretaceous coal fields lie in the Rocky Mountain region, between the one hundredth and one hundred and fifteenth meridians, and the Tertiary coal fields are between the one hundred and twentieth meridian and the Pacific coast. During the three great coal-forming periods, therefore, the Carboniferous, the Cretaceous, and the Tertiary, there has been a successive westward shifting of the zone within which conditions favorable for the accumulation of coal prevailed. Exceptions to this westward progression of the coal-forming zone were the deposition of coal east of the Carboniferous fields in Triassic time and south of the Carboniferous fields during Tertiary time.

Carboniferous coal fields.—There are five main subdivisions of the Carboniferous coal fields. They may be briefly characterized as follows:

The anthracite field is confined to eastern Pennsylvania and contains 484 square miles of productive area. It consists of several long, narrow, synclinal basins, whose axes are approximately parallel, extending in a northeast-southwest direction. They do not differ materially from the ordinary synclines of the sharply folded Appalachian belt, except that they are sufficiently deep to have preserved the Coal Measures, which have elsewhere throughout this folded belt been generally removed by erosion in the synclines as well as upon the anticlines. This field has been thoroughly developed, and a larger proportion of its coal has been mined than of any of the other fields.

The Appalachian field, which has been subdivided into northern and southern fields, extends from the northern border of Pennsylvania southwestward 850 miles to central Alabama. It embraces portions of nine States, and contains, approximately, 70,800 square miles, of which about 75 per cent contains workable coal. The eastern margin of this field forms the western border of the sharply folded Appalachian belt, and along this margin the strata have suffered some folding, a few outlying synclines being nearly or quite separated from the main field by steep eroded anticlines. In general, however, the strata in this field are either gently undulating or essentially horizontal. The formations which make up the Coal Measures are generally thickest along the eastern margin of the field, thinning rapidly westward. In the same direction there is a corresponding decrease in number and thickness of the coal beds. These formations consist of overlapping lenses of conglomerate, sandstone, shale, coal, and occasionally limestone, none of which can be traced throughout the entire field. Some coal beds, as the Pittsburg and Sewanee, may be identified over several thousand square miles, but more generally the workable coal is in local thickenings of beds that are elsewhere worthless. For this reason correlations of individual beds in distant parts of the field are of doubtful value, although particular horizons may often be closely correlated by means of the fossil plants they contain. Some portions of the field have been carefully prospected, chiefly those in which development has been most active, but large areas, particularly in West Virginia and Kentucky, remote from lines of transportation, remain practically unknown.

The Northern Interior field lies wholly within the State of Michigan and has an area of approximately 11,000 square miles. It forms an oval area whose outlines are imperfectly known, since the region is deeply covered by glacial drift. Prospecting is done entirely by means of the drill, and on account of the expense involved the proportion of the field underlain by workable coal can not at present be estimated. The strata appear to dip from the margins of the field toward its center, the formations thickening in the same direction. It is probable that this field was formed in an isolated basin and that its strata have never been continuous with those of the fields to the southeast and southwest, in Ohio and Indiana.

The Eastern Interior field embraces portions of Indiana, Illinois, and Kentucky, having an area of 58,000 square miles. It forms an oval basin whose longer axis extends northwest and southeast, nearly at right angles to the axis of the Appalachian field. The strata about the margins of the basin have gentle dips toward its center, while in the interior of the basin they are practically horizontal. The workable coal beds are confined to the lower portion of the Coal Measures, and hence reach the surface in a broad belt about the margins of the basin. The development of the field has been confined to this belt, although the coal beds are supposed to extend beneath the unproductive formations which occupy the surface in the central portion of the field. It is estimated that about 55 per cent of the area is productive under present conditions, and that a considerable proportion of the remainder will become productive when conditions render mining at greater depths profitable. The Eastern Interior field is separated from the fields on either side by broad, gentle anticlines, from which the Coal Measures, which may originally have been continuous, have been removed by erosion.

The Western Interior and Southwestern fields form a practically continuous belt of Coal Measure rocks extending from northern Iowa southwestward 880 miles to central Texas, and embrace an area of 94,000 square miles in Iowa, Missouri, Nebraska, Kansas, Indian Territory, Arkansas, and Texas. At the eastern margin of these fields the underlying older formations reach the surface, while along their western margin the Coal Measures pass beneath the Permian and other formations of the plains region.

In the Western Interior field and the northern portion of the Southwestern in Indian Territory, as well as in the portion lying in Texas, the strata are nearly horizontal, having a uniform gentle dip to the west. In that portion of the field which lies in Arkansas and extends westward through the central part of Indian Territory the strata are somewhat sharply folded. This belt forms the northern border of the intensely folded and faulted Ouachita Mountain zone, whose structure corresponds closely with that of the Appalachians.

Triassic coal fields.—Several small basins of Triassic rocks in the Piedmont region of Virginia and North Carolina are coal bearing. They contain an aggregate area of about 1,000 square miles. The most important of these, and the only ones at present productive, are the Richmond and Deep River areas. The strata of these basins rest directly upon the crystalline rocks of the Piedmont Plateau. They may originally have been continuous and nearly horizontal, but are now separated and considerably folded and faulted. They have also been invaded by dikes and sheets of igneous rocks, which have at some points converted the coal into natural coke or carbonite. While the coal is in some places of excellent quality, it shows great irregularity, as would be expected from the conditions under which it was deposited and the movements to which it has subsequently been subjected. These fields are chiefly of historic interest, since the first systematic coal mining in the United States was carried on within their borders.

Cretaceous coal fields.—As conditions had been favorable for the accumulation of coal in the region east of the one hundreth meridian during Carboniferous time, so they were favorable for its accumulation during Cretaceous time in the region between the one hundredth and one hundred and fifteenth meridians. Since the deposition of the Cretaceous formations in this region it has been subjected to the action of mountain-building forces and to intense volcanic activity. Hence the coal-bearing formations, which may originally have been continuous over much of this region, occur in small, irregular basins separated by larger areas of elevation and erosion or by areas of igneous rocks. Although the folding of the strata and their invasion by igneous rocks have greatly reduced the area of the coal-bearing formations, the quality of the coal has been thereby greatly improved. In the extensive undisturbed Cretaceous areas which extend eastward from the Rocky Mountains beneath the plains region in Montana, Wyoming, and the Dakotas, there are numerous beds of lignite, while the same horizons on the flanks of the mountains yield high-grade bituminous coal.

The Cretaceous coal fields are included within a belt that extends from the Canadian boundary southeastward for a distance of 1,200 miles. Its axis coincides with the main range of the Rocky Mountains, but includes also numerous outlying ranges. Its greatest breadth is about 500 miles. It embraces portions of Montana, South Dakota, Wyoming, Colorado, Utah, and New Mexico. Mr. Storrs has described 45 separate areas within this belt, having an aggregate extent of 43,610 square miles.[a] All of these areas are known to contain workable coal, but many of them are undeveloped and practically unexplored, so that estimates of the productive area are not by any means exact.

Two small areas of Cretaceous coal-bearing formations in western Texas properly belong with the Rocky Mountain fields. The westernmost of these is the San Carlos coal field, in El Paso County. Considerable outlay has been made here in development, but all the

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, p. 422.

coal thus far discovered is a low-grade fuel, and the field is not now producing. The Eagle Pass field is much the larger and more important of the two, and contains some coal of excellent quality. It extends from the northern border of Uvalde County about 75 miles southwestward to the Rio Grande, and beyond the international boundary expands to a broad area in Mexico. The strata have been considerably disturbed, and probably only a small proportion of the field will prove to be productive.

Practically all the available information concerning these Texas Cretaceous coal fields is contained in a report by T. Wayland Vaughan, entitled Reconnaissance in the Rio Grande coal fields of Texas: Bull. U. S. Geol. Survey No. 164, 1900.

Tertiary coal fields.—The Tertiary formations in various parts of the United States contain a large amount of vegetable organic matter which, in many places, forms beds of lignite. In a few places near the Pacific coast conditions have been favorable for the conversion of this lignite into true coal. The most important deposits of this Tertiary coal are in Washington. Here the folding of the inclosing strata and the intrusion of igneous rocks have converted the lignite into coal of fair quality. Similar conditions have prevailed at a few points in the extreme western portion of Oregon and in central and southern California. The productive fields are all small and have a total area of about 1,000 square miles. How much of this is productive has not yet been determined, even approximately, except in a few of the most thoroughly developed basins. As in the Rocky Mountain Cretaceous fields, the coal beds show great variability in thickness and character, and mining is attended by considerable difficulty, owing to the disturbed condition of the strata.

In addition to the coal-bearing Tertiary areas of the Pacific coast, large areas of Tertiary formations occur in the southern portion of the United States, which contain extensive beds of lignite. These Tertiary lignites contain a large amount of fuel which will doubtless some time be utilized. Beginning at the Georgia-Alabama line, a narrow belt of lignite-bearing formations extends westward nearly to the Mississippi River. West of the Mississippi the same formations occupy a much broader belt, extending from Little Rock southwestward through Arkansas, Louisiana, and Texas. The boundaries of these areas are quite indefinite, owing to the presence of later deposits, and probably only a small proportion of the area contains lignite beds of sufficient thickness and purity to be utilized.

CLASSIFICATION OF THE COAL AS FUEL.

The various fuel requirements call for coals of varying composition, and the adaptability of any coal to a particular purpose is determined largely by the relative abundance of the several fuel constituents.

These consist of the volatile hydrocarbons and of the nonvolatile or fixed carbon. This relation is expressed by the *fuel ratio*, a quantity obtained by dividing the percentage of fixed carbon by the percentage of the volatile combustible constituents of the coal. In general the fuel value or heating power increases with the increase of the fuel ratio, since more heat is developed in the combustion of carbon than of the hydrocarbon compounds. This increase in fuel value, however, continues only to a certain point, beyond which the difficulty of effecting combustion more than makes up for the greater amount of heat evolved. Thus the graphitic anthracite of the Rhode Island field can not properly be regarded as a fuel, since the percentage of volatile constituents is so small that these have to be supplied by the addition of another coal before it will burn.

In addition to its fuel constituents, a coal contains others which are nonessential. The most important of these are water and ash. The former not only replaces an equal weight of combustible matter but also absorbs heat in its volatilization. An excessive amount of water, therefore, detracts seriously from the fuel value of a coal. Its presence is further detrimental in causing the coal to break up into fine particles as it dries out. The amount of water generally varies inversely as the fuel ratio, being less than 1 per cent in some anthracites and from 15 to 25 per cent in lignites.

The ash simply occupies the place of combustible matter and is in general purely negative in its influence on the fuel. When very abundant it may seriously retard combustion, and when it contains easily fusible constituents it may become a positive detriment by forming clinker on the grate bars. Sulphur is detrimental in a steaming fuel chiefly by reason of the corrosive effect that its products of combustion exert on iron surfaces with which they come in contact.

For most metallurgical purposes it is essential that the coal should be relatively free from certain injurious constituents, such as sulphur and phosphorus.

The amounts of water and ash which a coal contains are not shown by its fuel ratio, and hence this does not serve to indicate its fuel value so much as its adaptability for specific purposes. Thus it is evident that for gas-producing purposes a coal should be chosen having a large proportion of volatile constituents; in other words, a low fuel ratio.

The coking quality of a coal depends on conditions which are in a measure independent of its chemical composition, although coking coals do not have a very wide range in fuel ratios, which generally fall between 1.20 and 2.50. By no means all coals will coke, however, whose ratios fall between these limits.

The coal of the Carboniferous fields considered as a whole show a decrease in their fuel ratios from east to west. In the Rhode Island field the coal has suffered so high a degree of metamorphism that it has passed the anthracite stage and has been partially converted into graphite, practically all the volatile compounds having been driven off. The Pennsylvania anthracite has fuel ratios varying within rather wide limits. In the analyses accompanying Mr. Stoek's paper[a] the maximum is 27 and the minimum 5.11, though most of the samples analyzed fall between 9 and 22, the average of 16 analyses being 14.11.

Within a narrow belt along the eastern margin of the northern Appalachian field the coal is relatively hard and high in carbon, forming an intermediate variety between the true anthracite on the east and the true bituminous on the west. The fuel ratios within this belt are generally between 3 and 5.

In the greater part of the Appalachian field the coals have fuel ratios ranging from 1 to 3, and as a rule the ratios are higher in the northern and eastern portions of the field as compared with the southern and western portions. There are, however, many exceptions to this rule.

The field presents certain well-marked types of coal which for particular purposes are regarded as the standard fuels. Thus the coal of the Pittsburg bed, in the Connellsville district, is usually taken as the standard with which other coking coals are compared. In the same way the Pocahontas coal may be considered a standard steaming fuel. Small areas occur in this field containing special varieties of coal, such as splint, cannel, block, etc., which are particularly well suited for certain purposes—as gas-making, domestic, and locomotive fuel.

The Northern Interior field contains only bituminous coal, which forms a fair steaming fuel, though it is inferior to most of the Appalachian coals. It generally contains a high percentage of ash and sulphur. Its fuel ratios vary from about 1.13 to 1.63, the average of 8 representative analyses given in Dr. Lane's paper[b] being 1.40.

Three varieties of coal occur in the Eastern Interior field. By far the largest part of the coal mined is soft bituminous, making a good steam fuel. In a belt along the eastern margins of the field in Indiana is a variety known as block coal, which differs from the ordinary bituminous in its physical characteristics rather than in chemical composition. It is especially well adapted for domestic fuel. In the Kentucky portion of the field are numerous small areas of cannel coal, particularly valuable for gas making and domestic purposes. The means of the fuel ratios obtained from a large number are as follows: For Indiana coals, 1.30; Kentucky, 1.57, and Illinois, 1.71.

The coal of the Western Interior field is fairly uniform in composition, having an average fuel ratio of about 1.30 and forming a fair steaming fuel. In the Southwestern field considerable more diversity is found, the coal varying from soft bituminous, with a fuel ratio of

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, p. 73.

[b] Ibid., p. 307.

1.14 in northern Texas, to a semianthracite in Arkansas, with a fuel ratio of nearly 9. The range in character of the coals in this field is shown in the accompanying table:

Table showing fuel ratios of coals in the Southwestern field.

	Number of analyses.	Minimum fuel ratio.	Maximum fuel ratio.	Mean fuel ratio.
Arkansas:				
Semianthracite	27	--------	8.96	5.79
Semibituminous		5.04	7.62	
Bituminous		3.51	4.99	
Indian Territory:				
Bituminous	24	1.26	5.22	2.68
North Texas:				
Bituminous	7	1.14	1.79	1.45

The Atlantic coast Triassic coal closely resembles the Carboniferous coals of the Appalachian field, but is generally higher in ash and sulphur. In the Richmond area the fuel ratios range from 1.8 to 3.4, the average of 7 analyses given by Mr. Woodworth being 2.4.[a] In the Deep River area they range from 1.6 to 3, the average of 17 analyses being 2.11.

In the Rocky Mountain and Pacific fields the coal presents very great diversity in character, the same basin sometimes containing all the intermediate varieties between lignite, with a fuel ratio less than 1, and anthracite with a ratio of 20 or more. These abrupt changes in chemical composition and physical properties are due to the varying degrees of alteration which the coal has undergone. The alteration is produced by the pressure due to the weight of overlying strata or to the folding of the strata by mountain-building forces and by the metamorphism of intrusive igneous rocks. The first of these agencies, vertical pressure, is least effective, but most widespread in its effects; the second, lateral pressure, is more effective and relatively local, while the third, intrusion, produces effects which are extremely localized and correspondingly intense. As a result of these conditions the coal of the plains region is largely lignite, although the lowest beds, those which have been most deeply buried, approach most nearly to true coal. Along the flanks of the mountains and in the interior basins, where the inclosing strata have been moderately folded, the coal is chiefly bituminous. In the same regions more intense folding and the intrusion of igneous rocks have converted the bituminous coal into semibituminous or anthracite.

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, p. 37.

DEVELOPMENT, PRODUCTION, AND MARKETS.

The first development of the several coal fields of the United States has been in response to the fuel demands of adjoining regions, while an abundant fuel supply has determined the location of many industrial establishments, which have in turn greatly increased the demand. The tonnage of coal produced in the various coal fields, as shown in the table on p. 257, is not proportional to their area, but depends on other conditions, such as transportation facilities, extent of markets, and character of the fuel. The largest output in proportion to area is in the Pennsylvania anthracite field, where 118,528 tons were produced in 1890 for each square mile of productive area. This large output is due to the superiority of anthracite as a domestic and locomotive fuel and the density of the population in regions adjacent to this field. The distribution of the anthracite product to the various States and the extent to which it competes with the product of other fields are shown in Mr. Stoek's paper.[a]

Owing to its location and the excellent character of its coal, the Northern Appalachian field controls the market for bituminous coal in the Eastern States, coming in competition in the northeastern portion of this territory only with the Nova Scotian field. It is the nearest of the large bituminous fields to the seaboard, and will therefore supply a large proportion of the coal which must be mined to meet the growing demands of the export trade. Its coal reaches the seaports between New York and Norfolk by a number of direct railroad lines, the most important of which are the Pennsylvania, Baltimore and Ohio, Chesapeake and Ohio, and Norfolk and Western.

The Southern Appalachian field supplies the South Atlantic and Gulf States as far west as the Mississippi. Its southern portion is almost as near the seaboard as the Northern Appalachian field, and it will in time support a large export trade, particularly to Central and South American ports, and on the completion of an isthmian canal to Pacific coast ports also.

Appalachian coal has an outlet to the West by way of the Great Lakes, the Ohio River, and numerous trunk-line railroads. Lake transportation is interrupted in winter, but during the summer season the Northern Appalachian field supplies most of the markets on the Great Lakes, competing with the nearer Northern and Eastern Interior fields. By means of the Ohio River the Northern Appalachian field supplies adjacent portions of Ohio, Kentucky, and Indiana, as well as markets along the Lower Mississippi, where it competes with the Southern Appalachian field.

The markets for the coal of the Northern Interior field are chiefly within the field itself and in the immediately adjoining region. A

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, p. 103.

small amount finds a market in the northern peninsula of Michigan and in Wisconsin. The coal of this field is inferior to that of Pennsylvania and Ohio, and can compete with the latter only when it has a decided advantage in the matter of freights.

The markets of the Eastern Interior field are also chiefly within its own limits and in immediately adjacent regions. It supplies the Chicago market in part and also some territory to the northwest and southwest. It occupies a central position among the Carboniferous coal fields, and its product comes in competition with that from all the others. It supplies the markets westward to the margin of the Western Interior field, but goes eastward only a short distance into the region which separates it from the Appalachian field, where it competes not only with the better coal from the latter field, but also with the cheap fuel supplied by the natural gas fields of Ohio, Indiana, and Kentucky.

The Western Interior field supplies the markets within its own borders and toward the north and west, where it comes in competition with the Rocky Mountain fields.

The Southwestern field supplies the markets in a large territory toward the south and west, in which it had little competition until the development of the California and Texas oil fields made liquid fuel available. Practically all the coal used by the Southern transcontinental railroads, as well as the Texas roads, comes from the north Texas and Indian Territory fields. The hard coals of the Arkansas field supply an extensive region west of the Mississippi River with a high-grade domestic fuel, which bears a relation to the neighboring soft coals somewhat similar to that borne by the Pennsylvania anthracite to the Appalachian bituminous coals.

Considering the entire region between the Appalachian coal field and the Rocky Mountain fields, there is observed a general westward movement of the coal. Thus the product of the Western Interior field goes west almost exclusively, that of the Eastern Interior field goes west to and within the borders of the Western Interior field, while the Appalachian coal goes west across both the Eastern and Western Interior fields and beyond the territory of the latter, competing with the Rocky Mountain coals to some extent. This westward tendency is due chiefly to the higher grade of the Eastern coals, but in part also to the fact that railroad freight rates are generally lower westward than eastward; water transportation also favors the westward rather than the eastward movement of coal.

The region west of the one hundredth meridian, which constitutes about half the area of the United States exclusive of Alaska and the other outlying possessions, contains less than 20 per cent of the coal fields. The largest area entirely without coal lies between the Rocky Mountains and the Pacific coast. This, however, is a region in which the population is scanty and the fuel requirements are consequently small. The Pacific coast markets are supplied chiefly by the Washington fields, though considerable coal comes from the Nanaimo district in British Columbia, and some also from England as ballast in grain vessels, and from Australia as a return cargo.

The development of the coal resources of Alaska is as yet in the experimental stage. A local fuel supply is of the greatest importance to this territory, and the present indications are that such a supply will be furnished by some of the fields now known or others not yet discovered.[a]

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[a] Practically all the information at present available concerning these Alaskan coal fields was summarized by Mr Brooks in the Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 521-569.

RECENT WORK IN THE BITUMINOUS COAL FIELD OF PENNSYLVANIA.

By M. R. Campbell.

INTRODUCTION.

During the past three years the United States Geological Survey, in cooperation with the State, has been engaged in a geologic survey of the bituminous coal field of Pennsylvania. The region is one in which considerable geologic work has already been done, and consequently particular attention has been paid to those features which had received least attention in the previous work.

In this region the feature of greatest economic importance is coal, but petroleum, natural gas, and clay have each come to be recognized as second in value only to the great coal beds which have made this part of the State famous. Inasmuch as the accumulations of oil and gas are directly influenced by the geologic structure of the region, and since the economical mining of coal and clay also depends upon the same element, it was decided to give most attention to the working out in detail of the form and dimensions of the folds which traverse the strata in the bituminous coal field. As is well known, the rocks of the northern end of this field are crumpled into long, narrow folds which traverse the basin along lines rudely parallel with the Allegheny front and gradually decrease in magnitude from east to west and also from the point of the basin toward its center in the southwestern corner of the State. Although these facts have long been understood, the exact form and irregularities of these folds have never been accurately determined.

Since the geologic structure is based upon very accurate contour maps, in which the vertical element is generally ascertained with a spirit level, the determination of the attitude of the beds is a comparatively easy matter. Some particularly prominent bed was selected as the reference stratum, and its altitude was determined at a great many points. From these collected data contours of equal elevation were drawn upon the surface of the stratum so selected, and by this means the size and shape of the folds are made manifest.

Aside from this structure work, the outcrops of the coal were carefully studied and correlated, and they are represented on the geologic maps by means of heavy lines, which show the extent of their known outcrops and the position which they occupy in the hillsides.

MONONGAHELA VALLEY.

Up to the present time six 15-minute quadrangles have been surveyed in the southwestern part of the State, where the great Pittsburg coal bed outcrops. In this territory coal is by far the most important economic factor. The area so far surveyed covers nearly the whole of the celebrated Connellsville coke field, a portion of the gas coal field of the Irwin or Port Royal basin, and much of the territory along Monongahela and Youghiogheny rivers, in which the coal is mined for fuel only. The determination of the geologic structure in this field is of the utmost importance to coal operators, for their mines must be developed in accordance with it, and for this purpose alone the representation of the structure by means of contour lines is worth many times the cost of the work.

In this part of the field there are a number of coals higher in the series than the great Pittsburg bed, but they are not utilized at present, and presumably they will not be until the great coal bed beneath them is exhausted. Of these coals the more important are the Redstone, lying from 50 to 80 feet above the Pittsburg; the Sewickley, at about 120 feet, and the Waynesburg coal, at from 330 to 400 feet. The last-mentioned coal is the thickest bed above the Pittsburg horizon, but it is generally so full of impurities that its value is not so great as that of some of the smaller beds.

Below the Pittsburg coal there are several beds of coal in the Allegheny measures, but they probably will not be utilized until the better coal is exhausted. The most important of these beds is the Upper Freeport, which lies at the top of the Allegheny formation. Along the west foot of Chestnut Ridge this bed attains a great aggregate thickness, but it is so badly broken by shale partings that it is expensive to mine, and the fuel when mined is of inferior quality.

Associated with the coal beds of the Allegheny formation are some valuable deposits of fire clay, which are being worked to some extent along the Youghiogheny River and on Chestnut Ridge. These clays are highly refractory and of great importance in the coke regions, where the consumption of fire brick in the building of ovens is enormous.

The territory surveyed in Monongahela Valley includes two or three prominent gas fields and a few very small pools of oil. The largest gas fields are located along the crest of the Bellevernon or Waynesburg anticline. They have two points of development—one near Waynesburg, in Greene County, and the other where the axis crosses the Monongahela River near Bellevernon. A small but very productive field has lately been developed upon the Fayette anticline in Fayette County, just west of Uniontown. These gas fields are usually found upon the crests of the anticlines, and it is possible that they may be extended along the axial lines. The highest point of the Fayette anticline, near Jacobs Creek, has never been tested by the drill, and it is possible that a new field may be developed at this point. From a structural standpoint it seems to be a very promising field, and it is to be hoped that before long the drill will be put down in this region.

The quadrangles surveyed in this part of the field are the Uniontown, Masontown, Brownsville, Connellsville, Latrobe, and Waynesburg. The work on the first two quadrangles has been completed, and the results are published in the Masontown-Uniontown folio. The Brownsville and Connellsville will likewise be published together, and will soon be ready for distribution. The reports on the Waynesburg and Latrobe have not yet been submitted, and it will be some time before they are published.

ALLEGHENY VALLEY.

Regular areal surveys have also been carried on in the Allegheny Valley and in territory adjacent on the east. This includes the Kittanning, Rural Valley, Eldersridge, and Indiana quadrangles, and is located mainly in Armstrong and Indiana counties, but includes also a narrow strip of the eastern part of Butler County.

So far as the stratigraphy is concerned the work is almost identical with that of previous surveys. No marked differences occur, except that in places extensive developments have taken place in late years, and some of the coal beds may be traced beneath the surface with much more certainty than was possible at the time of the other surveys of the region. From an economic standpoint the Upper Freeport and the Lower Kittanning coal beds are the most important stratigraphic features, and their underlying fire clays are also of great value. They have a wide distribution over this territory, and they are worked along the Allegheny River, Redbank and Cowanshannock creeks, and on the Kiskiminitas River.

The key rocks in this part of the basin are not so good as they are in the Monongahela Valley, and consequently folds have not been so definitely located as in the Monongahela Valley. The principal work of the present survey is the determination of the structure, and the results are very different from those contained in the published reports.

The opinion is prevalent among oil men in this region that the pools of oil bear no definite relation to the geologic structure. As determined by the second geological survey, the structures in the vicinity of Bradys Bend trend regularly about 35° E., while the oil pools generally extend either in an east-west direction, or nearly at right angles to this, in a north-south direction. It is manifest that it is impossible to harmonize these supposed facts, and consequently it was natural for the oil men to arrive at their conclusion that the accumulations of oil bear little or no relation to the geologic structure.

Oil does not occur in the eastern part of the territory, but the principal anticlinal folds show some extensive fields of gas. The extensions of these fields are always along the crest of the anticlines, and the gas men soon found that the folds as previously mapped are incorrect. Instead of coming to the conclusion that the gas fields bear no relation to the structure, they at once satisfied themselves that the previous determination of the structure was inaccurate.

The areal mapping of the territory shows conclusively that the gas men are correct in their conclusions, and that when the structure of the oil field is correctly represented it is entirely in harmony with the location of the oil pools.

One of the most pronounced changes in the interpretation of this region is in what was formerly called the Bradys Bend anticline. This was supposed to cross the river at the mouth of Redbank Creek and to extend in a straight line along a course about north 35° E. The present work shows that the location of this anticline near the Butler County line is correct, but instead of crossing the river at the mouth of Redbank Creek it swings sharply to the east and crosses the river just above the mouth of Mahoning Creek, corresponding at that point with the anticline formerly known as the Kellersburg, and extending across Redbank Creek on the line formerly supposed to represent Anthonys Bend anticline. In other words, the anticlines formerly designated Bradys Bend, Kellersburg, and Anthonys Bend are all on the same fold. The synclinal basin west of Bradys Bend anticline shows a corresponding swing to the east and agrees approximately with the Lawsonham syncline, as previously determined. The abrupt bend in this synclinal basin gives strikes nearly east and west in the vicinity of Bradys Bend and also nearly north and south on the Butler County line. This is in perfect agreement with the trend of the oil pools in this region, and is conclusive proof that when the structure is well understood it may be used as a guide in extending oil operations.

The Fairmount syncline was fairly well determined in previous surveys, except that in the vicinity of Mahoning Creek it bifurcates and the right branch swings to the east along the creek and replaces what was formerly called the Leechburg syncline. This change has no direct effect on any economic product, but it shows that the previous determination of straight axes is very misleading.

The most important change in the eastern part of Armstrong County is in the anticline which lies next east to the Fairmount syncline. In previous work this had been broken up and received different names; along Crooked Creek and Kiskiminitas River it was known as the Bagdad anticline, while on Pine and Mahoning creeks it was called Greendale anticline. These two folds are now known to be continuous, and instead of extending in a straight line to the northeast after crossing Pine Creek, it swings sharply to the right in harmony with the right fork of the Fairmount syncline, and at the crossing of Mahoning Creek corresponds with what was formerly known as the Glade Run anticline. We have, then, instead of the Bagdad, Greendale, and Glade Run anticlines one continuous fold which will probably receive the name of the Greendale anticline. This eastward swing of the anticline between Pine and Mahoning creeks had been determined by the gas men previous to the present survey, but it had never been mapped, and consequently its position is not generally known.

The data concerning the great synclinal basin east of the Greendale anticline have not yet been worked up, and consequently it is impossible to say what are the details of structure in this broad basin.

In the southern part of Armstrong and Indiana counties, errors have been found in the former determination of the position of the axes. Heretofore the Roaring Run anticline was not supposed to extend to the north much beyond the crossing of Crooked Creek. In the course of the present work this fold was found to cross Crooked Creek and then swing sharply to the east and to enter Indiana County along the South Fork of Plum Creek.

One of the most pronounced errors in the previous determinations of the structure of this region occurs in Indiana County, where numerous diamond-drill holes show that there is a pronounced syncline through the town of Indiana, where formerly an anticline was supposed to exist.[a] The first anticline west of Chestnut Ridge is one of the most pronounced folds of the region. It has been traced continuously from the West Virginia line to Conemaugh River, and in previous reports it was extended across Indiana County, and was given the name of the Indiana anticline. This name has been extensively used by several writers, and is in current use to-day to designate the long anticlinal fold previously described. The present work has demonstrated clearly that this anticlinal fold dies out near the Conemaugh River, and the two synclinal basins on either side coalesce and extend beyond the town of Indiana along a continuation of the same line that the anticline follows farther south.

The direct results obtained during the course of this survey in the Allegheny Valley are regarded as the most important contribution to the economic geology of the coal field that has appeared during the present decade. When rightly understood they are of the greatest importance to oil and gas men and of nearly equal value to coal operators.

The amount of data required for such work is enormous, and consequently the work of office preparation is necessarily slow. The maps of the Indiana folio are now being engraved, and before many months they will be ready for distribution. The reports on the other quadrangles are not so far advanced, but will be published as soon as it is possible to assemble the data and engrave the maps and print them.

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[a] Richardson, G. B., The misnamed Indiana anticline: Jour. Geol., Vol. X, pp. 700-702.

BEAVER VALLEY.

Only a small territory has been surveyed in Beaver Valley. This territory is included in the Beaver quadrangle, which lies mainly in Beaver County. The structure and stratigraphic results differ very little from those obtained in previous surveys. The principal point of improvement is in the excellent topographic map upon which the material will be shown and in the great detail with which the stratigraphy was worked. The Upper Freeport and Lower Kittanning coal beds are the principal sources of fuel in this region, but the most valuable deposits are probably the fire clays which are associated with the Kittanning group of coals. These are widely developed geographically and have been worked for a great many years. They have given the region prominence in the manufacture of clay products, but not all of the raw material has been derived from the local beds. Some oil and gas occurs in this region, but the fields are not large and the wells are generally small producers.

COAL RESOURCES OF THE YUKON BASIN, ALASKA.[a]

By Arthur J. Collier.

INTRODUCTION.

The coal beds of the Alaskan part of the Yukon Basin occur in soft sandstones and shales, with intercalated beds of conglomerate. These beds are in part in the Nulato series of the Upper Cretaceous and in part in the Kenai series of the Eocene. The two series are apparently conformable and have strikingly similar lithologic characters. They can be separated only after close stratigraphic and paleontologic study, and hence it is not now possible to state definitely what part of the coals are Cretaceous and what part are Eocene.

For the purpose of discussing its coal resources the Yukon Basin of Alaska may be divided into three provinces. The Upper Yukon includes that part of the valley lying between the international boundary and the great lowland known as the Yukon Flats. The Middle Yukon includes that part of the valley lying between the Yukon Flats and the mouth of the Tanana, and the Lower Yukon the portion of the valley from the mouth of the Tanana to the sea. In the Upper and Middle Yukon provinces the coal-bearing rocks occur in small basins surrounded by older rocks. The sandstones of these basins, as far as determined, belong to the Kenai series, and are correlated with the coal-bearing beds of southern Alaska. With a single exception these coals are either high-grade lignites or lignitic bituminous coals.[b]

The coal-bearing beds of the Lower Yukon are exposed continuously for 200 miles along the river, and they probably extend westward to include the area which has been reported near Norton Sound. This terrane is made up of sandstones, shales, and conglomerates, which probably form an uninterrupted sedimentary series, ranging in age from the Middle Cretaceous to the Upper Eocene, and hence including both the Nulato and the Kenai series. Both these series carry coals of economic importance in this province, practically all of which are of a bituminous character.

In the following pages the localities will be described according to

[a] Abstract of paper in preparation.

[b] A coal whose content of water is above 10 per cent and whose fuel ratio is less than 1 is regarded as a lignite. The fuel ratio is the quotient of the fixed carbon divided by the volatile combustible matter. Coals whose classification by this rule is in doubt have been called lignitic bituminous coals.

their geographic position, beginning at the international boundary and going down the river.

UPPER YUKON PROVINCE.

Mission Creek and Seventymile River.—A small basin of coal-bearing rocks, 7 or 8 miles in width, lies near Mission Creek, 12 miles below the international boundary. The beds are of Kenai age and the coals are probably lignites. Twenty-five miles below, on Seventymile River, is another small basin of Kenai rocks from which coal has been reported, but nothing of economic importance has as yet been developed at either of these localities.

Washington Creek.—On Washington Creek, which enters the Yukon from the south, about 82 miles below the international boundary, there is a large area of coal-bearing rocks which is probably a part of a long basin or series of basins lying south of the Yukon and including the coal-bearing formations on Seventymile River, Bonanza Creek, and Coal Creek. No fossils were obtained in the Washington Creek coal basin, but an Upper Eocene age is inferred from the lithologic character of the sandstone, the mode of occurrence of the coal beds, and the character of the coal. In all these respects this coal basin resembles that at Cliff Creek, in Canadian territory, from which Eocene fossils were obtained. The coal here occurs in a formation consisting of alternating beds of lignite, clay, and carbonaceous shale, resembling that at Cliff Creek. In this formation seams of clear coal above 5 feet in thickness occur. The coal is a high-grade lignite, having an average fuel ratio of about 1 and a water content of from 10 to 15 per cent. The ash in samples analyzed varies from 2 to 4 per cent, and the sulphur is less than three-tenths of 1 per cent. Wherever they have been opened the coal beds of the Washington Creek Basin show no evidence of faulting, and the coal is not crushed, but can be obtained in large pieces which "check" but do not break up readily on exposure to the air. Coal beds have been opened in this basin at localities several miles apart, showing that they have considerable extent. Where these beds have been prospected the dips vary from 35° to 45°.

The relief of the basin is low, and probably the greater part of the coal lies below drainage level, so that pumping will be necessary if the mines are worked.

This coal has not been mined on a commercial scale. The development in evidence consists of a tunnel 65 feet long and a slope 106 feet long. Other workings were of a temporary nature and have caved in. A good winter trail has been opened from the coal beds to the Yukon River, and last winter 5 tons of coal were sledded to the Yukon for a steam test on a river steamer. This is reported to have given entire satisfaction. A railroad 10 to 12 miles in length will be required to bring this coal to the Yukon.

Bonanza and Coal creeks.—A similar basin is reported on Bonanza

Creek, a tributary of Charley River, about 10 miles northwest of the Washington Creek Basin.

Coal Creek, about 11 miles below Charley River, has coal of a similar character. These deposits are about 6 miles from the Yukon, and they have not yet been successfully exploited.

Nation River mine.—The localities thus far described all lie on the south side of the Yukon and seem to belong to a series of Kenai basins which extends from the Klondike River, in Canadian terrritory, northwest to Coal Creek, in American territory, a distance of about 160 miles.

On the north side of the Yukon, 52 miles below the international boundary, coal outcrops, and has been mined to some extent on Tahkandit or Nation River, 1½ miles from the Yukon. The coal-bearing formation extends down the Yukon for several miles and is generally more intensely folded than the sandstones above described. From the evidence in hand it may be regarded either as Permian or a later formation, presumably Kenai, infolded with Permian rocks.

The coal is distinctly bituminous, having a fuel ratio of 1.39 and a water content of 1.39 per cent. The ash percentage is 3.04, while the percentage of sulphur is very high as compared with other Yukon coal, being 2.98 per cent. This coal shows no vestige of woody structure and in the laboratory makes a good coke. The coal has been intensely crushed and affected, probably by a shearing movement of the inclosing sandstone, so that the bed is not well defined, but the coal was found in lenses and kidneys often as large as 8 feet thick and 13 feet long.

In 1897 the Alaska Commercial Company attempted to open a coal mine at this place. About 2,000 tons[a] of coal were mined and sledded to a landing on the Yukon River. Owing to the irregularity of the bed and the consequent uncertainty of the supply and expense of mining it was abandoned several years ago.

MIDDLE YUKON PROVINCE.

Between the Upper Yukon and Middle Yukon provinces, along the river, there is a break of about 300 miles in which there are no coal beds known.

Dall River.—On Dall River, which enters the Yukon from the north side, at the lower end of the Yukon Flats and about 450 miles below the international boundary, a coal bed occurs, 70 miles from the Yukon, in shales which are supposed to belong to the Kenai series. This coal bed contains irregular streaks of clay, but the lower 4 or 5 feet of the seam are believed to be of good quality. No practical tests and no analyses of the coal have been made.[b]

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[a]For estimates of the amounts of coal produced the writer is indebted to Mr. W. E. Williams, a mining engineer who has had charge of coal mines on the Yukon since 1897.

[b]Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound: Professional Paper U. S. Geol. Survey No. 10, 1902.

Salt Creek.—Coal is also reported by prospectors to occur on Salt Creek, which enters the Yukon from the north, 25 miles below Dall River.

Drew mine.—The Drew mine is the only point at which coal has actually been mined in this province. It is on the right bank of the Yukon opposite the mouth of Hess Creek, 25 miles above Rampart and about 500 miles below the international boundary. Its position is an important one, since there are no valuable coal deposits known along the Yukon, either above or below it, within 200 miles. The coal-bearing formation exposed here is confined to a great bend of the Yukon River, and its known extent does not exceed 4 square miles, though it may be continued beneath the silts of the Yukon and Hess Creek. The coal-bearing formation here consists of a great thickness—probably over 5,000 feet—of soft sandstones, shales, and conglomerates of Kenai age, standing nearly vertical and striking at right angles with the course of the river.

From croppings seen along the river bank, it is believed that there are seven seams of coal contained in about 1,000 feet of soft sandstone and shale of the upper part of the series, but only one has been exploited. Within the mine this bed was found to consist of two seams of clean coal in about 19 feet of coaly shale. These seams measured 13 and 25 inches and were separated by 4 feet of bony coal and black shale. The analyses show that the coal from the two seams is lignitic and quite similar in quality, having fuel ratios between 0.93 and 1.08, and a water content above 9.5 per cent. Both samples show over 13 per cent ash. A sample taken from the croppings of one of the other veins which has been partially opened up had a fuel ratio of 0.72 and a water content of 14.44 per cent, but the percentage of ash is only 4.64.

The development in this mine includes a shaft 75 feet deep, from the foot of which a crosscut tunnel about 30 feet long reaches the coal bed. The shaft is cribbed and housed and equipped with steam hoisting gear. A bunker of about 80 tons capacity is conveniently located on the river bank, from which the coal can be loaded on steamers. About 1,200 tons of coal have been mined here, the greater part of which was used for steaming purposes on river boats, but did not give entire satisfaction. This dissatisfaction was due in part, no doubt, to the inexperience of the firemen and the unsuitable grates used. The coal was carelessly mined so that, as supplied at the bunkers, it contained more or less unnecessary dirt, but in spite of this it sold readily for $15 per ton while the mine was in operation. For the past two years the mine has been shut down under an attachment suit instituted by the Northern Commercial Company.

Minook Creek.—A series of sandstones, probably of Kenai age, outcrops along the Yukon in the vicinity of Minook Creek, and also extends up the valley of that stream. Attempts at coal mining have been made on Minook Creek, near the mouth of Hunter Creek, but the workings have been abandoned and have since caved in, so that the thickness of the bed could not be determined. A sample taken from the dump of the old prospect shows the coal to be a glossy lignite, which tends to break up into small cubical grains on drying. The analysis shows a fuel ratio of 0.87 and a water content of 11.21 per cent. Probably in freshly mined coal the water content would be much higher.

Below Rampart.—A similar coal outcrops 2 miles below Rampart on the left bank of the Yukon. A sample from the dump of an old prospect showed upon analysis a fuel ratio of 0.86 and a water content of 16.43 per cent. Between Rampart and the mouth of the Tanana two large areas of Kenai sandstone occur which have been reported to carry beds of coal, but so far as is known to the writer they have no commercial importance.

Cantwell River.—On the Cantwell River, which is a southern tributary of the Tanana River, about 100 miles from its junction with the Yukon, Brooks reports a great thickness of lignite-bearing sandstones believed to be Eocene. At one locality about 50 to 60 feet of lignite is contained in fifteen different seams. The analyses of this fuel shows that it has a fuel ratio of 0.66 and a water content of 13.03 per cent.

LOWER YUKON PROVINCE

Palisades.—At the Palisades, a series of silt cliffs about 55 miles below Tanana, a number of beds of lignite are exposed in the face of the cliff. This lignite is of Pleistocene or late Tertiary age and occurs in beds often several feet in thickness. It is of inferior quality, being but little changed from wood or peat, and has no economic value.

Nohatatiltin.—The Nohatatiltin coal bed is situated on the right bank of the Yukon 55 miles above Nulato and about 760 miles below the international boundary. It is in sandstones containing fossils of Eocene age, which probably overlie conformably Upper Cretaceous rocks of the Nulato formation. Two beds of coal were examined and two others are reported to have been opened by prospectors. Owing to the disturbed condition of the sandstone it is not certain that these may not all be parts of one faulted bed. The largest bed seen has a thickness of 1 foot and is not of commercial importance. The coal is a low-grade bituminous, having a fuel ratio 1.17 and a water content 6.88 per cent.

Pickart mine.—This mine is 10 miles above Nulato, on the right bank of the Yukon, and 425 miles from its mouth. The coal bed is contained in a typical exposure of the Nulato sandstone, from which Upper Cretaceous fossils have been obtained. One coal bed 30 inches thick and having a dip of 35° has been exploited. The coal is bituminous, having a fuel ratio of 2.38 and a water content of 1.03 per cent. In the laboratory it makes a compact coke.

Mining was begun at this place in 1898 by the Pickart Brothers. About two years ago the mine passed into the hands of the Alaska Commercial Company, and in the summer of 1902 it was abandoned on account of some "rolls" in the floor of the bed which cut off the coal. The development consists of a drift tunnel about 600 feet long, above which all the available coal has been mined. No bunkers were used. The coal was piled on the river beach at the mouth of the mine and loaded on steamers by means of wheelbarrows.

Nulato coal bed.—About 1 mile above Nulato, a prospect hole shows 2½ feet of bony coal, with several bands of clay, in the Nulato sandstone. This seam contains 6 inches of clean coal, which is used to a limited extent for blacksmithing at Nulato.

Bush mine.—This mine is located on the right bank of the Yukon, 4 miles below Nulato. The inclosing rock is Nulato sandstone. The development is not far enough advanced to show the nature of the coal bed. In the tunnel, which extends about 40 feet, large bodies of crushed coal 4 or 5 feet in thickness are exposed. The coal is regarded as bituminous, having a fuel ratio of 1.76 and a water content of 11.17 per cent. The high percentage of water is probably due to decomposition of the coal in the croppings. No coal has been produced, but the owners have contracted to deliver 400 tons before next summer.

Blatchford[a] *mine.*—This mine is located 9 miles below Nulato. The coal bed occurs in sandstone, probably of Upper Cretaceous age, which has been correlated with the Nulato sandstone. One workable coal bed has been opened at this place. This bed has been crushed and sheared by the movements of the inclosing strata, making it very irregular. Large masses, 8 feet in diameter, have been found and mined out, showing that before it was disturbed the coal bed probably had considerable thickness. The coal has a tendency to break up into fine pieces, though it is a bituminous coal, having a fuel ratio of 3.30, the highest of any coal on the Yukon, and a water content of 1.36 per cent. The ash is only 2.22 per cent, making it by proximate analysis the best coal seen by the writer on the Yukon River. This mine has no visible development or permanent equipment. The workings lie below the level of the river, and the entrance is covered with water during the summer months, so that it can be worked only in winter after the freezing up of the river, when the ice filling the upper workings must be mined out before the coal can be reached. The mine has probably produced about 300 tons of coal.

Williams mine.—This mine is located on the right bank of the

[a] This name is also written Blatsford. The correct spelling is in doubt.

Yukon, about 90 miles below Nulato. The coal is in sandstones, from which fossils of Eocene age have been collected.

One bed 39 inches in thickness, in two nearly equal benches, separated by a clay parting about 1 inch thick, has been opened. The bed, which has a dip of 45°, is very regular and shows no variation, either in strike or thickness, in a distance of 400 feet. The coal is bituminous, having a fuel ratio between 1.20 and 1.50 and water content between 6 and 7 per cent. The ash in the lower bench is 3.53 per cent and in the upper bench 8.63 per cent. The coal does not coke. This mine produced some coal as early as 1900, and early in 1902 it passed into the hands of the present owners. The equipment consists of a drift 400 feet long, starting from the river bank above high water. The greater part of the coal above this drift has been mined. The coal cars bring the fuel to the mouth of the mine, where it is piled on the river beach and loaded on steamers by means of wheelbarrows. One thousand seven hundred tons of coal, which sold at the mine for from $10 to $15 per ton, have been produced.

Coal mine No. 1.—This mine is on the right bank of the Yukon, 25 miles below the Williams mine. The coal is contained in sandstones, which may be either Upper Cretaceous or Eocene in age. One coal bed, having a thickness of from 2½ to 3 feet, has been mined. A sample of the coal taken from the cropping shows on analysis that the coal is bituminous, with a fuel ratio of 1.61 and a water content 4.82 per cent. The Alaska Commercial Company attempted in the winter of 1898 to open a mine here, and 900 tons of coal were taken out, but the mine was abandoned the same year on account of the difficulty encountered in keeping out the water.

Hall Rapids.—Near Hall Rapids, about 30 miles above Anvik, a small bed of coal has been found in a formation consisting of white and yellowish tuffs of undetermined age. This coal has a lignitic appearance, but on analysis shows a fuel ratio of 1.35 and a water content of 8.23 per cent. The coal bed is probably of no value on account of its limited extent. Similar coals or lignites are of frequent occurrence in these tuffs.

On the Upper Koyukuk River.—A coal bed containing 9 feet of comparatively pure coal occurs near Tramway Bar.[a] This coal is either Upper Cretaceous or Eocene, but the exact age is undetermined. The analysis shows that it is a bituminous coal, having a fuel ratio of 1.40 and a percentage of moisture of 4.47 per cent.

Anvik River.—On the Anvik River, about 50 miles up, coal is reported by Mr. J. W. Chapman, missionary at Anvik. The point is about 10 miles back from the Yukon and probably is in a general way opposite the Williams mines. The coal is exposed in the river bank and is used by the natives in making black paint.

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[a] Schrader, F. C., Reconnaissance on Chandlar and Koyukuk rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, Part II, p. 485.

SUMMARY.

The coal-bearing formations are distributed along the Yukon conveniently for steaming purposes from the international boundary nearly to the mouth of the river. The coal beds are practically undeveloped, though limited amounts of coal have been mined at eight different points scattered along 1,000 miles of the river. Probably about 9,000 tons have been produced in American territory, which have sold at from $10 to $20 per ton. The seams from which coal has been produced vary in thickness from 13 inches to 5 feet, and in some instances they have been crushed and broken by movements of the inclosing strata, so that the beds are very irregular. The coal varies in quality from lignite to semibituminous. It has been used chiefly for steaming purposes on river boats and has come into competition with wood cut along the river. During the summer of 1903 crude oil from California will be burned on some of the steamers on the Yukon. Should its use on the Yukon prove practicable, the development of the coal beds will no doubt be retarded by it.

The Yukon will probably never supply coal for exportation, but the coal beds at present known seem to be capable, with proper development, of furnishing all that will be required for local use.

RECENT WORK IN THE COAL FIELD OF INDIANA AND ILLINOIS.

By Myron L. Fuller and George H. Ashley.

INTRODUCTION.

The coal investigations recently conducted by the United States Geological Survey in the States of Indiana and Illinois were limited to the southern portions of the two States, the areas covered being included in two adjacent thirty-minute quadrangles. The easterly one, known as the Ditney, embraces portions of Pike, Gibson, Vanderburg, Warrick, Spencer, and Dubois counties of Indiana, and the westerly quadrangle, known as the Patoka, includes the remaining parts of Gibson and Vanderburg counties, portions of Posey and Knox counties in Indiana, and of Wabash, Edwards, and White counties in Illinois. The combined area of the two quadrangles is 1,872 square miles.

The investigations in the Ditney quadrangle were prosecuted in 1900 and 1901, and the results have already appeared in the form of a geologic folio,[a] in which are given, in addition to the descriptions, maps showing the outcrops of the geologic formations, contours showing the approximate depth of the principal coal, and a large number of sections showing the thickness, character, and structural relations of the coals. The investigations in the Patoka quadrangle were prosecuted in the latter part of 1902, and the results will be prepared and published in the same form as those relating to the Ditney quadrangle.

COALS OF THE DITNEY QUADRANGLE.

Five or more beds of this quadrangle are of sufficient thickness to warrant development, at least for local supplies, but only one of the beds, the Petersburg coal, is worked for purposes of shipment. The other veins, however, especially the Millersburg coal, are extensively mined in the fall and winter months to supply local demands. The coals vary greatly in thickness at different points, and all of them show marked and sudden changes, due to their accumulation, it is believed, in basins of variable depth, or in series of basins that were only partially connected or even completely separated. The coals above the Millersburg are few in number, are usually under a foot in thickness, and, except in rare instances, are not workable even for local purposes.

[a] Geologic Atlas U. S., folio 84, Ditney, Ind.

MILLERSBURG COAL.

Because of the covering of glacial drift and of certain confusing associations there is not that certainty in the tracing of this bed that characterizes the tracing of the more prominent Petersburg coal, but what appears to be a single bed, or at least a bed of a closely equivalent horizon, has been traced in the area under discussion from near Chandler on the south to Petersburg on the north, the outcrop passing near Lynville, Oakland City, Ingleton, Dongola, Glezen, Rumble, and Clark. The outcrop is worked by strippings at over a hundred points, the workings being especially numerous along Squaw Creek east of Millersburg, south of Lynville, north of Ingleton, on both sides of the Patoka River at Dongola, along Robinson Creek, southeast of Rumble, and between Rumble and Petersburg. The thickness is generally insufficient to warrant shafting, but the coal is worked from shallow shafts at Millersburg, east of Elberfeld, and at Union. A shaft is now (1902) being sunk to this coal near Buckskin, where the coal is reported to reach a thickness of over 6 feet.

The thickness of the Millersburg coal varies from 2 to 6 feet or more, 3 feet probably being a fair average for the area as a whole. A number of the more characteristic local measurements are given in the table on page 288.

The interval separating the Millersburg coal from the next lower or Petersburg bed is generally from 70 to 90 feet, but if the correlations are correct the interval increases to about 100 feet near Ingleton and to 120 feet near Oakland City.

PETERSBURG COAL.

The outcrop of the Petersburg coal is largely hidden by glacial deposits in the northern portion of the quadrangle, but over an area beginning near Cato and continuing to the southern border, south of Boonville, it has been opened at many points and is worked at short intervals. The dip being very gentle, averaging only about 20 feet to the mile to the west, and the coal lying at or near drainage level over considerable areas, the outcrop partakes of all the sinuosities of the drainage lines, its length being several times that of the quadrangle.

The coal is of variable thickness, but probably averages about 5 feet in this quadrangle. East and northeast of Boonville, however, its average thickness is somewhat greater, being not far from 6 feet, and thicknesses of 7 feet are common in many of the mines, while in pockets a thickness as high as 9½ feet is reported. In this region it is solid and uniform throughout, except that the upper 3 to 6 inches is dry, resembling cannel coal in places. Thicknesses of 8 feet occur in many of the mines about Petersburg. At other points thicknesses of 4 to 6 feet are most common. Measurements at a large number of points are given in the table on page 289.

It is believed locally that the coal worked at or near the surface at Ayrshire and between Winslow and Littles is a "floating vein," lying about 60 feet above the Petersburg bed, and it is claimed that an 8-foot bed has been found by drilling about 60 to 80 feet below the one now worked. A careful study of the available data, however, leads to the belief that the coal at Ayrshire, Winslow, Oakland City, and Littles all comes from the Petersburg bed, and that the 8-foot bed below is either a newly discovered bed or the continuation of one of the thin beds of the Brazil formation which outcrops farther east.

The coal frequently carries partings of bony coal, shale, etc., which sometimes reach considerable thicknesses. Such a parting occurs at Scalesville and continues to thicken southeastward, until at a mine northwest of Folsomville it forms a parting 3½ feet thick between the two benches, but south of Folsomville it soon runs out. At several points the coal is associated with a small overlying vein known as a "rider." In the region between Winslow and Selvin the rider is a 6-inch vein, occurring from 5 to 15 feet above the main bed. At Cabel a rather thick rider occurred just above the main coal, and the two were worked together at one time, but the working did not prove profitable.

The following analyses, made by the State geological and natural history survey, give some indication of the chemical character of the bed in this quadrangle. While they do not indicate a coal of very high grade, the ease and cheapness with which it may be worked makes it a valuable vein. The roof, as a rule, is excellent, being of the tough, black, sheety variety which maintains itself without props for years, even in large rooms.

Analyses of Petersburg coal.

Mine.	Total combustible matter.	Volatile combustible matter.	Fixed carbon.	Moisture.	Ash.	Sulphur.	Evaporative effect.[a]
De Forest	84.16	39.09	45.07	6.08	9.76	2.14	12.5
Ayrshire	82.47	41.32	41.15	10.75	6.78	0.81	12.36
Blackburn	87.33	43.38	43.95	7.47	5.20	5.21	12.9
Woolley, Petersburg	85.31	43.51	41.80	6.87	7.82	3.56	12.6

[a] Pounds of water evaporated per pound of coal.

Mines of small size are operated at a large number of points, and in the aggregate have a large output. The larger mines, however, are of necessity located near the railroads. There are perhaps 20 mines shipping coal, the most important locations being Petersburg, Ayrshire, Littles, Oakland City, Massey, Cabel, Boonville, De Forest, and Chandler. The small mines, frequently only strippings, are especially numerous north and northeast of Winslow, south of Augusta, west of Stendal, north and northeast of Scalesville, between Scalesville and Folsomville, and between Folsomville and Boonville.

LOWER COALS.

The coals below the Petersburg bed in this quadrangle are of relatively little importance. Several of them, however, reach a thickness of 3 feet in places, are usually of a semiblock character, and on the whole are of much better quality than the Petersburg bed. On account of the cheapness of the coal from the latter, however, little attempt has been made to develop the lower beds; and as natural outcrops are very rare, their tracing is attended with much difficulty and uncertainty, and it is only in exceptional cases that their thickness and quality can be determined. While some of the coals may locally thicken to workable beds, it does not seem probable that they will be developed for at least a considerable length of time. The more important of the lower beds are the Houchin Creek, Survant, Velpen, Rock Creek, and Holland, although some of the still smaller and less persistent beds have been opened occasionally.

Houchin Creek coal.—This coal is one of the minor beds and lies between the Petersburg and Survant coals. It is exposed in the vicinity of Houchin Creek, Selvin, and Hemenway, and at other places. Its thickness is somewhat variable. Near Houchin Creek, south of Cabel, and in the district northwest of Hemenway it has a thickness of 12 inches, but at the Heming opening north of Selvin and elsewhere it reaches a thickness of 18 inches. It is almost invariably overlain by black, sheety, bituminous shale like that overlying the Petersburg coal.

Survant coal.—This is frequently a coal of some importance, reaching a thickness of 5 feet in the hills near Gentryville, though its thickness is not usually over 3 feet. It lies, on an average, about 45 feet below the Houchin Creek coal and outcrops in the hills from near Velpen, southward to near Tennyson, passing near Stendal, Selvin, and Heilman. It is a semicoking coal, and is characteristically overlain by a massive sandstone or by a light-colored shale that breaks into rhombs. At one point near Survant the interval is only 6 feet between this coal and the coal above, but as a rule the space is at least 30 feet. The Survant coal is probably the same as the Garrison coal north of Tennyson, the Taylor coal at Selvin, the Corn coal north of Stendal, the Miller coal west of Pikeville, the coal under the bridge at Survant, and the Hollenburg coal southwest of Velpen. The table on page 289 includes a number of the characteristic measurements of this coal.

Velpen coal.—At a distance of from 30 to 60 feet below the Survant coal is the Velpen coal, one of the most persistent beds in the region. It is frequently spoken of as "the 18-inch vein," as it maintains that thickness with great persistency. It is characteristically covered with a black, bituminous, sheety shale, above which there is often a foot or two of limestone. The interval between it and the Survant coal is, as far as seen, all clay shale, with the exception of the black shale and the limestone over the lower coal and the clay under the coal above. The Velpen coal is abundantly exposed around Velpen, at Pikeville, northeast and south of Selvin, and southwest of Heilman, and is probably the coal occurring just east of Grass. Around Selvin it is reported in a number of places to be underlain at a distance of only a few feet by 3 feet of coal of poor quality. At no place was this underlying coal seen. One or two thin bands of impure coal are reported to come between the two in places. Among the measurements taken are the following: Lynch opening, northeast of Velpen, 18 inches; near Velpen, 30 inches; Hagmyer opening, east of Stendal, 12 inches; Byers opening, north of Selvin, 18 inches, and Irwin opening, east of Grass, 20 inches.

Rock Creek coal.—This coal underlies the Velpen bed at an interval of from 40 to 50 feet. It is usually of a better thickness than the latter, often running up to 3 feet. It frequently, however, splits into two benches, usually not more than a foot apart and often separated by a mere film, though it is supposed to be in places split into benches 5 or 6 feet apart. The thickness of the benches and of the intervening partings are given in the table on page 290. Its outcrop extends from near White Sulphur Springs, north of Velpen, to near Chrisney, passing near Velpen, Pikeville, Zoar, and Holland. It shows as a double coal, with a parting of variable thickness at numerous points, notably near Velpen, Pikeville, Zoar, west of Holland, and throughout Warrick and Spencer continues generally.

Holland coal.—This coal normally lies from 70 to 90 feet below the Rock Creek bed, and although it is often thin or wanting, it sometimes acquires a workable thickness. The outcrop of the coal or the cherty limestone associated with it has been traced from a point some 3 or 4 miles north of Duff southward to Gentryville and vicinity and eastward to Dale. The limestone outcrops abundantly southeast of Holland, but the coal, if there, frequently fails to show in outcrop. The thickness of the coal at various points is shown in the following table. Where there are partings the figures given are for the combined thickness of the benches.

Coal thicknesses, Millersburg, Petersburg, Survant, and Holland coals.

MILLERSBURG COAL.

Location.	Thickness.	Location.	Thickness.
	Inches.		*Inches.*
Whitlock mine, west of Petersburg	48	McGladden opening, southeast of Lynnville	36
Alexander opening, south of Petersburg	56	Orths opening, west of Eby	39
Carr opening, southwest of Rumble	50	Thompson mine, east of Elberfeld	63
Dongola clay and coal bank	30	Gander opening, Millersburg	72
Oakland City quarry	25	Edward opening, northeast of Chandler	58
Bird shaft, Francisco	30	Exposure near Newburg	18
Tevault opening, south of Spurgeon	36		
Daubs opening, east of Lynnville	36		

Coal thicknesses, Millersburg, Petersburg, Survant, and Holland coals—Cont'd.

PETERSBURG COAL.

Location.	Thickness.	Location.	Thickness.
	Inches.		*Inches.*
Mud Creek, east of Petersburg	108	Sims opening, north of Dickeyville	66
John Bradfield mine, north of Alfords	88	McCarty opening, northeast of Dickeyville	72
Willis opening, northeast of Cato	50	Hodge opening, east of Dickeyville	48
Nelson opening, south of Whiteoak	54	Zint opening, northwest of Folsomville	54
Johnson opening, southwest of Cato	58	Kelly opening, northeast of Boonville	82
Vicinity of Winslow	66	Caledonia mine, east of Boonville	90
Shaw opening, southeast of Winslow	60	Reynolds opening, southeast of Boonville	66
Ayrshire mine	60	Day opening, west of Midway	66
Harding opening, southeast of Winslow	84	Blackburn mine, northeast of Petersburg	80
Hog Branch, southwest of Survant	48	Smith mine, northeast of Petersburg	118
Mines at Cabel	54	Woolley mine, Petersburg	108
Fettinger opening, south of Cabel	54	Mine at Littles	72
Simmons opening, southwest of Cabel	60	Carbon mine, Sophia	54
McKinney opening, southeast of Spurgeon	66	Massey mine, east of Dongola	108
Wm. Stevens opening, northeast of Spurgeon	96	Ingleton opening, northeast of Oakland City	84
Budka opening, south of Stendal	46	Johnson shaft, Oakland City	51
Wilmeyer opening, south of Stendal	60	Mason opening, west of Coe	56
Wildes opening, north of Scalesville	74	Bird mine, Francisco	48
Spradley opening, northwest of Selvin	54	Broadwell opening, northeast of Eby	66
Douglass opening, northeast of Scalesville	66	Air Line mine, Chandler	63
Cox opening, north of Scalesville	35	Woolley mine, Boonville	87
Vicinity of Scalesville	54	Taylor opening, south of Boonville	48
Madden opening, Dickeyville	36		

SURVANT COAL.

Crow opening, north of Algiers	42	Taylor opening, near Selvin	24
Hollenburg opening, southwest of Velpen	28	Hemenway opening, southwest of Selvin	18
Survant	30	Garrison opening, north of Tennyson	32
Miller opening, northwest of Pikeville	36	Fisher opening, southeast of Tennyson	36
Davis opening, southwest of Pikeville	36		
Sickman opening, southeast of Pikeville	36		

HOLLAND COAL.

Highway north of Duff	9	Tormohlen opening, southwest of Holland	16
Payne opening, east of Velpen	13	Romines opening, east of Gentryville	36
Stoncamp opening, west of Duff	40	Woods opening, southwest of Dale	36
Coto opening, south of Duff	40	Brant opening, southeast of Chrisney	36
Cooper opening, southeast of Holland	32		

Thicknesses of benches and partings of the Rock Creek coal.

Location.	Thickness of upper bench.	Thickness of parting.	Thickness of lower bench.	Total thickness of coal.
	Inches.	*Inches.*	*Inches.*	*Inches.*
Gray opening, Bear Creek, north of Otwell	6	4	18	24
Froman opening, northeast of Velpen	20	18	24	44
Rock Creek, northeast of Pikeville	12	7	12	24
Ilert opening, southeast of Pikeville	12	4	3	15
District west of Duff	12	12	8+	20+
Myers opening, east of Stendal	6	69	2	8
Hildebrand opening, east of Stendal		0		40
District east of Zoar	18	18	10	28
District west of Holland	12	14	12	24

GEOLOGIC STRUCTURE.

Rather pronounced local dips are occasionally found, but a careful tracing of the Petersburg and Millersburg coals by outcrops, wells, or shafts, shows that although there are many irregularities and even reversals, the general dip is nearly west, the amount varying from 15 to 40 feet, with an average of about 20 feet to the mile. As a result of that dip the coals disappear one after another beneath the surface to the west, and at the western limits of the area are from about 50 feet, in the case of the Millersburg, to nearly 500 feet, in the case of the Holland coal, beneath the level of the bottom of the deepest valleys. The depth of the Petersburg coal below the valley bottoms in the western part of the quadrangle appears to vary from 150 to about 200 feet.

COALS OF THE PATOKA QUADRANGLE.

COAL AND LIGNITE IN INDIANA.

Coal.—With one or two exceptions none of the coals outcropping in that portion of Indiana included in the Patoka quadrangle are now worked, even for local supply, though temporary openings have frequently been made in the past. The one mine in the area—the Oswold, at Princeton—gets its supply from a bed supposed to be the Petersburg, reached by a shaft at a depth of about 440 feet. The coal averages about 6 feet 6 inches in thickness. The mines working the same bed at Evansville are just outside the quadrangle.

A considerable number of deep borings have been made at Princeton and elsewhere, in which coals of some thicknesses were encountered. Some of these are given on the following table:

Depth and thickness of coals in deep wells.

Town.	Location.	Depth.	Thickness.
		Feet.	*Feet.*
Princeton	Kurtz place	146	1
		258	2½
Do	Southern Railway shops	199	2
		346	7
		451	2
Do	Hall place	365	6
		470	6
		670	6
		730	7
		1,020	3
Do	Evans place	62	1½
		281	½
		402	6
		514	6
Do	Near preceding	80	1½
		283	3
		422	7
		471	7
		593	4
		628	3½
		670	4
Do	Tompkins place	82	1
		281	2
		396	6
		462	5
		604	6
		723	6
Hazelton	Thorn place	44	1
		105	1
		221	4
Do	Top of bluffs 2 miles east of town	116	½
		172	1½
Fort Branch	Peter Hoffman place	56	1
		178	5
		250	3½
Do	Grove mill	301	5
		408	7
Haubstadt	Sec. 3, T. 3 S., R. 11 W	60	2
		80 to 100	4

A coal sometimes reaching a thickness of 18 to 24 inches outcrops near the levels of the flats along the tributary of the Patoka River, northeast of Princeton, and near Townsend's quarry, north of the Patoka. It was formerly opened by strippings at several points. Two or more very thin coals show in the river bluff south of Patoka, one of which also outcrops near the base of the sandy bluffs 1½ miles northwest of the town. A coal of variable thickness occurs along the bluffs bordering the White River, east of Hazelton, and is now being worked locally on a limited scale. This coal is not found at Hazelton, but about 2 miles northwest of the town it outcrops with a thickness of 3½ feet in the banks of the White River, and is now worked by a stripping at the Wharf mine. Very thin coals occur in the Gorden Hills, near the dam at Grand Rapids, in the hills 2 miles southwest of Princeton, and at several points northeast of Owensville. A coal reaching a thickness of several feet is reported in the the Mumford Hills. With the exceptions noted above, none of the occurrences mentioned have been developed.

In the southwestern portions of Vanderburg and in southeastern Posey County there is a rather persistent coal, lying about 100 feet above the main limestone (Somerville) of the region. Where pure it is but a few inches in thickness, but where shaly it sometimes increases to 18 inches or more. It is associated with a thin limestone and appears to be persistent for a considerable number of miles. West of Blairsville and Lippe this coal disappears below the surface and is succeeded by another small coal of similar character and association about 70 feet higher up. This can be traced to a point west of the Mount Vernon division of the Evansville and Terre Haute Railroad, where the outcrop disappears beneath a deep covering of glacial drift, loess, and marl. Both coals have been worked occasionally for fuel for thrashing machines, but are not worthy of systematic development.

Lignite.—Coals from a few inches to a foot in thickness have been reported from a large number of the wells sunk in the glacial drift of the Patoka area. No samples were seen, but from the descriptions the material would seem to be a poor grade of lignite. The lignites appear to occur in a dark-grayish clay, usually reported as "blue mud," but they are also associated with water-bearing gravels in several instances. Though apparently sometimes overlaid by till, the beds associated with the lignites are probably water deposited.

COAL IN ILLINOIS.

Friendsville coal.—Only one coal has been mined in the portion of Illinois included in the quadrangle, though several smaller coals with thicknesses varying from 6 to 18 inches have been opened. These, however, are not persistent. The Friendsville coal outcrops near Friendsville and possibly at a few other points, but has seldom, if ever, been opened on its outcrop. It underlies the surface of Wabash County at a moderate depth from a point north of Friendsville southward to Bellmont and Keensburg and westward to the bottom land of Bonpas Creek. No coal which could be correlated with the Friendsville bed has been recorded in the wells near Bonpas Creek, with the possible exception of one point southwest of Cowling. It has not been found in Edwards County. Neither has it been recognized at Mount Carmel nor southward along the Wabash River above Rochester, and there is every evidence that it has pinched out and disappeared. A deep drilling at Grayville, made expressly for information regarding coals, failed to find any over a few inches in thickness, indicating that the Friendsville vein has disappeared to the southwest as well as to the west and east.

The Friendsville coal maintains rather persistently an average thickness of about 3 feet. It is mined by shafts 1 mile east of Friendsville, 2 miles southeast of Friendsville, 1½ miles south of Bellmont, and at McClearys Bluff, on the Wabash River. It has been mined in the past at Sugar Creek, Maud, and at several points northwest of Mount Carmel. The coal burns moderately freely, but has a large ash constituent and does not coke.

The dips of the Friendsville coal are more irregular in character but less in amount than those exhibited by the coals in Indiana. The general dip, however, is still to the west. The highest altitudes at which the coal occurs is from 450 to 460 feet, these altitudes being reached at a number of points between Mount Carmel and Friendsville. East of Friendsville the altitude of the coal declines to 400 feet or less near Crawfish Creek, while to the west, southwest, and south the gentler but more persistent dip carries it downward to an altitude of about 350 feet in the vicinity of Gards Point, 385 feet at Maud, 395 feet at Bellmont, 360 feet at Keensburg, 370 feet at Rochester, and 335 feet 1½ miles southwest of Cowling.

GEOLOGICAL SURVEY PUBLICATIONS ON COAL, LIGNITE, AND PEAT.

A number of the more important United States Geological Survey publications on the subjects of coal, lignite, and peat are listed below:

ASHLEY, G. H. The Eastern Interior coal field [Illinois and Indiana]. In Twenty-second Ann. Rept., Pt. III, pp. 265–306. 1902.

BAIN, H. F. The Western Interior coal field [Iowa, Missouri, Kansas]. In Twenty-second Ann. Rept., Pt. III, pp. 333–366. 1902.

BROOKS, A. H. The coal resources of Alaska. In Twenty-second Ann. Rept., Pt. III, pp. 517–571. 1902.

CAMPBELL, M. R. Geology of the Big Stone Gap coal field of Virginia and Kentucky. Bulletin No. 111. 106 pp. 1893.

CAMPBELL, M. R., and MENDENHALL, W. C. Geologic section along the New and Kanawha rivers in West Virginia. In Seventeenth Ann. Rept., Pt. II, pp. 473–511. 1896.

CHANCE, H. M. Anthracite coal mining. In Mineral Resources U. S. for 1883–84, pp. 104–143. 1885.

DALL, W. H. Report on coal and lignite of Alaska. In Seventeenth Ann. Rept., Pt. I, pp. 763–808. 1896.

DILLER, J. S. The Coos Bay coal field, Oregon. In Nineteenth Ann. Rept., Pt. III, pp. 309–376. 1898.

HASELTINE, R. M. The bituminous coal field of Ohio. In Twenty-second Ann. Rept., Pt. III, pp. 215–226. 1902.

HAYES, C. W. The coal fields of the United States. In Twenty-second Ann. Rept., Pt. III, pp. 7–24. 1902.

——— The southern Appalachian coal field [Alabama, Georgia, Tennessee, Kentucky, Virginia]. In Twenty-second Ann. Rept., Pt. III, pp. 227–264. 1902.

LANE, A. C. The Northern Interior coal field [Michigan]. In Twenty-second Ann. Rept., Pt. III, pp. 307–332. 1902.

SHALER, N. S. Origin, distribution, and commercial value of peat deposits. In Sixteenth Ann. Rept., Pt. IV, pp. 305–314. 1895.

SMITH, G. O. The Pacific coast coal fields [Oregon, Washington, California]. In Twenty-second Ann. Rept., Pt. III, pp. 473–514. 1902.

STOEK, H. H. The Pennsylvania anthracite coal field. In Twenty-second Ann. Rept., Pt. III, pp. 55–118. 1902.

STORRS, L. S. The Rocky Mountain coal fields [Montana, Wyoming, Colorado, Utah, New Mexico]. In Twenty-second Ann. Rept., Pt. III, p. 415–472. 1902.

TAFF, J. A. Geology of the McAlester-Lehigh coal field, Indian Territory. In Nineteenth Ann. Rept., Pt. III, pp. 423–600. 1898.

——— Preliminary report on the Camden coal field of southwestern Arkansas. In Twenty-first Ann. Rept., Pt. II, pp. 313–329. 1900.

——— The Southwestern coal field [Indian Territory, Arkansas, Texas]. In Twenty-second Ann. Rept., Pt. III, pp. 367–414. 1902.

TAFF, J, A., and ADAMS, G. I. Geology of the eastern Choctaw coal field, Indian Territory. In Twenty-first Ann. Rept., Pt. II, pp. 257–311. 1900.

VAUGHAN, T. W. Reconnaissance in the Rio Grande coal field of Texas. Bulletin No. 164. 100 pp. 1900.

WEEKS, J. D. The manufacture of coke. In Mineral Resources U. S. for 1883-84, pp. 144-213. 1885.

WHITE, D. The bituminous coal field of Maryland. In Twenty-second Ann. Rept., Pt. III, pp. 201-214. 1902.

WHITE, D., and CAMPBELL, M. R. The bituminous coal field of Pennsylvania. In Twenty-second Ann. Rept., Pt. III, pp. 127-200. 1902.

WHITE, I. C. Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia. Bulletin No. 65. 212 pp. 1891. (*Out of print.*)

WILLIS, B. The lignites of the Great Sioux Reservation [Dakota]. Bulletin No. 21. 16 pp. 1885.

——— Some coal fields of Puget Sound [Oregon]. In Eighteenth Ann. Rept., Pt. III, pp. 393-436. 1898.

WOODWORTH, J. B. The Atlantic coast Triassic coal field [Virginia, North Carolina]. In Twenty-second Ann. Rept., Pt. III, pp. 25-54. 1902.

OIL, GAS, AND ASPHALT.

A number of papers describing the results of recent field work by the Survey in various oil, gas, and asphalt fields are here presented. In addition to this new material, a chapter on the origin and distribution of asphalt and bituminous rocks in the United States is here reprinted, in greatly condensed form, from a detailed publication on that subject issued by the Survey in 1902. This has been done, as the portion reprinted serves as an excellent summary of the subject, and as an introduction to the other papers on asphalt here included.

ORIGIN AND DISTRIBUTION OF ASPHALT AND BITUMINOUS ROCK DEPOSITS IN THE UNITED STATES.

By G. H. Eldridge.

CLASSIFICATION OF HYDROCARBONS.

The classification of W. P. Blake, slightly modified, follows.

Classification of natural hydrocarbons.

Hydrocarbons.
- Gaseous
  - Marsh gas.
  - "Natural gas."
- Bituminous
  - Fluid
    - Naphtha.
    - Petroleum.
  - Viscous (malthite)
    - Maltha.
    - Mineral tar.
    - Brea.
    - Chapapote.
  - Elastic
    - Elaterite (mineral caoutchouc)
    - Wurtzilite.[a]
  - Solid
    - Asphaltite
      - Albertite.
      - Impsonite.
      - Grahamite.
      - Nigrite.
      - Uintaite (gilsonite).
    - Coal
      - Lignite.
      - Bituminous coal.
      - Semibituminous coal.
      - Anthracite coal.
- Resinous
  - Succinite (amber).
  - Copalite.
  - Ambrite, etc.
- Cereous
  - Ozocerite.
  - Hatchettite, etc.
- Crystalline
  - Fichtelite.
  - Hartite, etc.

[a] Wurtzilite might, perhaps, better be classed with the asphaltites.

Classification, or grouping, of natural and artificial bituminous compounds.

Bituminous compound.	Natural.	Mixed with limestone ("asphaltic limestone").	Seyssel, Val de Travers, Lobsan, Illinois, Utah, and other localities.
		Mixed with silica and sand ("asphaltic sand").	California, Kentucky, Utah, and other localities. "Bituminous silica."
		Mixed with earthy matter ("asphaltic earth").	Trinidad, Cuba, California, Utah.
		Bituminous schists	Canada, California, Kentucky, Virginia, and other localities.
		Fluid	Thick oils from the distillation of petroleum. "Residuum."
	Artificial.	Viscous	Gas tar. Pitch.
		Solid	Refined Trinidad asphaltic earth. Mastic of asphaltite. Gritted asphaltic mastic. Paving compounds.

A glance at the above tables will convince one of the impossibility of establishing hard and fast lines between the substances enumerated. The classification, however, seems to the writer to be the most satisfactory of the several attempts met with in the literature of the subject.

It will be observed that there has been omitted from the table one of the commonest terms in use, "asphalt," or "asphaltum." By many disinterested authorities this word is restricted to the solid forms of the purer bitumens, forms including those grouped by Professor Blake under the general derivative, "asphaltite." This usage is reasonable, and by adhering to it confusion will be avoided in both science and trade. Industrially, however, the word "asphalt" is unfortunately made to include almost every compound of bitumen with a foreign material, chief among the latter being sandstone and limestone.

Mr. Clifford Richardson, in his Nature and Origin of Asphalt, a contribution (October, 1898) from the laboratory of the Barber Asphalt Paving Company, gives the following definition of asphalt:

> The natural bitumen, which is known as asphalt, is composed, as far as we have been able to learn, of saturated and unsaturated dicyclic, or [a] polycyclic, alicyclic hydrocarbons and their sulphur derivatives, with a small amount of nitrogenous constituents. Asphalt may, therefore, be defined as any hard bitumen, composed of such hydrocarbons and their derivatives, which melts on the application of heat to a viscous liquid; while a maltha or soft asphalt may be defined as a soft bitumen, consisting of alicyclic hydrocarbons, which, on heating, or by other natural causes, becomes converted into asphalt. The line between the two classes can not be sharply drawn.

"Bitumen," also, is a term that has been omitted from the table, although its adjective, "bituminous," is employed. The word

[a] In the original report the word "or" was inadvertently placed after instead of before "polycyclic."

"bitumen" has in the main been used to include the three varieties of hydrocarbon compounds known as petroleum, maltha or mineral tar, and the solid substances included under the asphaltites and often designated, one or another of them, "asphalt." The adjective "bituminous," however, may be applied to a sandstone or other rock impregnated with bitumen, as thus understood; and if such bitumen has any of the characteristics of the so-called asphalts, the compound may receive the name "asphaltic sandstone," "asphaltic limestone," etc.

GENERAL FEATURES OF THE HYDROCARBONS.

The relations, chemical or other, between the hydrocarbons of the table on pages 297–298, were they worked out, would doubtless show the utmost complexity, for complexity exists even in the substances themselves, nearly all of which are separable by the action of solvents or by fractional distillation into two or more components that are in turn divisible into series of hydrocarbons, in many instances of great extent.

In Dana hatchettite and ozocerite are found among the simple hydrocarbons as members of the paraffin series C_nH_{2n+2}, while fichtelite, hartite, and a number of others occur in this division of the hydrocarbons, but of series other than the paraffin, and in many instances altogether of doubtful reference.

The resinous compounds belong to the class of oxygenated hydrocarbons, the membership in which is very extended and of great variety. Concerning this class, Dana remarks that it embraces "chiefly the numerous kinds of native fossil resins, many of which are included under the generic term 'amber;' also other more or less closely related substances. In general, in these compounds, weak acids (succinic acid, formic acid, butyric acid, cinnamic acid, etc.), or acid anhydrides, are prominent."

Between the coals—especially the bituminous and cannel varieties—and the resinous and asphaltite divisions of this table relations are readily found; indeed, for a number of years, only two or three decades ago, grahamite, on account of its composition, was regarded by men high in authority as a true coal, notwithstanding its wholly different mode of occurrence.

Albertite, grahamite, uintaite, etc., are now accepted as closely related varieties of asphaltum. This relationship is evident both in their chemical composition and in their mode of occurrence, yet they are readily distinguished by their behavior toward solvents, by the action of heat upon them—their fusibility, so called—and by other properties.

Wurtzilite, in outward appearance, bears a striking resemblance to the asphaltites, but is distinguished from them by its behavior toward solvents and by its marked sectile and elastic properties. Yet, while uintaite itself is exceedingly brittle, one of its leading features, developed in the manufacture of black japans and varnishes made from it, is this very property of elasticity, attainable in such perfection in no other hydrocarbon compound except elaterite and wurtzilite.

Elaterite, though elastic, is quite distinct from wurtzilite. Dana, in remarking upon the results attained by the authorities which he consulted, states that this substance "appears to be partly a carbohydrogen near ozocerite and partly an oxygenated insoluble material."

The viscous bitumens of the table vary markedly in consistency. Maltha has the greatest fluidity, brea and chapapote the least—these are, in fact, solids. Each member of the group shades into the next on either side, even maltha into petroleum and chapapote into the asphaltites. From this it will be inferred that the application of the several terms is decidedly indefinite. In regard to brea and chapapote, usage seems to make them synonymous, unless it be that the solidity of chapapote is a degree greater than that of brea, by no means an assured distinction.

The viscous compounds stand between the solid asphaltites on the one hand and petroleum on the other. "The fluid kinds," observes Dana, "change into the solid by the loss of volatile matter by a process of oxidation which is said to consist first in the loss of hydrogen and finally in the oxygenation of a portion of the mass."

Richardson, in his Nature and Origin of Asphalt, observes:

> Asphalts are distinguished by the large amount of sulphur they contain, and it is to its presence that many of the important characteristics, and perhaps, in part, the origin of this form of bitumen, is due. The soft asphalts or malthas contain much less sulphur than the harder ones, or if the former are rich in sulphur, they are then in a transition stage and will eventually become hard. But a small portion of the constitutents of a hard asphalt are volatile even in vacuo, but they can be separated by solvents into an oily portion, which is soft, or softens readily when heated, and a harder portion, which does not melt by itself without decomposition, and is a brittle solid, but soluble in the oily or softer portion. The harder and least soluble portion always contains the larger part of the sulphur. It seems, therefore, that sulphur is the effectual hardening agent of [many] natural asphalts, in the same way that it is of artificial asphalts which are produced by heating a soft natural bitumen with sulphur.

But Mr. Richardson adds that "some natural bitumens occur which have become hardened in another way and perhaps by oxygen." This refers particularly to the asphaltites.

Boussingault's investigation, in 1837, into the composition of asphalt also developed some results of especial interest. He took for his experiments the viscid bitumen of Pechelbronn, France. At a temperature of 230° C., in an oil bath, he separated an oily liquid, to which he gave the name "pétrolène," regarding it as the liquid constituent of bitumen, which, mingled in varying quantities with a solid substance, "asphaltène," forms the bitumens of different degrees of fluidity. He describes asphaltene as brilliant black in color and luster, with a conchoidal fracture, and heavier than water. Toward a temperature of 300° C. it becomes soft and elastic. It begins to decompose before it melts, and burns like the resins, leaving an abundance of coke.

Dana, in his System of Mineralogy, quotes several analyses of petrolene by Boussingault, one of which gives C. 87.45, H. 12.30.

DISTRIBUTION OF THE ASPHALTS AND BITUMINOUS ROCKS OF THE UNITED STATES.

The distribution of asphalts and bituminous rocks in the United States is wide. The asphaltites are found in West Virginia, Indian Territory, Colorado, and Utah; bituminous limestones in Indian Territory, Texas, and Utah; bituminous sandstones in Kentucky, Missouri, Indian Territory, Texas, Utah, and California;[a] earthy bitumen of greater or less purity, occurring as veins, in California; while brea may occur in all petroleum areas, but in the present investigation was found only in Indian Territory, Wyoming, and California, although small bodies are reported in Montana.

The stratigraphic range of the bitumens and their compounds is as wide as their geographic distribution. Their oldest association observed is with the Ordovician shale of the Tenmile region in eastern Indian Territory, where impsonite, an asphaltite closely related to albertite, occurs in vein form. Other veins of like material, as well as a bituminous sandstone, occur in the series of Ordovician sandstones overlying the shales along the Indian Territory-Arkansas line. In central Indian Territory, in the Buckhorn district, are other bituminous sandstones, also of Ordovician age, though perhaps not to be correlated with the foregoing. Above these, in direct succession, is the summit limestone of the Ordovician, at least for this locality—a massive bed of variable thickness, the maximum being approximately 400 feet. The entire body of rock is varyingly impregnated with bitumen, the more highly enriched portions to an average of 6 to 8 per cent. In this same locality the Lower Coal Measures also, at one or more horizons, are richly infiltrated with bitumen, one of their limestones carrying an average of 14 per cent. The Lower Coal Measures are unconformable with the underlying formations, and the occurrence of bitumen at the several horizons suggests a common source and origin for it, and an inflow to its present reservoirs, perhaps subsequent to the laying down of all the sediments involved, if not, indeed, subsequent to their folding. On the other hand, from the presence in the Coal Measure conglomerate of an occasional pebble, believed to be of Ordovician bituminous sandstone, particularly observed by Mr. Taff, there may have been two or more distinct flow periods.

West and south of the Arbuckle Mountains the Coal Measures again

[a] Since the writer's field investigation indefinite accounts of bituminous sandstones in Alabama and Illinois have appeared in certain newspapers.

carry bitumen in some of their members—grits and limestones. These horizons, however, may be quite different from those in the Buckhorn region.

Near Higginsville, Mo., the Warrensburg sandstone, which occupies what Mr. Arthur Winslow, the State geologist, considers a channel of erosion in the Coal Measures, and which is assigned to the Carboniferous, is also infiltrated with bitumen to about 6 per cent.

In West Virginia the grahamite vein, which has brought much renown to the region of its occurrence, occupies a vertical fissure in the Waynesburg sandstone and adjoining beds above and below, all of which are horizons in the Upper Productive and Upper Barren Coal Measures of the Carboniferous age.

The bituminous sandstones of Kentucky are closely successive members of the Chester formation and the basal portion of the Coal Measures, and all, at one point or another, are impregnated to a degree sufficient to render them economically available for paving purposes, their contents ranging between 5 and 9 per cent.

The Permian, or what is at present accepted as the Permian, in central Indian Territory has been penetrated by fissures, through which petroleum has risen into its surficial sandy members and has also been converted to brea as surface deposits. This occurs at Wheeler, a settlement about 40 miles west of Ardmore. The locality is practically that of the enriched Coal Measure sandstones south of the Arbuckle Mountains, and there is little doubt that a common source supplied all the different horizons that now constitute the exposed storage reservoirs of the former fluid petroleum.

The Trinity sand of the Lower Cretaceous is a bitumen-bearing formation at many points in its area of outcrop in southern Indian Territory and northern Texas. This is particularly the case where it rests upon the Carboniferous, an occurrence that is significant of the derivation of its bitumen from a source perhaps identical with that from which the several members of the Coal Measures have derived theirs.

The Glenrose formation, also a member of the Trinity division of the Lower Cretaceous, in one of its limestones carries the bitumen of the deposits of Post Mountain, near the town of Burnet, Burnet County, Tex. The Anacacho formation of the Texas Upper Cretaceous, corresponding to a horizon near the base of the Montana of the Rocky Mountain section, carries the rich bituminous limestones extensively quarried in the vicinity of Anacacho Mountain, 18 miles west of Uvalde, in southern Texas. In this connection the presence of important oil horizons in the Montana formation of the Florence oil field in Colorado is not unworthy of note.

The Middle Park formation of Middle Park, Colorado, largely a terrane of eruptive material and a correlative of the Denver of the plains—a formation for the present termed post-Laramie, without assignment to Cretaceous or Tertiary—also carries bitumens. The deposit occurs in the northern portion of Middle Park, almost in the heart of the Rocky Mountains. It is here an asphalt resembling gilsonite and occupying an irregular fissure or series of fissures in the clays, sandstones, and conglomerates of the formation referred to. The occurrence is, so far as known, limited to the immediate region in which it is found, and is thus comparatively isolated, the nearest asphalt being the gilsonite found along the Colorado-Utah line, 150 miles distant.

The bitumens of the Tertiary horizons are apparently confined to the West—to Colorado, Utah, and California. The various divisions of the Eocene in eastern Utah and just across the line in Colorado are noted both for the variety of their asphalts and for the size of their veins. It is in this region, of the White and Green rivers and the celebrated Book Cliffs, that the great veins of uintaite are found and that the minor seams of wurtzilite, ozocerite, and nigrite occur. Bituminous limestones are also of wide distribution, though confined to the Green River shales. The asphaltites occur in fissures both in this formation and in those overlying, especially the Bridger and Uinta. Maltha springs also occur, and even petroleum is reported in one of the members of the Cretaceous, a few miles east of the Utah-Colorado line. The Green River shales are noted throughout the West for their bitumen contents, and it is surmised that they are the source of the asphalts, at least, of this vast area. The variation in the ultimate material as it to-day fills one fissure or another is perhaps due in part to a change somewhat allied to fractional distillation in petroleum technology and in part to the degree to which oxygen absorption has been carried on. In any event, the variety of bitumen found can hardly excite wonder when considered as to the origin of the material and the differentiations that take place in artificial distillation. It is, indeed, to be expected.

The occurrence of bitumens in the Neocene is confined to California. The rocks of this period here embrace a heavy series of shales with local sandstones, tuffs, etc.—the Monterey formation; a conspicuous body of massive sandstone with a minor proportion of shales, known as the San Pablo formation, but in doubt as to its position as a member of the Miocene or Pliocene, and hence in the region of its occurrence regarded as Middle Neocene; and a succession of sandstones, conglomerates, and clays, probably Pliocene, but for the present termed Upper Neocene, with the specific name Paso Robles assigned to it.

In addition to the foregoing, there are certain and important sandstones and sand aggregates of somewhat doubtful age, but where encountered seeming to lie beneath the shales of the Monterey rather than in them, and often against and upon granite. Such is their occurrence in the vicinity of Santa Cruz, and again at one or two points in the range bordering the Salinas Valley on the east. These sandstones are locally heavily impregnated with bitumen, and near Santa Cruz are extensively quarried for paving purposes in San Francisco and elsewhere.

The Monterey formation is of particular importance, in that for almost the entire length of the State its terrane is more or less conspicuously marked with petroleum or maltha seepages, while its sandy members may appear as minor storage reservoirs of oil, these now altered at the outcrop to a material of pasty consistency, which forms with the sand grains an asphaltic compound of considerable richness. Such sandy beds occur at Point Arena, in the San Antonio Valley, and in the region of the Sisquoc. The shales of the Monterey are not only generally bituminous, but some of their more arenaceous and porous members are also especially rich, doubtless having received an inflow of petroleum from their adjoining and less open associates. It is in the shales of the Monterey, too, as well as in the Middle Neocene, that veins of the more solid bitumens, mixed with clastic material derived from the country rock, are found. Except for the clastic material, the bitumen would resemble in structure the asphaltites, though still differing from them in other features. Veins of this description are conspicuous in the vicinity of Santa Maria, Santa Barbara, and Asphalto. Near the latter place the asphaltic material is intimately related to, even associated with, petroleum.

The San Pablo formation, at least that portion of it in the San Luis Range, has been converted into a vast storage reservoir. It is the surface terrane over an area of nearly 50 square miles a short distance southwest of San Luis Obispo, and perhaps half its outcrop here shows impregnation with bitumen in greater or less degree, locally to a high degree. In the same region scattered bodies of the Paso Robles formation have also been infiltrated where resting on the San Pablo or the Monterey.

The San Pablo is also, perhaps, represented in the region of the Sisquoc, 40 miles southeast of Santa Maria, where along the southern base of the San Rafael Range is a highly enriched body of sandstone, of doubtful correlation from its structural association with recognized Monterey sandstones, but possibly of the age suggested. It is locally one of the richest sandstones in California.

In the region of La Graciosa Hills, 6 to 10 miles south of Santa Maria, there rests upon the Monterey, unconformably, a heavy body of loosely coherent sands or sandstone commonly regarded as Pliocene. Cracks have developed in the formation, and have been filled with bitumen carrying from 30 to 60 per cent of clastic matter. The material resembles in general appearance that already referred to as of vein form in the Middle Neocene near Asphalto. Here, again, it has been found in association with petroleum.

Post-Pliocene sandstones are found with small gash veins and other irregular but more or less extensive bodies of the solid bitumens in the region of Mores Landing, 7 miles west of Santa Barbara. A material in many ways resembling gilsonite was found as a minute pocket in the sandstone, but the mass of the bitumen is of the solid variety, mixed with 20 to 40 per cent of clastic material. Twelve miles east of this occurrence is the important petroleum-producing region of Summerland. Pleistocene or Recent sands have been heavily charged with bitumen at Carpinteria, 12 miles east of Santa Barbara. They have been for the most part removed, but the continuous flow of maltha in the floor of the quarry would quickly impregnate an equal body were the excavation to be filled with fresh sand from the adjoining ocean beach.

Surficial deposits of brea are well distributed over the United States. Those observed by the writer were in Indian Territory, Wyoming, and California, the first no longer increasing from active springs, the others still forming. The source of their malthas is naturally extremely varied. In addition to the above, there are doubtless many others of but little less importance scattered through the oil regions of the country.

ORIGIN OF THE DEPOSITS.

The origin of the hydrocarbons and bituminous compounds may be traced, the writer believes, to petroleum. This is a natural inference from chemical relations. The fact that there may be a wide variation in the composition and physical aspect of the bitumens, whether of asphaltites or of sandstones, matters not, for important differences are found in petroleums themselves; the variation in the asphaltites, indeed, may be somewhat more marked, for in the passage from petroleum to its derivatives the process may have stopped at any point, with a corresponding development of physical as well as chemical distinctions. But in the geologic investigation of the asphaltites, bituminous sandstones, and related materials the view of their origin suggested by chemistry has in many ways been reenforced. The asphaltic earths, and solid bitumens in part, are frequently associated with active petroleum springs, or are found in regions renowned as oil producing. The sandstones and limestones are found resting upon formations conspicuous for their yield at other points; indeed, in one instance they were found upon a formation actively yielding oil directly beneath them, and this at the present day. The sandstones, therefore, can hardly be regarded other than as storage reservoirs for the oil thus received; the limestones, it is sometimes thought, may have been the locus of origin as well as of storage.

The asphaltites and closely associated hydrocarbons—ozocerite, for example—can hardly have been derived otherwise than by the draining of petroleum pools or strata richly saturated with oil. In the case of gilsonite, the absence of every trace of petroleum in the inclosing sandstones and its evident prevalence in the underlying Green River shales indicate the latter series as the one-time source of the oil which on entering the fissures was converted into the asphaltites. Moreover, locally, for a foot or two adjacent to the veins, the sandstone is filled with interstitial gilsonite, which is evidence of infiltration from the petroleum-filled fissure into the sandstones rather than into the fissure from the rock on either side. The channels by which the shales were drained are cracks that extend from the bottom of the main portion of the fissures, in some instances several hundred feet, into the underlying bitumen-bearing beds, but even here the draining of the strata must have been marvelously rapid to have been so complete as the conditions indicate before being interfered with by the closing of the fissures from the settling or readjustment of the shale, always a rock of exceeding instability. The writer believes, however, that the filling of the fissure could have been derived from no other source. The origin of the cracks is, of course, well understood. They occur in all formations and in all localities and are a concomitant feature of folding, though perhaps at times developed from shrinkage.

In the filling of all reservoirs, whether fissures or sandstones, the investigator is struck with the almost inevitable slowness of the process and the vastness of the area of fine-grained sediments that must have been drained to yield the supply absorbed. Then, too, in the case of the asphaltites the hardening must have been very gradual, the material passing through a viscous stage, during which fragments dropped from the walls into the bitumen and yet were supported, even as a rock is supported upon the surface of a thickening maltha pool at the present day. After solidification was complete the crushing strains from readjustment of the strata became manifest in the penicillate structure developed in the asphalt next to the walls of the vein. It is probable that during the filling of the crack this readjustment was continuously going on, but it could become evident only after the vein material had been hardened sufficiently to record it.

THE PETROLEUM FIELDS OF CALIFORNIA.

By G. H. ELDRIDGE.

INTRODUCTORY.

The petroleum fields of California, as at present known, lie on either side of the Central Valley of the State, in the Coast Range, and along the Pacific front. The greatest development has taken place south of the parallel of San Francisco, although northward from this are many prospects and one developed field of minor commercial importance—that in the vicinity of Eureka, Humboldt County.

The Coast Range, considered as a topographic province, includes all the mountains lying between the great Central Valley of California and the Pacific Ocean. It has no well-defined axis, either topographic or geologic, but consists rather of a number of parallel ridges having a general elevation of between 3,000 and 4,000 feet, with occasional peaks extending to somewhat greater heights.

Structurally the Coast Range consists of numerous parallel anticlines and their corresponding synclines. There is no dominant axial fold, the crust having been crumpled into a close succession of ridges of varying amplitude and height of arch. The topographic trend of the general range from San Louis Obispo north is about N. 30° W., veering westward south of this. The structural trend of the folds composing it, however, is between N. 20° and 40° W. from the thirty-sixth parallel north, N. 50° or 60° W. in the region of San Luis Obispo, and from Point Conception east N. 80° to 90° W. Throughout the entire range it is distinctly diagonal to the coast line, except, perhaps, along the Santa Barbara Channel. Faults, of course, occur.

The large productive oil fields of southern California include the Oil City, adjacent to Coalinga; the McKittrick; the Sunset and its extension, the Midway; the Kern River; La Graciosa; the Summerland; the Santa Clara Valley; the Los Angeles; and those of the Puente Hills.

THE OIL FIELDS.

COALINGA DISTRICT.

This district extends along the eastern base of the Mount Diablo Range for a distance of about 30 miles, Coalinga, the small town from which it is named, lying somewhat nearer the northern end. Three areas of oil development exist, which may be designated the Oil City field, the Kreyenhagen field, and the Avenal field, but the first only is of special productiveness. Coalinga is accessible by rail from the main lines of both the Southern Pacific and the Atchison, Topeka and Santa Fe railroads.

The topographic features of the region are those of a high, rugged range, bordering a desert. The line of mountain and desert passes southeast from Coalinga in a direct course for 30 miles, but immediately north of the town there is the reentrant angle of a valley and syncline which separates the main range from one of the diagonally transverse spurs and anticlines that are such conspicuous features of the structure of the Coast Range. It is at the southeast end of this anticline that the Oil City petroleum field has been developed.

The formations involved in the anticline embrace at least 1,000 to 2,000 feet of massive concretionary sandstones of Tejon (Eocene) age, overlain by 800 to 1,000 feet of purple and gray shales, clays, thin sandstones, and limestones, that have also been referred by some to this period; 100 or 200 feet of clays and sandstones that may prove to be Lower Miocene; 200 feet of siliceous shales typical of the Monterey (Upper Miocene); and, unconformable with these, a great thickness of conglomerates, sandstones, and clays, recognized by their fossils to be San Pablo (Middle Neocene). The conglomerates of the San Pablo in this region contain pebbles of quartz, black chert, jasper, serpentine, siliceous shale, and sandstone, the matrix being of the same materials; the sandstones, which are coarse, are chiefly quartzose; the clays are generally gypsiferous.

The Oil City field, as already suggested, is developed about the southeastern terminus of one of the diagonally tranverse anticlinal spurs that extend from the Coast Range into the valley of the San Joaquin. The axis here dips rapidly to the southeast, and within 10 miles of the higher crest of the range evidence of the fold has completely disappeared beneath the valley deposits. The line of junction between mountain and desert on the northeast side of the fold extends for 20 to 30 miles without conspicuous break. With the exception of severe crumpling in the immediate vicinity of the axis, accompanied perhaps by some faulting, and a comparatively gentle flexure on the southern periphery of the uplift in the vicinity of Oil Creek, the anticline appears to be unaffected by minor folds. The measures exposed in the heart of the anticline are the massive Tejon sandstones. Encircling these are the overlying shales, and these in turn are followed by the heavy and resistant conglomerates and sands of the San Pablo.

The oil-bearing horizons of this field are two: one, a sandstone in the lower portion of the shales that are by some regarded as the upper member of the Tejon; the other, the lower sandstones and conglomerates of the San Pablo. It is estimated that approximately 1,500 feet of measures separate the two horizons. Owing to this distribution there are two distinct areas of wells—an inner, in immediate proximity to the axis of the anticline; and an outer, of more extended area, encircling the point of the anticline in the San Pablo formation, and extending well along the southwest side of the general fold. The oil from the shales regarded as Tejon is of greenish color and varies in gravity from 33° to 38° B.; that from horizons in the San Pablo is brownish black and of a gravity from 16° to 24° B., the higher in the eastern portion of the field. The production from both horizons is large. The depth of wells varies from 800 to 2,000 feet.

M'KITTRICK DISTRICT.

This district lies on the edge of the desert at the eastern base of the Coast Range, about 50 miles west of Bakersfield. The railway station is McKittrick. The Coast Range in the vicinity embraces a number of parallel ridges, the highest constituting the eastern border of the Carriso Plains. From this each succeeding ridge attains a lower altitude, until the outermost line of hills is but a gentle elevation above the general valley. The developed oil field in the region of McKittrick lies along an interior ridge, separated from the outer ridge by a valley 1½ miles wide. The length of this district is about 25 miles.

The formations involved in the occurrence of oil are the Monterey and the San Pablo, an unconformity existing between the two. The Monterey consists principally of siliceous shales, with their chalky, earthy, or more argillaceous modifications. Gypsiferous clays, limestones, and sandstones are but slightly developed, except in the northwestern portion of the field, where certain beds have the general aspect of the lower division of the Miocene. The siliceous shales within a zone 200 or 300 feet in width extending for 8 or 10 miles along the middle portion of the field, have, in a great degree, lost their stratified nature and become fissile by reason of the severe crushing to which they have been subjected in the sharp folding and faulting that has here taken place. Along this line of faulting the shales are of a chocolate brown, from the dried bitumen with which they have been infiltrated.

The San Pablo, consisting of the conglomerates, sandstones, and clays typical of it, is well developed, and the terrane is marked, as elsewhere, by a deep deposit of dust wherever weathering has been carried to an extreme. The lowest stratum of the formation exposed in the field is a sandstone, conglomeratic in layers, the pebbles of which are of granite, siliceous shale, quartzite, and occasionally a pyritic rock that has been derived, perhaps, from some bed of much earlier age. This sandstone and conglomerate is generally exposed in close proximity to the fault referred to above, and is also stained with bitumen.

The structure of the McKittrick district is that of a sharp anticline, en échelon with adjacent anticlines of the range. Along its axis is developed the fault mentioned, which locally is of the nature of an overthrust, the siliceous shales of the Monterey west of the plane being pushed up well over the sands, conglomerates, and clays of the San Pablo. While this fracture and fold, along which most of the producing wells of the district are located, are the most important of the region, other folds and faults exist in lines parallel with these, and at either end of the district one or another of them may become the chief fissure, yet apparently, so far as is at present known, without especial accumulation of petroleum. Of the overthrust nature of the main fold interesting evidence exists in the material that is brought up by the bailer in drilling—not only sands more or less saturated with oil, but pebbles characteristic of the San Pablo. Conspicuous among the latter are those of siliceous shale of the Monterey type, bearing foraminiferal remains, fish scales, and pholas borings. A noteworthy feature of the line of disturbance for several miles, both northwest and southeast of McKittrick, also, are the dikes of sandstone richly impregnated with bitumen. These vary in length from a few feet to a half mile or more, and in width up to 10 or 15 feet; their depth, of course, is unknown. Gash veins of high-grade asphalt also occur.

The productive oil wells of this district for its entire length lie within a zone less than a quarter of a mile wide, and in places less than 200 feet wide. Their depth varies from 200 to 1,500 feet, the shallower holes being in the center of the field, opposite McKittrick. The yield is from a few up to 700 barrels, the latter exceptional. In gravity the oil varies between 11° and 17° B. While the narrow, productive zone is persistent in the general directness of its trend—about N. 60° W.—it is, nevertheless, somewhat undulating, according as the axis of crumpling or faulting varies.

SUNSET DISTRICT.

This district lies in the southwest corner of the San Joaquin Valley, along the eastern base of the San Rafael Range, about 35 miles in a direct line southwest of Bakersfield, with which it is now connected by a branch of the Atchison, Topeka and Santa Fe Railway. It is also distant from the McKittrick district about 25 miles, but recent developments in the Midway field, the northwestern extension of the Sunset, are gradually diminishing this gap. The Sunset field, like those to the northwest, is developed in the lower foothills of the Coast Range. The physical aspect of the region is that of moderately rugged mountains, 3,000 to 4,000 feet in altitude, bordered by a desert.

The formations involved in the geology of the district include, in the higher portions of the adjacent range, a great series of massive, gray, concretionary sandstones and dark-colored shales, probably Tejon; on the slopes, local developments of gritty sands, brown and yellow limestones, and gypsiferous clays, perhaps a lower division of the Miocene, the upper division consisting of siliceous shales, typical of the Monterey; in the low outer ridges, a succession of conglomerates, sandstones, and clays, many hundred feet thick, the equivalent of the San Pablo, of Middle Neocene age; and in the valley, Recent gravels. Between the San Pablo and older formations—the horizon of most importance from the petroleum point of view—there exists a marked unconformity, the line of union as exposed lying now at one horizon, now at another, in beds both above and below the break in continuity. Just within the border of the younger formation the development of the oil field has taken place, the wells drawing their petroleum from one or more of the conglomerates and sandstones adjacent to the plane of unconformity.

Structurally, the strata of the Sunset district, while thrown into an anticline of great extent, present in detail a succession of folds, those of greatest amplitude lying farthest within the mountains, the general trend of all being about N. 50° W. Faults also exist, but none of large displacement was detected within or near the oil-producing area itself. The greatest crushing has been effected in the shales of the Monterey, but along the desert edge the San Pablo also shows a number of minor flexures, some developed en échelon, to which is due the frequent offsets to be observed in the trend of the oil belt. The general dip of the strata in the oil-yielding territory is northeast or toward the valley. Its direction is, however, modified by the flexures referred to, and by other and local variations in strike.

The wells of the Sunset district attain a depth of from 500 to 1,500 feet, and while there is a similarity in the oil sands, it is questionable whether the same horizon is everywhere the productive zone, for the San Pablo is deposited against a slope of the Miocene, from which it might have drawn the petroleum into several beds abutting it at the plane of unconformity. The wells in the Midway field are somewhat deeper than those in the Sunset area proper, having been drilled farther out on the slope of the anticline. The especial interest of these wells is their position along the exterior of the anticline at a very considerable distance from both axis and end, and in a locality where the strike and dip are apparently maintained with great regularity. The gravity of the oil in the Sunset district varies from 11° B. in very shallow wells in the southeastern part of the field, to 17° or 18° B. in the deeper ones in the northwestern portion.

KERN RIVER FIELD.

The Kern River field, the most productive in California, lies about 3 miles north of Bakersfield, in Kern County, near the southeastern extremity of the San Joaquin Valley. As at present developed it occupies an area north of the river of approximately 12 square miles, extending but a few hundred feet south of the stream. The general trend of the oil-yielding zone is N. 40° W., coincident with the strike of the rocks. The field has excellent railway facilities, and an 8-inch pipe line to Point Richmond, on San Francisco Bay, about 300 miles distant, is under construction. In addition, there is a tank storage capacity in the field of nearly 2,000,000 barrels. Refineries, also, are nearing completion. The production of the field at the time of the writer's visit was approximately 3,000 cars a month, actual shipments.

In topographic position the field lies at the edge of the uplands of the San Joaquin Valley, 12 miles from the base of the Sierras, and on the southwest slope of the low ridge which separates Kern River from its tributary, Poso Creek, about 7 miles to the north. Although immediately adjacent to the fertile farms of the valley, the surface aspect of the region itself is that of a desert hopelessly beyond reclamation. The strata underlying are soft and yielding to atmospheric agents, and lie at but a shallow dip (SW.), and as a result, erosion has transformed the area for many miles into typical "bad lands." South of the river a mesa country prevails.

The surface geology of the Kern River field is comparatively simple. The principal geologic formation of the region adjacent on the east is determined by its fossils to be of Lower Miocene age. This passes beneath the productive area, but whether upon more detailed examination some of the surficial beds of this area will not be found to be representative of the San Pablo is an open question. The strata of the Lower Miocene include conglomerates, sandstones, and clays, the several members of this series into which it may be differentiated upon physical or other grounds arranging themselves in broad or narrow zones of outcrop according to the thickness to which they have been developed and the angle of their always gentle dip. But while the differentiation of horizons mentioned is comparatively distinct over broad areas, there are local gradations from one zone to another that frequently render it impossible to trace a maintenance of regularity in the succession of strata. The entire series of beds, in fact, has the appearance of a shore deposit along the granite range of the Sierra, in which currents and waves have played their part in the distribution of materials, with the result that a sandstone at one point may thicken or thin, and, according to conditions, be replaced by clay or conglomerate, which, in their turn, again act in like manner. This relation of the sediments one to another, which is evident from the surface outcrops, is especially emphasized in the hundreds of wells bored in the 12 square miles of the Kern River field. Even in the wells of a single company, where the records have been uniformly kept, this variation of sediments is a conspicuous feature, and it is impossible for one to say from the record of one well what may be expected in a hole to be drilled at a distance of 200, 400, or 600 feet from it. A feature that is to be considered in this connection, however, is the fact that because of the lenticular form assumed by the deposits of sands, gravel, and clays, a certain interlocking of sediments has taken place that has permitted a free circulation of oil throughout the entire thickness of the oil-bearing zone, rendering it remarkably productive.

The geologic structure of the entire region of which the Kern River field is a part has not yet been worked out. There is a general southwesterly dip of the Miocene beds from the Sierra granites outward, and there is abundant evidence also of subordinate folds, the axes of which lie more or less diagonal to that of the Sierra uplift. It is on the southwestern slope of one of the anticlines of this series that the oil field has been developed. The axial trend of this fold is approximately N. 40° W., with local variation to N. 60° or 70° W. With the rarest and most local exceptions, the dip is southwest, usually under 5° and often but 2° or 3°; and in an examination of the Lower Miocene beds from the immediate vicinity of the granite outward there was found at no point a dip in excess of 10°. Along the line of the granite, however, the dip may be considerably steeper, indicating the extent to which the Tertiaries have been involved in the general uplift of the main range. The axis of the Kern River anticline appears to lie in the valley of Poso Creek, but the minor undulations are so numerous that without detailed examination it is hazardous to say just where the center of the arch is situated.

A study of the well records of this field points to the existence of a general body of sands and gravels from the surface to a varying depth up to 200 feet. Beneath this there is usually a stratum of blue clay, also varying in thickness from a few feet up to 100 feet. This clay is impermeable to the waters which nearly everywhere exist in the sands above. Below the clay in all wells is an alternation of sand and clay without regularity and varying in their relative thicknesses from point to point. These sands constitute the oil reservoir of the field, and as high as 400 or 500 feet of them have been encountered in a single well. In a great many wells 200 or 300 feet of oil-bearing sand are found. Below the oil sands is another thin, blue clay, in which the casings are, as a rule, landed. Occasionally a well has perforated this, penetrating a water-bearing sand beneath, and in one or two instances holes have been carried to still greater depths, penetrating a second clay underlying the oil sands, and finally passing into a mass of sand and gravel which yields an enormous amount of water. Many of the wells of this field at first flow, but sooner or later all require pumping. The production is from light up to 600 barrels a day, according to the age of the well, its condition, and the amount of sand upon which the well has to draw. The gravity of the oil varies from 13° to 17° B., the lighter being found in the western portion of the territory. The color of the oil is black.

LA GRACIOSA DISTRICT.

This district lies in La Graciosa Hills, 10 miles south of Santa Maria, in the northwestern part of Santa Barbara County. The hills attain an altitude of 500 or 600 feet above sea level, and their trend is northwest-southeast, coincident with the structural development of the country. Their surface aspect is that of grassy pasture lands or of areas more or less densely covered with the live oaks peculiar to the Pacific coast. The region is rendered accessible by a line of railway to Santa Maria and San Luis Obispo.

The geology of the region embraces an underlying series of folded Monterey shale, of both the soft and more organic material and that which is hard and siliceous, the former predominating. So far as observed by the writer, this series of beds is not exposed at any point in its entirety. Overlying the Monterey unconformably is a heavy and extensive deposit of Pliocene sands, grits, and conglomerates. The composition of these is chiefly quartzose, although there is a mingling of other débris derived from the underlying shales and from the granite and eruptives of more or less distant localities. The full thickness of the Pliocene deposits is undetermined.

The structure of La Graciosa Hills is that of an anticline, the axis of which has a general trend of N. 55° W. The Monterey shales, which occupy its heart and are exposed over considerable areas, are greatly contorted, but the younger sands of the Pliocene, where mantling the older formation, dip to the northeast and southwest from but 2° to 25°, according to their position on the flanks of the fold. A marked unconformity exists between the Pliocene and Miocene deposits, and it is impossible to suggest the surface configuration of the sea floor upon which the younger of the two formations was laid down.

The developments in the fall of 1902 were chiefly confined to the Carreaga ranch, on the southwestern slope of the anticline and hills, but drilling was being prosecuted at a number of points west of the producing area. On the Carreaga ranch the wells start in the Pliocene conglomerates and sandstones, passing into shale below, and thence to the oil sands. Whether the shale was of the Monterey or not is a question for future determination. Difficulty will attend its solution because of the uncertainty of measurements by reason of the uneven surface attendant upon the unconformity existing between the siliceous shales and the younger sands. Texture, however, may aid.

The wells of this territory are large producers and the oil is of high gravity.

SUMMERLAND FIELD.

This oil field extends along the Pacific shore for nearly a mile in front of the small village of Summerland, 5 miles east of Santa Barbara. The wells are located on the bluffs, the shore, and upon wharves extending into the sea for nearly a quarter of a mile. The physical aspect of the country is that of an undulating but highly cultivated terrace, 3 or 4 miles wide, lying between the sea and the lofty and abrupt range of the Santa Ynez Mountains, which parallels the whole coast of Santa Barbara County.

The formations of the region are the equivalents of the great red sandstone series of the Sespe Canyon, 50 miles to the east; a series of rusty sandstones and shales, with their interbedded, concretionary limestones overlying the foregoing; siliceous and argillaceous shales of Monterey type; a succession of conglomerates, sandstones, and clays believed to be the equivalent of the San Pablo, and from 100 to 200 feet of Quaternary sands and gravels. An unconformity is evident between the Quaternary and the San Pablo and between this latter formation and the Monterey.

The structure of the region has not been entirely worked out, but there exists an anticline with axis exposed in the red beds along a line midway between ocean and mountain base. North of the axis there is, for a distance, apparently the same succession of strata as in the Sespe region; that is, the red beds are overlain by a series of rusty sandstones, shales, and limestones. Beyond these, however, along the higher mountain slopes, the present examination did not extend. South of the anticlinal axis the red beds, with a dip southward of from 45° to 80°, are succeeded by shales of Monterey type, and these, in the immediate vicinity of the shore, by the probable equivalent of the San Pablo. The Quaternary is exposed in the ocean bluffs, and here and there overlaps the older formations far toward the mountains. From the difference in the succession of the formations south and north of the anticlinal axis it is possible that an important fault extends along the bench lands of this portion of the ocean's front, the throw of which can not be less than 4,000 or 5,000 feet. An alternative of this fault may be an unconformity between the siliceous shales of the Monterey and the red beds of the Sespe formation.

The Summerland oil field is developed in strata having a southerly to southwesterly dip of from 30° to 90°. It lies at a distance of approximately 1 mile from the axis of the anticline. The source of the oil is in one or more sands of the formation believed to be the equivalent of the San Pablo, at a distance not far from its line of union with the underlying Monterey. The well records in the main point to a body of oil sand from 80 to 120 feet below the derrick floor, and to another 40 or 50 feet below this, but many of the wells extend to depths of 400 or 500 feet. The oil throughout the field is mixed with a considerable amount of water, which is probably due to careless methods in drilling, although it may be from the shallow depths of the wells that sea water has penetrated to the productive beds. The gravity of the oil in the upper and lower sands is said to be, approximately, 10° and 14° B., respectively. The yield of the Summerland wells averages a barrel and a half to two barrels a day, although occasionally a well is found that for a while has a yield of 10 or 15 barrels, but such wells are the exceptions. The district has been productive for several years, and the comparatively large original yield of the wells has now been reduced to a minimum.

SANTA CLARA VALLEY.

The valley of the Santa Clara is of structural development, modified by erosion. It heads in the San Gabriel Range and in the mountains to the north connecting this with other portions of the Coast Range and with the Sierras, and, after a westerly course of 75 to 100 miles, enters the Pacific a little south of the town of Ventura. The valley is given over to agriculture, but the mountains on either side are the loci of many important oil fields.

REGION NORTH OF SANTA CLARA RIVER.

The mass of rugged mountains north of the Santa Clara Valley, forming the watershed between it and the great Central Valley of California, represents the convergence of the several ranges which to the northwest maintain a conspicuous individuality. Pine Mountain, 8,826 feet in altitude, is their culminating point. The area thus occupied is a part of that recently set aside by the United States Government to be known as the Pine Mountain and Zaca Lake Forest Reserve. It is accessible only by trail, and is almost wholly uninhabited. The southern edge of this great range is one of the important oil fields of the Pacific coast.

The geologic structure of the region as a whole has never been determined, but, in the present investigation, that along the edge of the Santa Clara Valley was in part deciphered. It is probable that the converging ranges have each their own structural representative in this mountain mass, of which that studied is but a single member—the eastward continuation, perhaps, of the Santa Ynez Range.

The formations involved in the composition of the oil fields and their contiguous territory embrace several thousand feet of dark-gray quartzites and interbedded shales, which are believed to be Eocene. Overlying these are from 1,000 to 2,000 feet of red sandstones, conglomerates, and shales, the last in the minority. The age of these, also, may prove to be Eocene. From their remarkable development on the Lower Sespe River they are commonly designated by the name of this stream. Above the red beds is a succession of 200 or 300 feet of brown, rusty sandstones, followed by 1,000 or 2,000 feet of gray and purple shales, with thin, interbedded, fossiliferous limestones containing Lower Miocene forms. Succeeding the shales is a prominent, cliff-forming, yellowish-white, concretionary sandstone 200 or

300 feet thick, followed by other shales which are hard, very siliceous, and light gray or white. Overlying these is a second sandstone, somewhat similar to the first, but less concretionary, and this again is overlain by other shales siliceous in tendency, but generally more earthy and friable, and of a brownish color. The correlation of this series in its entirety is in doubt, but the lower, highly siliceous shales are unquestionably of the Monterey type, while the sandstones and the associated shales may also prove to be of the same formation. Unconformable upon the foregoing rest several thousand feet of conglomerates, sandstones, and clays, which carry fossils that identify the beds as of the San Pablo horizon in the Middle Neocene. Youngest of all are some late Pliocene or Pleistocene conglomerates along the slopes of the Santa Clara Valley.

The structure of the region is that of an anticline of very considerable proportions, modified by subordinate folds and faults of the utmost intricacy. Its axis has a somewhat irregular trend, varying from N. 70° W. to N. 80° E., the principal curvature occurring in the hills opposite the town of Piru. The heart of the anticline lies in Topa Topa Mountain and is occupied by the series of Eocene quartzites and shales. Around these circle successively the Sespe red beds, the Lower Miocene shales, the Monterey, and the equivalents of the San Pablo, the last occupying vast areas extending from 15 to 30 miles or more east of the heart of the fold. On the north the anticline is limited by other folds of equal importance. On the south the flexure is modified by a succession of sharp folds of greater or less extent, and by faulting, an especially important line of fracture passing east and west in front of San Cayetano Mountain, extending westward into the Ojai Valley, and eastward, perhaps, crossing the Santa Clara Valley. Numerous branches are given off from this fracture, particularly toward the west.

It is in such an assemblage of strata, with the intricate folding to which they have been subjected, that the oil wells of the region under discussion occur. In horizon the oil is drawn from the lower, middle, and upper portions of the Sespe red beds, from the rusty series at the base of the Lower Miocene, and from sandy measures in the overlying shales; from the great sandstones which succeed and are associated with the shales of Monterey type; and, finally, from the equivalents of the San Pablo beds themselves. In addition, oil is known to occur in the Eocene quartzites forming the heart of the anticline. Fifteen thousand feet of strata, therefore, yield petroleum at one point or another in this field. The distribution of the developed oil areas is either in a broad sweep about the axis of the main anticline itself, in close proximity to the axes of some of the subordinate folds, or along one or more of the great fault lines of the territory, such, for instance, as that south of the San Cayetano Mountain and extending westward through the Silverthread district into the

Ojai Valley. The wells of this field vary in depth from 1,000 to 2,000 feet. The oil is said to have a minimum gravity of about 12° B., and a maximum of about 25° B. The yield of old wells varies from 1 to 20 or 30 barrels a day, though that of new ones rises considerably above this.

REGION SOUTH OF SANTA CLARA RIVER.

On the south of the Santa Clara Valley, separating it from that of the Simi, are the Santa Susana Mountains and their westward extension, Oak Ridge. The former of these is in direct continuation also with the San Gabriel Range, farther to the east. This linear series of ridges in its entirety may be regarded as a unit both topographically and structurally. The San Gabriel Range has an altitude of over 5,000 feet, the Santa Susana Mountains of nearly 4,000 feet, and Oak Ridge rises a little above 3,000 feet. The northern face of the uplift is particularly rugged.

The formations entering into the composition of the Santa Susana Mountains and Oak Ridge are as follows: At the base, heavy-bedded yellow sandstones, here and there pebble-bearing; overlying these, in their most differentiated form, are from 300 to 500 feet of conspicuously banded red and gray arenaceous clays, clayey sandstones, and grits; above this, a yellow and gray sandstone, varyingly prominent; still higher, from 400 to 600 feet of alternating gray and chocolate-brown shales, sandstones, and thin fossiliferous limestones. These are followed by from 200 to 500 or more feet of chalky and siliceous shales of the Monterey type, and these, again, unconformably, by a great mass of heavy, coarse, granitic sands and conglomerates. Of the foregoing beds the last may be the equivalent of the San Pablo, while the portion underlying the siliceous shale is, in part, perhaps wholly, of the Lower Miocene, fossils of this age occurring a short distance above the banded red and gray series. Correlation, however, of this series of beds with those north of the Santa Clara Valley has only in part been possible. The San Gabriel Range is a crystalline complex.

While the Santa Susana Mountains and Oak Ridge may be regarded as a structural unit, there are, nevertheless, within the limits of the uplift many anticlinal flexures, at least four of which derive especial importance from being the loci of highly productive oil areas. Of these anticlines one extends from the western end of Oak Ridge for fully three-quarters of its length, the axis lying in the lower slopes bordering the Santa Clara Valley. The second, third, and fourth anticlines, instead of paralleling the general ridge, lie diagonally transverse to it and en échelon with one another. The western of these extends along the easterly fourth of Oak Ridge and crosses the divide in the gap between it and the Santa Susana Mountains; the middle anticline follows diagonally the northern face of the Santa Susana Mountains, crossing the divide a mile or two west of the low point between them and the San Gabriel Range; the eastern flexure conforms to the western extremity of this latter range, its axis, however, passing into the lower slopes of the Santa Susana Mountains about a mile north of the middle anticline. In addition to the foregoing are several intermediate flexures of minor importance. Faults, also, are present, the most prominent region of fracture and general disturbance being that of the Torrey wells, opposite the town of Piru. It is noteworthy that the line of this disturbance is in the direct trend of one to the north of the Santa Clara that may prove to be connected with the San Cayetano fault.

The productive oil wells of the Santa Susana Mountains and Oak Ridge lie in proximity to the axes of the anticlines or to the zones of crushing described. The horizons from which the oil is derived include one several hundred feet below the lowermost sandstones exposed in Oak Ridge; another, perhaps these sandstones themselves; a third, some of the sands in the brown and gray banded shales; and a fourth, possibly the lower beds of the probable equivalent of the San Pablo formation. The depth of the wells varies from 1,000 to 2,000 feet, according to location and the strata pierced. Their yield has been much greater than at present, except in instances where the territory is comparatively new. The gravity of the oil varies from 14° to 40° B., the former in the eastern portion of the field, the latter in certain of the wells in front of the Santa Susana Range and Oak Ridge.

LOS ANGELES FIELD.

Los Angeles occupies an area about 8 miles square, the greater portion lying west of the Los Angeles River at its debouchement from the low hills which to the west pass gradually into the Santa Monica Range and to the east into the San Rafael Hills and the Verdugo Mountains. The Elysian Park Hills north of the city attain an altitude of about 750 feet above sea level, about 500 feet above the city itself. Their trend is northwest-southeast, their southwestern slope gentle and extending well within the city limits, their northeastern slope abrupt and paralleling the Los Angeles River. The area of productive oil wells extends in a belt one-fourth of a mile wide from a point near the river at the northern edge of town to the western limits of the city in the vicinity of Third street, a distance of about 3½ miles. Still farther to the west, 8 or 9 miles beyond the municipal boundary, are a half dozen more wells that may prove to be in an area structurally related to the Los Angeles field proper.

The formations involved in the geology of the oil field embrace a series of heavy-bedded, quartzose, somewhat concretionary sandstones, with thin, interbedded shale and an occasional calcareous layer, constituting the main portion of the hills north of the city; overlying these, at least 300 or 400 feet of siliceous shale of Monterey type, and above this a succession of sandstones and sandy clays which have generally the appearance of the Pliocene strata of the Pacific coast, and some of which also carry fossils of this age. An unconformity doubtless exists between the last formation and that underlying. Above all, here and there, are recent gravels.

The structure of the Los Angeles field is anticlinical, the axis of the fold lying along the river valley above the city, its direction approximately northwest-southeast. The extent and precise nature of the anticline is undetermined, but the region of Los Angeles is apparently near the eastern end of the fold as it appears in the lower, concretionary sandstones, for the lines of stratification of these sandstones and of the overlying shales are traceable into the hills east of the river, where they turn northward, cross the Arroyo Seco into the San Rafael Hills, and thence veer to the west. The dip in the latter territory is northeast, the opposite of that in the same formation southwest of the river. Locally the anticline is modified by subordinate flexures, some of which are of important significance. Faults also are present.

The Los Angeles oil field is developed in the strata believed to be Pliocene, on the southern leg of the general anticline. The trend of the productive belt, however, instead of conforming to the axis of the main fold, follows the strike of the formations on the south of a subordinate fold divergent from the main flexure, and hence has assumed a direction closely approximating east and west. Evidence of this subordinate flexure and of the syncline which separates it from the main fold is to be found in the northwestern portion of the city. The average dip of the strata adjacent to the oil belt is between 30° and 50°, but local disturbances of the beds, sometimes marked, are found here and there, and it may be that faulting, too, has played its part in the accumulation of oil in the field.

The Los Angeles field was one of the earliest developed in California, and the lapse of time since the inception of drilling renders almost futile present-day attempts to obtain reliable data concerning the conditions of occurrence of the oil. There exist, however, the reports of the California State mining bureau, in which the progress of development has been well recorded by Mr. Watts. It is sufficient here that the wells probably draw their oil from two, three, or more horizons in the sands and arenaceous clays that overlie the siliceous shales. The general depth of the wells is from 600 to 1,200 feet. Their individual production is small compared with many in the great fields of the State, and, moreover, they show a gradual decrease year by year. This, however, has been partially compensated by the product of new wells. The gravity of the Los Angeles oil varies between 11° and 18° B.

PUENTE HILLS.

The Puente Hills are a low east-west anticlinal ridge about 25 miles long and of varying breadth, their western end lying 10 miles a little south of east from Los Angeles. The altitude of their highest point is 1,655 feet above sea level. Their slopes are comparatively smooth and well grassed, and in certain localities there are limited areas of oaks. Tributaries of the San Gabriel drain them on the north, and of the Santa Ana on the south, but for most of the year the stream courses are dry.

The formations embrace sandstones, shales, and conglomerates, which from present evidence are to be regarded as equivalents of the Lower Miocene, Monterey, and San Pablo formations. The Lower Miocene is represented by several hundred feet of yellow and gray concretionary sandstones, with thin, interbedded layers of siliceous shales of Monterey type. These sandstones have an enormous development in the eastern half of the Puente Hills, and according to report continue southeastward across the Santa Ana River into the Santa Ana Range, where fossils have been found in them which determined their horizon.

The interbedded shales of this series, while of the Monterey type, are hardly to be classed in this division of the Miocene, by reason of their occurrence in the midst of sandstones which are known to carry Lower Miocene fossils. On the other hand, in the western half of the hills there are strongly developed siliceous shales that carry Monterey fossils and are to be regarded of this age.

The third and youngest series of rocks in the Puente Hills, forming a prominent terrane along their southern base, is referred, from its fossils and its lithologic features, to the horizon of the San Pablo. The formation here consists of several heavy conglomerates, sandstones, and argillaceous shales and clays. The sandstones and clays break down and disintegrate to the same impalpable powder as do those of the formation in the region of Sunset, McKittrick, and Coalinga. This formation rests unconformably upon those below.

The structure of the Puente Hills is that of an anticline modified by numerous subordinate flexures, the axes having a general trend of N. 65° W. The western half is greatly contracted in its width, while the eastern half is correspondingly expanded. Faults, also, have entered to an important degree into the structure of the hills, especially along the southern slope. Of these, or of an excessively sharp crumple accompanied by minor anticlinal flexures, an especial instance is to be found in a line of disturbance that passes immediately north of the Santa Fe wells, crosses to Brea Canyon, and is, in fact, traceable at intervals over the entire distance to the region of the Whittier wells. The Santa Fe and Brea Canyon wells are close to this line of disturbance; perhaps, also, the wells east of Whittier. The Puente wells, lying between the latter and those of Brea Canyon, are situated at some distance from the fractured zone, yet are to be found in an area of considerable crumpling immediately adjacent to the axis of the main fold. The geology in the immediate vicinity of the Santa Fe, Brea Canyon, and Whittier wells is rendered still more complex by the proximity of the line of unconformity between the San Pablo and underlying formations.

The horizons believed to furnish petroleum in the Puente Hills are: For the Brea Canyon wells and most of those lying east of Whittier, the sands of the San Pablo formation; for the Santa Fe, the strata of uncertain horizon in the disturbed area at the base of the hills in their vicinity, in part, at least, of the Miocene; for the Puente wells, probably the more sandy horizons in the great body of shales constituting the heart of the main anticline in its more contracted part, the precise horizon of which in the Miocene is somewhat indefinite.

The wells in the Puente Hills are of wonderful productiveness, the yield of many rising above 200 barrels a day, and in instances approaching 1,000 barrels. As in the case of all fields, however, the production falls off in greater or less degree according to the life and condition of the wells and the territory drained. The depth of the wells is between 900 and 3,000 feet. The gravity of the oil varies from about 15° to 33° B. In color, both the black and green varieties exist.

The region is connected by pipe line and rail with the main railways of the Santa Ana Valley.

SUMMARY.

From the facts established in the preliminary examination of the oil fields of California it appears—

That the productive areas have been in every instance developed in connection with anticlines, either in proximity to their axes, along their flanks, or about their terminals.

That in several instances faults, or intense disturbances of the strata, have accompanied the folding, causing along their lines interstitial spaces in which petroleum could accumulate, and thus resulting in an increased supply and yield.

That there are at least ten or twelve horizons in the 20,000 feet or more of strata from Eocene to Pliocene that carry oil in quantities of economic value.

That the reservoirs are either conglomerates, sandstones, or the arenaceous members of the great shale groups in the Miocene.

That oil derived from shales is generally lighter than that of which sandstones and conglomerates are the source.

That the stratigraphic and structural conditions under which oil occurs in the known fields are many times repeated elsewhere in the Coast Range and the territory contiguous thereto, from which it may be argued that additional fields will in turn be discovered; and that this view is strengthened by small wells already drilled and by the known distribution of petroleum as evidenced by its seepage.

That the supply is exhaustible.

THE BOULDER, COLO., OIL FIELD.

By N. M. Fenneman.

INTRODUCTION.

For many years the rocks near Boulder have been popularly supposed to contain petroleum. The basis of such rumors lay partly in the strong bituminous odor of certain rocks and partly in certain cases of seepage known as "oil springs." Reports based on the former can be traced back to 1867, at which time the black Benton shales were dug into in search of coal. Their evident bituminous character led Mr. Joseph Wolff and others about ten years later to attempt the formation of an oil company, with the intention of drilling near the center of the present developed field. The proposed location at that time was determined by going straight east from the excavations in the upturned Benton of the foothills to a point on the plains where it was supposed the same strata might be horizontal. The project failed for lack of funds.

The oil springs which have been reported lie north of this area, the one best known being on the Culver ranch on the north bank of the Little Thompson, 17 miles north of Boulder and several miles east of the foothills. Here, at the base of the heavy sandstone stratum in the Pierre (mentioned below), a seepage of oil has been observed for forty years. Several similar but less-known occurrences are reported from 5 to 10 miles north of Boulder.

In 1892 a well was drilled on Gunbarrel hill, 1 mile north of Boulder Creek and 7 miles east of the foothills. Accounts of this well are very conflicting. Sufficient encouragement seems to have been obtained from this attempt to keep alive the idea that future efforts in the vicinity would develop a producing field.

Upon the renewal of interest in 1901 the Boulder Oil Company was organized through the efforts of Mr. Isaac Canfield and Mr. Charles Page. The McKenzie well was drilled by this company. This well struck oil in January, 1902, since which time many companies have been organized and the exploiting of the field has proceeded without interruption.

The exact location of most wells has been determined by "bobbers." Rumors ascribe to Hayden various utterances on the subject of oil, and it is even claimed that he set stakes to mark the proper location of wells. A part of Sheet XII of his published atlas has been freely used as "Hayden's oil map," and the area of outcrop of his Colorado formation (including the Pierre) has been largely advertised as "Hayden's oil belt." The belief even exists among some investors that his survey was made for the purpose of locating oil.

GENERAL GEOLOGY.

The Boulder oil field, so far as developed, has its center about 3 miles northeast of the city of Boulder, Colo. Most of the wells which have attracted attention as producers lie in a north-south line a little less than 3 miles east of the prominent Dakota hogback which marks the eastern limit of the foothill belt.

Stratigraphy.—Practically the entire Mesozoic group is represented in this district, and most of it is of interest in the study of the oil. At the base are 2,000 feet of Red Beds of the foothills consisting largely of coarse, red, feldspathic sandstones or conglomerates, upturned at a high angle and forming a sharp and rugged ridge. The upper 400 feet are more argillaceous and vary more in color, from light-colored shales to dark-colored, ocherous, red shales and sandstones. These Red Beds rest upon the uneven surface of the pre-Cambrian and are themselves practically free from fossils and carbonaceous matter. They therefore form a definite base in which and below which it is useless to look either for the accumulation of oil or for its sources. All higher formations are associated in some way with indications of petroleum at various places in the Rocky Mountains, and in this connection will be mentioned below under the occurrence of the oil.

Overlying these Red Beds is the Morrison formation, consisting of about 250 feet of clays and limestones, with argillaceous and calcareous sandstones. These beds, like the upper ones of the Red Beds, are easily eroded, and the line of their outcrop is marked by a continuous valley. They are not notably fossiliferous in this immediate vicinity.

The Dakota sandstone (Upper Cretaceous) overlies the Morrison. Its outcrop, forming the well-known Dakota hogback, is, next to the crags of the red rocks, the most prominent feature of the foothill topography. The Dakota is here a 350-foot stratum of gray sandstone, sometimes at the base conglomeratic and often at higher horizons quartzitic. Its outcrop would, on the whole, indicate that the Dakota is here as elsewhere a porous stratum, though its high dip toward the plains soon carries it beyond the reach of the drill. Like the strata below this is also poor in fossils.

In general conformable on the Dakota are the Benton shales, dark and bituminous, with a thickness of 500 feet. Locally, as at the north end of the field, these shales become dense black limestone. Certain horizons are crowded with fossils, especially species of *Ostrea* and *Inoceramus*.

Above these shales the Niobrara formation has at its base 20 to 30 feet of limestone, compact, brittle, and fossiliferous. The remaining 300 feet vary from calcareous shales to shaly limestones; they are fossiliferous and bituminous, and certain beds, from a few inches to a few feet in thickness, are almost solid masses of *Ostrea* shells. The topmost beds are of a gritty, shaly limestone having a buff color.

Overlying these and prominent from their contrast in color are the dark shales at the base of the Pierre. They are sparingly fossiliferous, but contain much finely disseminated carbonaceous matter. The Pierre has a total thickness in this vicinity of probably 7,000 feet. The dark color belongs more particularly to the lower part, the remainder being generally lighter and having, after weathering, a characteristically greenish-drab tint.

While, as a whole, a remarkably uniform mass of shale, the Pierre has occasional beds which are more or less sandy, the constitution of these varying from clay shale to pure sand. Only one such sandstone attracts attention by its outcrop. This is a gritty bed lying about 2,000 feet above the base. Three miles north of Boulder it is about 100 feet thick, but it thickens rapidly toward the north. From about 3 miles north of Boulder its outcrop is almost continuous for many miles to the north. There has been considerable speculation concerning the relation of this sandstone to the oil, but, as will be seen below, the stratum has no special significance. The texture of the Pierre will be mentioned more particularly in connection with the subjects of drilling and the occurrence of the oil.

Structure.—All the strata are steeply upturned against the mountains. The Red Beds immediately west of the oil fields dip toward the plains at an angle of about 55°. Higher strata outcropping farther to the east have successively greater dips until the Niobrara is reached, which is about vertical. Eastward from this line there is a rapidly diminishing dip, and within a very few miles the position may be horizontal or even show local westward dips.

Minor folds almost certainly exist. In the absence of ledge-making strata they can not be determined by outcrops and have no influence on the topography. Excavations have, however, revealed occasional dips which are plainly not a part of the general eastward inclination. Also the data from one small group of wells, but 2½ miles from the foothills, strongly indicate local folding with dips as high as 15° or 20°. Here again the data are so limited that the direction of the folding is uncertain. If parallel to the mountains, it may be regarded as attendant upon mountain making; if the minor folds trend east and west, they are in harmony with the Boulder arch so far as that existed.[a] Other indications of a compressive force acting north and south are locally observable in the sinuous strike of the Niobrara limestone.

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[a] Eldridge, G. H., Mon. U. S. Geol. Survey Vol. XXVII, p. 110.

Of faulting it can only be said that it is as yet undiscovered and probably undiscoverable unless it affects the strong sandstone ledge mentioned above. Faults abound, however, near by, as in the vicinity of Marshall, where the stronger Laramie preserves at the surface the records of displacements. The possibility of such dislocations within the oil field demands consideration both in the explanation of the occurrence of the oil and in the exploitation of the field.

DRILLING IN THE PIERRE.

With few exceptions the wells thus far put down have been drilled in the Pierre. The exceptions are among the scattered wells to the east, which are on the very similar Fox Hills or even on the Laramie. These also traverse the Pierre for the greater part of their depths.

Rate of drilling and expense.—Drilling in this formation is comparatively easy and rapid. It is not uncommon to make 100 feet in a day at considerable depths, and this is sometimes done without change of bits. On the other hand, slow progress is made in certain beds. The average expense of drilling a well under contract with responsible parties is, at the present time, about $1.65 per foot for the first 2,000 feet. Below that depth the cost is greater. Under such contracts the owner of the well furnishes casing.

Water.—Surface water is usually encountered at about 15 feet and may be found in the first 100 or even the first 200 feet. Below the surface the wells are commonly "dry;" that is to say, the seepage into the well from the dense shales is so slow as to be of no significance in drilling. In isolated cases deep water-bearing strata are encountered, and such water is sometimes salt. At Lafayette, 11 miles east of the foothills, water is reported as spouting from 4 to 5 feet between the 10-inch drive pipe and the 8¼-inch casing. This water was struck at depths of from 400 to 700 feet and is still flowing after a period of four months. Hot water was reported found at nearly 2,800 feet about 12 miles north of Boulder. In one well the water from this depth was distinctly briny. Other wells have yielded salt water from much smaller depths. In one well now pumping the oil is mixed with about 10 per cent of salt water, which was encountered just below the oil. A slight admixture is found in at least one other well.

Many wells are cased only to the depth of the surface water. Others require 1,000 or even 2,000 feet of casing. In general deep casing is not for the purpose of shutting off water so much as to avoid caving, which is common though not general. It has necessitated the abandoning of several wells.

Reports of materials passed through.—By far the most common item in reports is shale or "slate," occasionally varied as "clay" or "soapstone." Sand or sand rock is often reported. With a showing of oil it is often called "oil sand," with no particular reference to correlation with the sands of other wells. The composition of these "sands" is generally far from that which the name would suggest. They are not generally distinguished from the shales in color, but contain varying proportions of siliceous grains. They are simply more arenaceous beds in the great mass of shale. Individual beds have all possible compositions between a good clay and a good silica sand, the latter being very rare. The thickness of these sandy beds may reach several hundred feet, but they are generally much thinner. In drilling, such beds are distinguished from the shales by their greater hardness, by the more rapid wear of the tools, and by the smaller amount of suspension in the water of the bailer. The washed-out samples commonly appear under close examination as a collection of gritty shale granules whose edges have been rounded under the drill. The better grades show an admixture of quartz grains, and exceptional beds are almost pure sand.

"Streaks" and "shells" are other terms used to indicate more than usual hardness at certain horizons. In the outcrops of these shales may frequently be detected hard beds a few inches or even several feet in thickness. They are either very calcareous or stained with iron oxide or both, and owe their superior hardness to concentration of these substances. Such induration may affect the entire bed equally, or may be concentrated into ellipsoidal concretions, which may be more or less separated, so that there are all gradations between the continuous hard plate and the isolated concretions. The word "shell" is suggestive of the latter, as the word "streak" is of the former, but in the reports the two words may be taken to be synonymous and alike indefinite. The comminuted fragments of these hard masses are not easily suspended in the water of the bailer and (probably for this reason, as well as their superior hardness) are not infrequently reported as sand. On the other hand, many of the so-called hard streaks are no doubt siliceous. The reports of "lime rock" are probably to be traced to the same occurrences. Many concretions, also, have been cracked, and the cracks subsequently filled with calcite.

The use of data obtained.—In such a mass of slightly differentiated shale the record of a well is somewhat monotonous and few have been carefully kept. Moreover, since the distinction between the shale and the so-called "sands" is merely one of degree, some drillers report large numbers of sand strata where others would report all shale. Under such circumstances a complete series of samples would seem to be the best possible log book. It has been difficult to obtain these, largely because of the same monotony which, to the superficial observer, has made the keeping of records unprofitable. Nevertheless, records and samples taken under all possible circumstances have been reduced to as much system as possible. For all important correlations the data have been carefully sifted. Only such observations have been employed as are least liable to error when made by the driller. Such, for example, are the "showings" of gas and oil, the occurrence of water-bearing strata, the character of such water, whether fresh or salt, and the hardness of the strata, as revealed by the frequency of the change of bits.

OCCURRENCE OF THE OIL.

The oil-bearing strata.—The beds from which the oil is obtained are the highly variable sands or sand rock described above as varying between clay shale and silica sand. Such beds may be met with at any depth and there is no depth at which such rock is certain to be found. Reports might indicate that it is slightly more abundant at a depth approaching 2,000 feet, but this may be due to the sharper lookout for sand as the well gets deeper. Not all of these strata contain oil or gas; some of the most porous sands give no indication of either.

The thickness of such beds may be anything up to 100 or 200 feet, but a stratum may yield oil or gas from a part of its thickness only. Such strata are plainly not so homogeneous as would appear from the bailings and are not porous sandstones. Except in an oil well they would probably not be called sands at all. It is not uncommon to drill many feet into such strata and then strike a showing of oil or gas with no attendant change in the texture of the rock that can be detected in the bailings.

The lateral extent of these "sands" is generally small and always uncertain. Their outcrops are so few, so short, and so far apart as to afford little clue to the continuity of any one bed. As revealed by the drill, no one bed can thus far be definitely known to be more than half a mile in extent. Even that is a liberal assumption, based upon the encountering of sand at similar depths in all the wells within a radius of 80 rods. In even the best instance of this kind the texture of the sand varies from well to well, some having small quantities of oil, while others are dry. Moreover, a considerable local dip must be assumed in this case in order to correlate the sands of each well in a single continuous stratum. Hence it can not yet be affirmed with confidence that even in this case there is an uninterrupted sandy stratum one-half mile in extent. On the other hand it may well be that more discriminating reports would show continuity at many places where it does not appear from the reports received.

The horizontal limitations of these sandy strata are probably best accounted for upon the supposition that their composition and texture vary from place to place, and hence a sand stratum may grade into a shale at no great distance. The supposition that the deposits are in lenses of somewhat homogeneous character must also be admitted as possible, though direct evidence of such stratification is lacking. Such lenses should be readily recognized in a group of wells. Variations in thickness doubtless accompany the variations in material.

The number of such strata passed in one well varies greatly. The drill may pierce several thousand feet of shale with little change in character, or a single boring may traverse half a dozen arenaceous strata, two or three of which may yield showings of oil or gas or both. These more porous strata are generally well separated, one from another, by the intervening compact shales. Oil may be found in any one of such strata or may be absent from all. It may appear in a lower while absent from a higher stratum, and seemingly the reverse may be equally true. Showings of oil or gas may occur in relatively dense beds while absent from porous sands near by.

The isolation of the porous beds is well illustrated by the occurrence of deep veins of water in some wells and their absence from neighboring wells at similar depths, or the deeper waters of one well may be salt and those of a near-by well fresh.

The mutual independence of the several oil pockets is not emphasized by any great diversity in the character of the oils from the different wells. With a few exceptions there is approximate uniformity, as shown by standard physical tests. Considering the striking uniformity of the great body of shales, this approximate uniformity is to be expected. It is too early to tell to what extent the yield of one well may be influenced by the pumping of adjacent wells.

Relation to folds.—It will be seen from the above that the accumulation of oil is not yet seen to be related to folds in the strata. Anticlinal arches of impervious stata are unnecessary to form receptacles for oil and gas in so dense a rock as the Pierre shales. If such folds exist they do not appear at the surface, and they can not be recognized from well data until the same stratum can be identified in different wells. This would require a degree of precision in observation and reports not yet attained in this field. In the meantime the ever-increasing closeness of the wells is making the correlation of data more definite.

While there is as yet no evidence that deformation of strata has anything to do with forming receptacles for the oil, it is not yet certain that the distribution of oil is independent of folds. According to the most plausible theories we may suppose that the substance of these oils was at a former time disseminated through lower rocks rich in organic matter. The concentration of this widely disseminated bituminous matter implies a movement through the rocks, perhaps for long distances. Such movement is conditioned by the texture of the rocks traversed. The permeability of rocks in the axial plane of an anticline may differ materially from that in the axial plane of a syncline. It is conceivable, therefore, that in a system of folds, however gentle, the upward movement would be affected both in velocity and in direction by the position of the rocks to be traversed, whether under an anticline, a syncline, or the limb of a fold. Oil might therefore accumulate along certain lines, not because of being trapped in anticlinal arches, but because the products of the original decomposition or "distillation" (or whatever the process may be conceived to be) have been able to rise along certain lines and not along others.

Whatever the explanation finally adopted, it is a noteworthy fact that the wells now pumping are, almost without exception, located on a nearly straight line, whose trend is north and south, parallel to the mountains. Should this line be found later to bear any relation to stratigraphic deformation, that relation will doubtless become an important element in future attempts to locate oil in this region. Such folds or faults, if determined at all, must be detected largely in accurately kept well records, because the rock disintegrates so readily as to make exposures of dips in surface outcrops of rare occurrence. There is no other way in which the same amount of work can yield results of such great financial importance as by the keeping of careful and minute daily records.

The distribution of oil in belts parallel to the mountains can not be considered proved by the meager data thus far obtained; and if proved, it might be due to causes not connected with structural deformation. A line parallel to the mountains was probably parallel to the shore line of the Cretaceous sea in which the sediments were laid down. The presence of oil might therefore be due to conditions of sedimentation at a nearly uniform distance from the shore, either the physical character of the sediments or the conditions favoring life. But these will not be discussed here.

Shooting of wells.—All the wells pumped up to the close of the year 1902 have been shot. The amount of nitroglycerin used in these shots has varied from 10 to 120 quarts. Dynamite charges have been as large as 500 pounds, 70 per cent nitroglycerin. The effects of these shots have not been uniformly favorable. The beneficial effects in a few of the best wells have doubtless been responsible for most of the later attempts. It is by no means certain as yet that this practice will be universal in this field. At least one well has recently begun pumping without being shot, and the owners have no immediate intention of shooting. The fact that the flow of some wells has decreased since the shooting will lead to greater caution, and it is to be hoped that it will lead to a more careful study of the conditions present in each well.

The beneficial or harmful effects of a shot must depend largely upon the texture of the stratum yielding the oil, for it seems to be true that some shales are compacted rather than shattered by the explosion. For this reason, shooting is not practiced in the Florence field, which, of all the older oil districts, the Boulder field most resembles. Owing to the difference in texture of the various beds yielding oil in the Boulder field, it is but reasonable to expect that the same shot which would prove beneficial to one well would be ruinous to another. On this account, if on no other, the texture and composition of the oil strata should be carefully studied by methods far more discriminating than the superficial ones now used.

A second reason for injurious effects from shooting lies in uncertainty about the exact depth of the sand which it is intended to shatter. Measurements of depths by steel tape are indeed becoming more common, but in a considerable number of wells the depths of all formations are known only by cable measurement. Even in wells but recently sunk, it is not uncommon that the stated depths of important sands are thus liable to errors of 25 to 50 feet.

The possible injuries from a shot at the wrong place may be readily seen from the following considerations: Given a porous rock saturated with oil which is under a certain pressure. This rock is now pierced by the drill. The oil soon fills the hole and is pressed upward for the sole reason that it has no outlet in any other direction, being surrounded (as in this field) by impervious rocks. This well is now shot in such a way as to rupture the impervious rocks which have surrounded the oil sand. The oil may now leave the sand by other openings beside the well and may thus be dissipated in other porous beds and the well may be ruined. Such an effect may be produced even by shooting at the proper depth if the charge employed be too heavy. In one instance a well was shot at 740 feet with 500 pounds of dynamite, 60 per cent nitroglycerine. The formation above the sand was a uniform dense shale. A good quality of sandstone was blown from the hole in chunks reaching a maximum of 14 pounds. The shale was ruptured to the surface. Open cracks of an inch or more extended for some rods from the well. Presumably also, cracks reached a considerable depth below the sand which was to be shattered.

It can not be too carefully borne in mind that the one object in shooting is to shatter the rock which carries the oil and that only. With this object in view, it is plain that intelligent and discriminating shooting must depend upon information which the following questions may suggest: Is the texture of the oil stratum such as to give promise that it will be shattered rather than compacted? What is the exact depth of its top (and bottom if drilled through)? How much of a shot will the overlying rocks bear without giving other outlets to the oil? This last question is one of great importance in this field. It is needless to say that such questions can be answered only by a carefully kept log and close study of samples, not only of oil sands but of all strata in order to properly forecast their behavior under the influence of a shot.

Sources of the oil.—The source of the oil is not yet determined within narrow limits. Much of the lower part of the Pierre is black with disseminated carbonaceous matter. The Niobrara below is similarly bituminous, yielding a strong odor from its more fossiliferous beds. The same is true of the Benton, whose shales are characteristically dark and whose bituminous odor is at least as well marked as that of the Niobrara. The Dakota bears oil in Wyoming, and asphalt oozes from its cracks at various places from Wyoming to southwestern Colorado. Even the Morrison beds contain some oil, as seen near the Florence field.

The strata thus enumerated have a combined thickness of from 5,000 to 6,000 feet below the horizon of the lowest oil reached in the Boulder field. Not all parts of this great thickness are equally probable sources of the oil. The lower beds of the Pierre are usually darker in color and richer in organic matter than those horizons immediately below the Boulder oil. The best of the "oil springs" also point to a source not higher than the principal sandstone stratum, which is about 2,000 feet above the base of the Pierre. The Benton and Niobrara are probably richer in oil than any higher strata, and surely in this immediate locality far richer than anything below. The more probable sources, therefore, lie between the top of the Dakota and the middle of the Pierre, a thickness of strata probably limited to 4,000 feet.

Of these 4,000 feet probably containing oil, from 400 to 600 feet of the most bituminous beds (the Benton shales) lie below the compact basal limestone of the Niobrara. This limestone, though less than 30 feet thick wherever quarried for lime west of the oil territory, is very dense, and where unbroken must probably prohibit the accumulation of oil above from sources below this horizon. That it is unbroken beneath the oil field is by no means certain. Within 5 miles (the vicinity of Marshall) faults abound, many of them having displacements far greater than the thickness of the Niobrara basal limestone. Pronounced rupturing of the strata is shown within 2 miles, by the Valmont dike. Such faulting as that at Marshall could not be detected on the outcrop of the homogeneous and easily weathered Pierre shales.

The folding which is almost certainly present would easily joint or brecciate the brittle Niobrara limestone to such an extent as to make it no barrier to the accumulation of oil above from the carbonaceous constituents of the beds below. For the present, therefore, the Benton shales should be taken into account, along with the higher strata, in the consideration of possible sources of oil in this locality.

PRODUCTION.

Since January 1, 1901, there have been built within 5 miles of the McKenzie well about 120 derricks. At 82 of these, wells have been drilled to depths varying from 200 or 300 to 3,400 feet. In addition to these, 13 scattered wells have been drilled at various distances from the foothills, both north and south of Boulder from the Cache la Poudre River on the north to Coal Creek on the south. Of these

82 wells within 5 miles of the McKenzie, 57 lie within a rectangle having a length of 3 miles north and south and a width of 2 miles east and west, comprising secs. 8, 9, 16, 17, 20, and 21, T. 1 N., R. 70 W. Outside of this rectangle but three pumps have yet been installed, none of which are at work at the present writing. Within this rectangle there have been installed in all 17 pumps, of which 13 are at work regularly. The records of shipment from the entire field to the present represent substantially the products of these 13 pumped wells.

Shipments prior to December 15, 1902, aggregated 9,000 barrels. At the present time the daily shipments are about 8,500 gallons, or about 200 barrels of crude oil. A small margin may be added to these figures representing the amount consumed at the wells for light and occasional fuel and sold at the wells for similar purposes. A small refinery has been erected, having a stated capacity of 70 barrels a day, but not much oil has yet been handled here.

The United Oil Company has laid its own pipe lines to all producing wells and has bought practically the entire product, which has been shipped to its refineries at Florence, Colo. The price now paid on six months' contract is $1 a barrel at the mouth of the well. As may be inferred from the price, the oil is of high grade. It is a light illuminating oil with paraffin base. A valuable residuum now sold for fuel may in the future add materially to the price of the crude product.

ASPHALT, OIL, AND GAS IN SOUTHWESTERN INDIANA.

By Myron L. Fuller.

INTRODUCTION.

During the field work in southwestern Indiana in 1902 two discoveries, one of asphalt and one of oil, resulted from the sinking of deep wells. While up to the end of the year no important developments had taken place, it is not impossible that the discoveries may lead to such developments in the near future. In the following paragraphs brief notices of the recent discoveries and a short discussion of the geologic structure are given.

ASPHALT.

During the drilling of a well by the Interstate Gas and Oil Company at Princeton, in 1902, a bed of asphalt several feet in thickness was found somewhat over a hundred feet below the Petersburg coal, or that which is mined three-fourths of a mile west of the well.

In this connection it may be of interest to note that a similar bed is supposed to have been encountered in the old Hall well on the southwest outskirts of the town, about a mile south of the new well, and that in the mine to the west of the well a black substance, known as liquid asphalt, seeps into the bottom of the mine at 450 feet to such an extent that some of the rooms have been abandoned and closed. It is said to enter through a nearly vertical "break," filled with clay.

OIL.

Probably the best showing of oil found in this portion of the State was obtained near Birdseye, Dubois County, in the summer of 1902. The first well was drilled by the Southern Indiana Oil Company, of Evansville, Ind. Oil was found in what the drillers call the "Trenton rock," at a depth of about 1,000 feet. The well is stated to have afforded about 5 barrels a day, but no pumping for the market has yet been done. Up to the end of 1902 three wells had been drilled, two of which obtained oil. Early in March, 1903, a flowing well in sec. 3, T. 3 S., R. 3 W., was reported to have been brought in by the Standard Oil Company, while another was about to be drilled in by the Southern Indiana Oil Company. The Ohio Oil Company is also operating in the field.

The producing formation was penetrated to a depth of only 30 feet. The oil is described as a high-grade 42 per cent lubricating oil. Very little gas was encountered, and no determinations of pressure or volume were made.

NATURAL GAS.

Some years ago a considerable pool of natural gas was struck in the "Jumbo" gas well, near the Woolley coal mine, at Petersburg, but although considerable deep drilling was done at various times about Petersburg, Oakland City, Princeton, and other points in the region, no commercial pools were developed. The "Jumbo" well, after flowing for a time, ceased to produce, but has since been cleaned out and now supplies the illumination for the town and furnishes the fuel for several hundred gas stoves. It is said to show a rock pressure of 585 pounds. A new well was being drilled at Petersburg during the summer of 1902.

CONDITIONS FAVORABLE TO SUCCESS IN DRILLING FOR OIL OR GAS.

While it is probable that similar if not greater pools may occur at other points in this region, their position can not be predicted in advance of drilling. The positions which are geologically the most favorable for drilling are the low anticlinal swells and the areas along the strike lines of the rocks just east of the points where their westward dip changes from flat to steep. Maps showing, by means of underground contours drawn on the Petersburg coal, the structure of the rocks in Pike, Warrick, and parts of Vanderburg, Spencer, and Dubois counties have been recently published by the United States Geological Survey.[a]

STRUCTURE.

The general strike of the beds in southwestern Indiana is nearly north and south. Although there are many irregularities and even reversals of the dip, the general inclination of the rocks is commonly not far from due west. The amount of dip varies from 10 to 40 feet, with perhaps an average of about 20 feet to the mile.

Among the more noticeable of the irregularities shown by the structural contours of the published maps of the Ditney folio are the shallow synclinal troughs near Littles, Ayrshire, Winslow, and near the county line north of Scalesville, and the low anticlinal swells northwest of Glezen, between Oakland City and the Patoka River, south of Winslow, near Arcadia, and southwest of Boonville. The crests of the swells afford, from a geologic standpoint, the most favorable locations for gas wells, while their flanks afford the most promising points for oil wells.

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[a] Geologic Atlas U. S., folio 84, Ditney. Descriptions by M. L. Fuller and G. H. Ashley.

The anticlinal swell northwest of Glezen is a broad, low swell, the crest of which may be considered as starting near Clark and as passing southwestward about midway between Glezen and Rumble and through the group of coal strippings at the head of Robinson Creek, finally subsiding at a point a little to the east of Oatsville. The second swell mentioned is first noticeable at a point about a mile south of Winslow. The crest passes a mile south of Ayrshire and through Sophia and Turkey Hill. It subsides before reaching Oakland City. The swell near Arcadia appears to be a somewhat irregular dome, the highest point of which is probably a little west of town. The axis of the last of the swells mentioned as occurring southeast of Boonville is apparently located a little over a mile south of the railroad at this place, from which point it extends southeastward toward Midway. It has, however, been traced only as far as the alluvial flats.

The change from flat to steep dips and vice versa are usually gradual and do not admit of very exact location. In general the dips are steeper east of a north-south line drawn through Oakland City, and are flatter from this line westward to the vicinity of Francisco, where they again appear to steepen. The minor irregularities, sometimes characterized by dips as high as 5° or 10°, are likely to be of more importance as regards the occurrence of oil and gas than some of the broader features, but they do not usually extend for more than a few hundred feet at the outside and their location can seldom be predicted.

STRUCTURAL WORK DURING 1901 AND 1902 IN THE EASTERN OHIO OIL FIELDS.

By W. T. Griswold.

INTRODUCTION.

In the latter part of the field season of 1901 the writer undertook the investigation of two important economic problems relating to the accumulation of oil, the field work being continued during 1902. The problems noted were, first, the determination of the degree of accuracy with which a stratum at considerable depth can be plotted under favorable conditions, viz, easily distinguished outcropping strata and high degree of accuracy in topographic and geologic work, and, second, the effect of geologic structure on the accumulation of oil and gas.

FACTORS CONTROLLING ACCUMULATION OF OIL.

Structure.—The theory that the accumulation of oil and gas is controlled by the geologic structure of the porous strata in which it is contained has been advanced by Prof. I. C. White, and discussed by many leading geologists under the general designation of the anticlinal theory.

The anticlinal theory ascribes the accumulation of oil and gas in pools of economic value to the influence of geologic structure. The oil and gas are supposed originally to have been widely disseminated throughout the sedimentary deposits in which they were formed, and their segregation is thought to be due to the different specific gravities of the various fluids occurring in the rocks. If a porous stratum contains gas, oil, and water, these fluids will arrange themselves according to their specific gravities, and if this stratum is not horizontal the lighter fluids will be forced toward the higher part of the stratum until their progress is stopped by change in structure or other conditions. In this case an accumulation of gas and oil will be formed that may be of sufficient quantity to be of economic value.

This theory is now generally accepted by leading geologists. Unfortunately, however, only a small percentage of the men actually engaged in the production of oil attach much value to any geologic theory. This is probably owing to the fact that the method of representing geologic structure by contours has not been previously applied to the oil-bearing strata, so that each oil operator might himself study the structural conditions which have produced valuable oil pools in the past. The many failures of those hunting for oil on the anticlinal theory have thrown discredit upon the ability of geologists to assist in the location of productive territory. Most of these failures have been due to lack of knowledge concerning the geologic structure or to the absence of other conditions necessary for the accumulation of oil. Although geologic structure is of primary importance, it is only one of three or more conditions that must be fulfilled in order to produce an oil pool of economic value.

Porosity of the sand.—The condition of the sand as to degree of porosity and capability of holding a fluid is a factor of great importance, and one that, with the geologic structure, governs the accumulation of oil. It is evident that when a sand is loose and composed of large grains fluids may pass easily between the particles, and that a much less slope or grade would cause salt water, oil, and gas to accumulate in separate bodies than if the sand were fine and close grained. The condition of the sand can in no way be determined except by the sinking of a test well. In many instances, within a distance of 600 feet from wells of large production from a good sand, other test wells have found the sand hard and closely cemented and incapable of holding fluids of any description.

Degree of saturation of sand and position of water line.—The saturated condition of the porous stratum is another factor of primary importance in the formation of a pool of oil, and one that has not been given due prominence. The water-line theory, as advanced by the writer, assumes that the tops of the anticlines often contain no liquid upon which the oil may climb, so that, while the gas from its lesser gravity may pass on to the very highest point of the stratum in which it is contained, the oil will rise only so far as it has the water for a supporting medium. The height of the water line thus gives a line of equal elevation along the strike of a stratum, which, when once determined by the drill, should be followed to keep on the line of oil-producing territory. The belt of oil accumulation may be illustrated by a comparison of it to the sand beach along the shore of the ocean, where the sea represents the salt-water area, the upland the area of dry rock, and the sand the belt of saturated oil stratum. This belt, like the ocean beach, may be narrow or widen out over considerable space, so that the saturated portion of the oil stratum may be wider or narrower, forming what appears to be a line of separate pools. The amount of saturation is different in different sands and also in various parts of the same sand. In a sand containing only small saturated areas the oil accumulation may be low down in the syncline, with an area reaching far above it that upon test would only produce dusters. Each independent structural basin must be considered separately as to the location of the water line. Great assistance would have been given in the location of this line of complete saturation had the unsuccessful test wells of the past been divided into two classes, as salt-water wells and dusters, instead of calling them all dry holes, as has generally been done.

The question of saturation does not assume the same prominence when searching for gas, though had it been noted and reasoned from, it would have saved many thousands of dollars expended in searching for oil near large gas wells.

In territory where the anticlinal folds are entirely below the saturated area the water-line theory is of no value, as the accumulations of gas are in the anticlinal arches, with the oil immediately below. Under this condition the crest of the anticline should be followed to find productive territory and the extent of the gas accumulation determined by test wells.

AREA SURVEYED.

The area selected for investigation in 1901 was the Cadiz quadrangle, an area containing about 240 square miles in Harrison and Jefferson counties, Ohio, and lying east and north of the town of Cadiz. The surface forms a plateau, which has been dissected by the streams to a depth of nearly 300 feet, exposing in outcrops six or seven easily distinguished beds of limestone and coal. The geologic section extends upward from near the base of the Conemaugh (Lower Barren) Measures to about the middle of the Monongahela (Upper Productive) Measures. The Pittsburg coal outcrops in the lowest valleys in the southeast corner and tops the highest hills in the northwest corner of the quadrangle.

Parallelism of strata.—As these beds are of sedimentary origin it is evident that there must be a certain degree of parallelism between the strata, hence a stratum lying 1,000 or 1,500 feet below the surface may be platted by data obtained from deep wells and from the outcropping strata with the same degree of accuracy as one but a couple of hundred feet below. The distance between two prominent strata, such as an outcropping coal at the surface and an oil sand below, may be increasing or decreasing. In the Cadiz quadrangle the distance from the top of the Pittsburg coal to the cap of the Berea grit sand is 1,481 feet at the Bricker oil pool, 1,490 feet at Hopedale, 1,527 feet at Bloomfield, and 1,564 feet at Smithfield.

The rate of variation of the interval between two strata can be determined only by actual boring tests. Over the Appalachian oil fields such tests have been made in great numbers by the "wild cat" wells searching for oil. There is hardly a portion of the country lying within the now producing oil fields where the record of such a well can not be obtained within a distance of 5 miles from a given point.

In extending the platting of substrata into entirely new territory a rate of increase or decrease must be assumed, which introduces a degree of uncertainty into the results.

METHOD OF CONSTRUCTING MAP OF THE OIL SAND.

Each outcrop was carefully located upon a topographic map previously made by the Geological Survey, and from the bench marks established by the Survey a spirit-level line was run to each outcrop, establishing its exact position above sea level. Then by adding to or subtracting from the elevation of the outcrop an amount equal to the vertical distance at that point between the bed leveled to and the Pittsburg coal the elevation of the Pittsburg coal at that point was determined. In this way the true altitude of the key horizon (in this case the Pittsburg coal) was established at five or six hundred places over the quadrangle. By connecting the points of equal elevation a contour map of the key horizon was constructed. The position of each oil well which had been drilled in the quadrangle was carefully located upon the topographic sheet. Spirit-level lines were run to the mouth of each well, establishing its elevation above sea. In most cases the steel-tape measurement of the distance from mouth of well to the Berea grit sand was obtained from those interested in the wells. By comparing the elevation of the mouth of the well to the contour map of the key horizon the distance from this horizon to the cap of the Berea grit sand was determined in different portions of the quadrangle. The distance was found to vary, increasing gradually toward the southeast. At the position of each test well the vertical distance between the Pittsburg coal and the Berea grit was marked upon the map.

The positions of the different test wells were connected by straight lines, and these lines were divided so that each subdivision represented the horizontal distance in which the vertical distance from the Pittsburg coal to the Berea grit decreased 5 feet. The points of equidistance from coal to sand were then connected, and a drawing was constructed, called the "convergence sheet." This shows by a series of lines the points of equal distance between the Pittsburg coal and the Berea grit. The convergence sheet was then placed over the plat showing elevations of the key horizon, and it showed at once the amount that should be subtracted from the elevation of the Pittsburg coal to determine the elevation of the Berea sand at any point. The elevation of the Berea sand at every point where it was determined was then marked upon the map and the points of equal elevation were again connected, resulting in a contour map of the oil-bearing sand.

STRUCTURE OF BEREA GRIT.

The contour map of the Berea grit sand shows a system of parallel folds in a northeast-southwest direction, crossed at nearly right angles by a system of broader and less pronounced folds, which break up the major structures into a series of elongated domes and canoe-shaped basins very similar to those of western Pennsylvania, as delineated by Mr. M. R. Campbell.

The most prominent feature is the main anticlinal arch, which extends from near Cadiz in a northeasterly direction, passing just east of the town of Salem, where it attains its greatest height. Thence it swings to a more easterly direction and rapidly falls away before reaching Richmond. The corresponding syncline parallels this fold on the western side, but it is interrupted by two cross anticlines, one near the line of the Pittsburg, Cincinnati, Chicago and St. Louis Railroad, the other very nearly agreeing with the location of the ridge road from East Springfield north toward Bergholz. It thus forms a canoe-shaped basin, whose lowest point is but a short distance east of the town of Jefferson. A part of another basin, which extends almost due east and west, appears in the northeast corner of the quadrangle, its center line being very near the location of a topographic feature known as Middle Ridge. To the east of the main anticline the sand descends in terraces or steps to the eastern limit of the quadrangle, the crests of the terraces extending in lines parallel to the main anticlinal fold. Over this slope the intersection of the cross folds moves the terrace toward the east. This causes the steep slope below the terrace to have a southeast strike for a short distance before again taking up a direction parallel to the major folding.

No long and steep slopes exist in the quadrangle. The descent is steepest on the face of the terraces, where it seldom amounts to 100 feet to the mile. This lack of decided slope for a considerable distance is unfavorable to the accumulation of a large pool of oil, since no large area of oil-producing territory has been drained into a single continuous reservoir.

OIL DEVELOPMENT.

All of the oil developments that existed at the time of survey are represented upon the map in Bulletin No. 198 of the United States Geological Survey—The Berea Grit Oil Sand in the Cadiz Quadrangle, Ohio. The valuable oil pools then known consisted of the Bricker and Snyder on the eastern side of the main anticline, the Jewett pool on its western side, and the Amsterdam pool at the head of the canoe-shaped basin east of Jefferson.

TESTS AND DEVELOPMENT DURING THE YEAR 1902.

During the year 1902 a number of new wells were drilled within the area mapped, with the object of extending the known productive territory and in the hope of finding new pools.

With a view of determining the degree of accuracy with which the contour map of the Berea grit sand had been made in the Cadiz quadrangle, and to learn if the future development of valuable territory would follow the theoretical reasoning of the published bulletin, a careful watch of the new work was kept during the last summer and level lines carried to the mouth of each new well of which a record could be obtained.

Piney Fork district.—In Bulletin No. 198 this locality is described as follows:

> To the west of Smithfield, on and near the Piney Fork of Short Creek, four test wells have been drilled. Well No. 182, on the farm of Alexander S. Thompson, gave a fair show of oil. This well is shown on the map to be on a small terrace. The other wells, Nos. 181, 183, and 240, were simply dry holes.

During the last year the Sutherland Oil Company, of Chicago, drilled two test wells in the Piney Fork district. The first well is on the Finley farm in the middle of sec. 22, T. 8 N., R. 3 W., on the east side of a small stream flowing into Piney Fork and just south of the Updegraff-Smithfield road. The map of the sand shows that the Berea grit is 505 feet below sea level and that the well is located at the foot of a rather steep slope. This latter condition would indicate the probability of a salt-water area. The elevation of the mouth of well is 984 feet above sea level, making, according to the map, a distance of 1,489 feet from well mouth to the Berea grit. The Berea grit was actually found at a depth of 1,487 feet, and the well produced salt water which rose 1,000 feet in the casing. The second test in this locality by the same company was made on the Thompson farm, on the east side of the creek and very near the northeast corner of sec. 29. The map shows the sand at this point to be 445 feet below sea level, and the well seems to be on the terrace previously referred to. The elevation of the mouth of the well is 1,012 feet above sea level; therefore theoretically the distance from surface to the sand should be 1,457 feet. The sand was found at 1,469 feet, showing the map to be in error 12 feet at this point. A showing of oil is reported from the Berea grit, with a strong flow of gas and some oil from the Big Injun. No further tests have been made in this locality.

In Bulletin No. 198 the following suggestions were made as to the northern extension of producing territory along the main anticline:

> North and northeast of the Snyder pool six wells have been sunk in the attempt to find other pools by an extension of the alignment of the Bricker and Snyder pools, with uniformly unfavorable results. With the information shown on the contour map these results might have been anticipated. It is here that the cross anticline breaks up the regular structure, and the terrace face is moved over to the east of the town of Hopedale, where it again takes up its northeasterly direction and is, in fact, the extension of the Bricker and Snyder pool terrace. Two test wells have been drilled in the southeast end of this terrace. The first well, No. 203, found a show of oil, and this led to the drilling of the second well, No. 204, with the intention of striking the sand fully 10 feet higher than in the first well. This the drillers failed to do, finding the sand only 2 feet higher in the second well than in the first. This slightly increased elevation caused an increase in the amount of oil found. The well was put to pumping, resulting in from $1\frac{1}{2}$ to 2 barrels a day.

Spellacy pool.—During the last summer Mr. Spellacy and partners drilled a test well on the line between secs. 14 and 15, T. 10 N., R. 4 W., in about the middle of the sections and about 1,500 feet north of the Cadiz-Hopedale road. The sand is here represented by the map to be 270 feet below sea level, and the location of the well is in the direct extension of the center of the Snyder pool. The elevation of the mouth of the well is 1,157 feet, making, according to the map, 1,427 feet from the mouth of the well to the Berea grit. The record by actual drilling gives 1,431 feet. This well produced 8 barrels a day for the first thirty days. Another well was drilled a short distance to the southwest, resulting in a producer, but smaller than No. 1. The next well drilled is to the east of No. 1 and about 600 feet distant. It came in a producer good for 20 barrels a day.

This new development, known as the Spellacy pool, caused new testing to decide whether the producing territory would keep to the northeast or make a sharp turn to the southeast, as shown by the contours of the geologic structure map. Testing was done in both directions. Messrs. Scott, Ripley, and others located a well on the Grant Bowles farm in the eastern part of sec. 13, T. 10 N., R. 4 W., just south of the Hopedale-Falks station road. At this point the sand is represented by the map to be 256 feet below sea level. The elevation of the well mouth is 1,203 feet, making an estimated depth of well of 1,459 feet. The elevation of the sand at the location of this well was shown by the map to be at the same elevation as the top limits of productive territories in the Snyder pool. This would indicate a small well or total absence of oil. The sand was found by drilling at 1,465 feet, and the result is a perfectly dry hole.

The Sutherland Oil Company, after careful study of the Berea grit map, decided to try a test well in the north part of sec. 8, three-quarters of a mile southeast from the Spellacy pool. The location selected is on the J. R. Skelley farm, one-quarter of a mile southwest of the limits of the town of Hopedale, south of the small stream and north of the 270-foot contour, as represented on the map of the sand. This contour passes through the most productive area of the Spellacy and Snyder pools. The elevation of the well mouth is 1,130 feet, and sand is represented by the map to be 268 feet below sea level, making an estimated depth of well of 1,398 feet. The sand was found at 1,407 feet, and a small producing well was obtained. A second well was at once put down in a line with the first well and the Spellacy pool. The elevation and record of well were not obtained, but it has come in a producer.

Hopedale development.—A new development entirely independent of the Spellacy pool, and due to the following suggestion quoted from page 23 of Bulletin No. 198, was undertaken to the east of Hopedale by the Welch Oil Company:

From the structure and indications of test wells already drilled, a very favorable line for finding oil seems to exist in a northeasterly direction from the southeast quarter of sec. 3, toward the town of Unionport.

The first location of a test well was made on the Allison farm, 1,200 feet south of the Hopedale-Bloomfield road and 1,000 feet east of the Lake Erie, Alliance and Wheeling Railroad. The sand is represented by the map to be 270 feet below sea level. The elevation of well mouth is 1,229 feet, making an estimated depth of well of 1,499 feet. The sand was found at 1,504 feet. The well is a small oil producer, with large amounts of salt water. In order to strike the sand above the limit of salt water, a well was drilled 500 feet north of the road just east of the town of Hopedale, on the farm of Mr. William Stringer. The location, as shown by the map, is at the highest point of the anticlinal nose, which extends south at the town of Hopedale. The sand is represented to be 242 feet below sea level, and the elevation of the mouth of the well is 1,228 feet, making an estimated distance to the sand of 1,470 feet. The sand was found at 1,476 feet. The result was a gas well with a pressure of about 400 pounds to the square inch. It now seems very probable that there is oil-producing territory between the Stringer gas well and the Allison small oil well.

Test well at Unionport.—The same company also drilled a "wildcat" test well in sec. 35, T. 9 N., R. 3 W., south of the railroad, and very near the eastern line of the section, on the farm of Mr. Lewis, west of the town of Unionport. The sand is here represented by the map to be 245 feet below sea level. The elevation of the well mouth is 972 feet above sea, making an estimated depth to the sand of 1,217 feet. The sand was found by the drill at 1,220 feet. The well resulted in a perfectly dry hole, with a hard and close sand.

Eastern Ohio Oil Company's test wells.—During the past year the Eastern Ohio Oil Company, of Chicago, drilled a number of test wells in the area southeast of Cadiz, with unfavorable results. No records of these wells have been obtained, and for that reason the expense of leveling to the mouths of the wells was not incurred.

Amsterdam pool.—Little new development has been undertaken in the north half of the area covered by the Cadiz quadrangle. The following reference to the Amsterdam pool is taken from page 24 of Bulletin No. 198:

> The accumulation from the canoe-shaped basin on the west side of the main anticline has been discovered in part at Amsterdam.
>
> The sand at the Amsterdam well is of such a poor quality that it probably would have been reported as all lime had it not been oil producing. The wells are small, but will probably improve when areas of better sand are found. The limits of this field have been determined across the dip of the sand by a salt-water well, No. 205, and a gas well in sec. 19, not located on the map. The extensions along the strike are as yet not defined by test wells. The indications are that the extensions will be to the southwest in a diagonal line through sec. 30, and to the east in an almost due east line through the south half of sec. 7.

The pool has during 1902 been slightly extended to the southwest by a well on the McGarey farm in sec. 30, which was located near the house of Mr. McGarey on the road from Yellow Creek to Kilgore. This well, although small, will produce a paying quantity of oil.

CONCLUSIONS FROM THE RESULTS OBTAINED.

The results of the developments during the last year seem to afford strong evidence in support of the theories advocated in Bulletin No. 198.

Over the area tested the map has proved to be of such accuracy that it may be relied upon within a limit of the contour interval. This should make the map of great value to the oil producer as a guide to the location of new wells.

It is believed that a map of the different oil sands can be made over the Appalachian oil field by careful geologic work and the united assistance of the oil operators in furnishing full and reliable well records that will be of immense value to the oil industry.

The result of the extension of the Snyder pool in a line exactly agreeing with the contour line representing the Berea grit furnishes strong evidence in favor of the water-line theory.

USE OF A MAP OF AN OIL SAND IN UNPROSPECTED TERRITORIES.

The use of a contour map of an oil sand to locate new pools in unprospected territory will materially aid the prospector, but can not be absolutely relied upon, as the other conditions necessary for an accumulation can only be learned by actual tests.

In the north part of the Cadiz quadrangle is an east-west syncline with a decided rise on its north side. Here is a favorable structure for an accumulation of oil and gas, though the exact point at which the oil would be found would be hard to select.

In making a systematic search for productive territory in this neighborhood the first test well should be drilled in the southeast corner of sec. 25, T. 11 N., R. 3, with a view of determining the condition of the sand, expecting if a favorable sand without oil is found to obtain salt water. If no good sand is found, the result is a complete failure and no information of value is gained. If, however, a good sand containing salt water is found, a move to the northwest equal to a distance that will cover two or three contours on the map of the sand would be advisable, and so on until oil or dry sand is found. If moves not longer than the distance between two contours are taken, it is not probable that the oil belt will be jumped, for the indications near the oil are such as to be distinguished by any operator. If oil is found, it probably lies in a narrow belt along the slope, and the extensions of the pool should be sought along the same structure contours upon which it is procured.

OIL FIELDS OF THE TEXAS-LOUISIANA GULF COASTAL PLAIN.

By C. W. Hayes.

INTRODUCTION.

Shortly after the discovery of oil at Beaumont, in 1901, the systematic study of the stratigraphy and structure of the Gulf Coastal Plain was undertaken. Mr. William Kennedy spent nine months in the field and the writer about two months collecting data for an economic report. A report has been prepared as a Survey bulletin, and is now in press, under the above title. The following is a brief summary of the conclusions there stated at length:

Location of the field.—The Gulf Coastal Plain oil field includes a belt of country from 50 to 75 miles wide bordering the Gulf of Mexico and extending from the vicinity of the Mississippi River in Louisiana westward about two-thirds of the distance across Texas.

TOPOGRAPHY.

While the whole of this belt is a nearly featureless plain, rising gradually from sea level at the Gulf coast toward the north and northwest, it may be divided into three subordinate belts, which are somewhat distinct: (1) Along the margin of the Gulf is a fringe of marsh land only slightly above sea level and subject to occasional overflow. This fringe is widest in Louisiana and decreases westward to the vicinity of Galveston, beyond which it is inconspicuous or absent. (2) Inland from the coast marsh is a somewhat broader belt of prairie land, its surface rising inland at the rate of about a foot to the mile. It has a stiff clay soil and is generally treeless, except for occasional bunches of live oak and a fringe along the water courses. (3) The third belt has a generally sandy or gravelly soil and is well wooded. Its surface rises more rapidly and forms a less perfect plain than the other two belts.

The only topographic features which relieve the monotony of the Coastal Plain are occasional low mounds or swells, which rise island-like above its even surface. These swells are of exceptional importance in the present connection, since they appear to be the external indication of conditions which have favored the accumulation of oil in commercial quantities. They vary considerably in size and amount of relief. At the one extreme are the "salt islands" of Louisiana, and

High Island, Big Hill, and Damon Mound in Texas, which rise from 40 to 80 feet above the surrounding plain and contain several thousand acres. At the other end of the series are the low, barely perceptible swells, such as Sulphur in Louisiana and Spindletop and Sour Lake in Texas. Experience has shown that the latter afford the more favorable conditions for oil accumulation.

STRATIGRAPHY.

The formations which underlie the Coastal Plain belong to the latest geologic periods, the Tertiary and Quaternary, and consist largely of unconsolidated clay, sand, and gravel. Some of the sand beds have become cemented, forming sandstones, and there are occasional beds of limestone, but these are relatively inconspicuous. The region has been repeatedly elevated and depressed and the coast line has migrated back and forth across it many times.

The formations of the Coastal Plain are briefly described below:

Beaumont clays.—These are brown, blue, and yellow clays containing nodules of limestone, also brown and blue sands and cypress logs; they have a thickness of 25 to 400 feet; they generally form clay soil and underlie the coastal marsh and prairie belt.

Columbia sands.—These are white, yellow, gray, and mottled sands with beds of blue and yellow clay and a heavy bed of gravel at base. They occupy a broad belt inland from the Beaumont clays and pass under the latter toward the Gulf. They have a thickness of 50 to 200 feet and form sandy and gravelly soil.

Lafayette sands.—These are blue and red thinly laminated clays and red and brown cross-bedded sands and gravels. They have a thickness of from 30 to 375 feet, form sandy soil, and are discriminated with difficulty from the Columbia.

Buried beds.—These beds do not outcrop at the surface, being entirely concealed by overlapping later formations, and are revealed only by drilling. They consist of (a) 300 to 480 feet of blue, brown, and gray clays and sand with thin beds of limestone and containing small quantities of oil; (b) 200 feet of blue clays and thin-bedded, irregularly deposited sandstones; and (c) 300 feet of blue, red, and gray clays and sands; thin-bedded limestones; limestones dolomitized and associated with sulphur, gas, and petroleum, and the Spindletop oil rock.

Frio clays.—These consist of 260 feet of variously colored thinly laminated clays, containing gypsum crystals and calcareous concretions.

Summary.—The foregoing descriptions of the Coastal Plain formations are necessarily very much generalized since the formations themselves vary greatly from place to place. The logs of closely adjacent wells present only a general resemblance, and it is impossible to identify with certainty any particular bed in wells separated by a greater distance than a few hundred feet. Even in the Beaumont district, where so much drilling has been done, it is possible to make only general statements regarding the stratigraphy. A part of this uncertainty results from the difficulty of obtaining an accurate record by means of the universally employed rotary drill, but a part also is due to the extreme variability in the character of the beds.

STRUCTURE.

The beds making up the Coastal Plain formations were deposited near the margin of a sea which varied in depth from time to time, or upon a coastal belt as wave-built beaches on river flood-plain deposits. The surface on which they were laid down had a gentle slope toward the southeast, and this slope was increased during their deposition by a slight tilting. Hence the beds all have a gentle dip to the southeast, but the lower or older beds have a somewhat greater dip than the higher or newer ones.

While this gentle southeast dip is the prevailing structure throughout the Coastal Plain, it is interrupted at numerous points by low oval domes in which the beds dip away from the center in all directions. This structure has been found to characterize all hills or swells which interrupt the even surface of the Coastal Plain. These domes do not appear to have been formed by lateral compression, such as has given rise to the anticlines of the Appalachian field, but rather are due to some force acting vertically and lifting a small portion of the earth's crust. This force appears to have become active some time during the Tertiary and to have continued since the deposition of the recent Beaumont clays.

CONDITIONS FOR THE ACCUMULATION OF OIL.

The conditions which are essential for the accumulation of oil and gas in commercial quantities are everywhere the same. They are (1) a source for the oil, either organic or inorganic; (2) a porous stratum which may serve as a reservoir; and (3) an impervious cap rock which will prevent its escape. Conditions which favor its accumulation, but are not always essential are (4) gentle undulations of the strata forming anticlinal arches or domes; and (5) complete saturation of the rocks with water and its slow circulation.

In the Gulf Coastal Plain there appears to be a very large amount of oil disseminated through the several thousand feet of underlying Tertiary and Cretaceous, and possibly also Carboniferous strata. Scarcely a well has been drilled in this region to any considerable depth which has not encountered traces of oil in some of the beds passed through. There is also an abundance of porous beds adapted to form reservoirs for the oil. These are unconsolidated sands and gravels, and in some cases, as at Spindletop, a very porous limestone or dolomite. The impervious cover required to retain the oil and prevent its escape from the reservoir rock to the surface is found in the beds of clay and compact limestone which make up the "buried beds" described in the above section on stratigraphy.

The structure of the Coastal Plain is not generally favorable for oil accumulation. The gentle southeastward dip of the beds does not appear to be sufficient for the easy migration of the oil to points of accumulation, and it is only where this uniform dip is interrupted by the dome-like structures mentioned above that accumulation has taken place. Hence the prospector should search for these favorable structures and while, as experience has shown, not all of them contain oil in commercial quantities, they afford by far the most probable localities for drilling. The elevations above the surrounding level plain which are depended on to indicate the presence of these favorable structures are due to the continued action of the elevating force, whatever it may have been, down to a very recent date. Where this force has been most active and the elevation has been greatest, as at High Island and Damon Mound, no oil is found. It is quite possible, therefore, that there may be within the Coastal Plain similar structures not marked by surface elevations, even more favorable to oil accumulation than any thus far discovered. These can be revealed only by the drill, but a careful study of the arrangement of the known domes may afford valuable suggestions as to their location.

The fifth condition favorable for oil accumulation, complete saturation of the strata with water, is probably very general in the Coastal Plain, but how much circulation this ground water has and what its effect on the accumulation of oil may be are points concerning which there are few data available.

THE OIL POOLS.

The actually productive oil territory, so far as at present known, forms but an extremely small fraction of the area of the Gulf Coastal Plain. Excepting the Spindletop pool the limits of the productive territory are in no case defined with any degree of accuracy. The separate areas or "pools," as they are generally called, will probably be found to vary in size from 200 to 2,000 acres. In this respect the field differs widely from the Corsicana field of central Texas and from the great Appalachian field, where the pools are much larger, but where the oil is in smaller quantity and generally under less pressure.

In this field productive territory has been developed at Beaumont, Sour Lake, Saratoga, and Jennings, while encouraging indications are found at Sabine Pass, Dayton, Columbia, Velasco, Anse la Butte, Vinton, and a few minor localities.

Of these the Spindletop pool at Beaumont is by far the best known. Oil was discovered in the Lucas well in January, 1901, and within a year and a half there were 280 producing wells, and a large number of dry wells had been drilled outside of the limits of the pool. It occupies an oval area about 3,000 feet in length and 2,700 in width, containing approximately 200 acres. The depth to the surface of the oil rock varies between 900 and 1,000 feet, a few wells only being outside of these limits. The oil rock is a crystalline dolomitic limestone, having an extremely porous structure. The most compact portions of the rock, as shown by the microscope, contain a larger proportion of vacant space than most of the oil-bearing Trenton dolomite of Ohio and Indiana. In addition to these minute spaces between the crystals of the rock, such as characterize ordinary oil sands, it contains many large cavities, certainly as much as an inch across, and probably much more. While no accurate determination of the relative volume of the open cavities can be made, it can hardly be less than one-third, and may be somewhat more when account is taken of the minute spaces between the crystalline grains. The exceptional character of this oil rock explains in a measure the remarkable features of the Spindletop pool. Its extreme porosity favors the storage of a very large volume of oil, and also favors the yielding of this oil with great rapidity when the reservoir is tapped. It also favors the early exhaustion of the oil in the pool and its rapid replacement by the underlying brine. It should have suggested to those concerned in the development of the pool that a few wells properly distributed would have drained the pool quite as effectively as the large number which have been drilled.

Associated with the dolomite, which forms the oil rock, is considerable selenite or crystalline gypsum. Another abundant accessory mineral is native sulphur. Large crystals, an inch or more in diameter, have been obtained from many of the wells, and it is reported by several of the drillers that the oil rock is overlain by a bed of sulphur, in some cases reaching a thickness of 40 feet. The thickness of the oil rock throughout the greater part of the pool is not known, though it has been penetrated to a depth of 96 feet. Toward the western edge it is probably less than 50 feet thick and, as shown by the Robertson well and the Higgins No. 3, is underlain by about 100 feet of white gypsum. Below the gypsum the Higgins No. 3 penetrated rock salt to a depth of 310 feet without passing through it.

Associated with the oil is always found a large amount of gas, and at several localities this form of hydrocarbon is found unaccompanied with oil. The composition of the gas has not been carefully investigated, but it is known to contain in addition to the light hydrocarbons a large proportion of sulphureted hydrogen.

At nearly all points in this field where oil has been found in commercial quantities it occurs under great pressure, which gives rise to the familiar phenomenon of gushing. Just how high the pressure has been in the Spindletop pool is not known, but it appears to vary between wide limits. In some wells it has shown almost explosive violence, blowing out casing and breaking heavy cast-iron valves.

This maximum pressure has never been even approximately measured. Some closed pressures of 500 pounds and over per square inch have been reported, but these are not well vouched for, and the only reliable measurements vary from 79 to 350 pounds.

While the cause of this pressure is not certainly known, it appears highly probable that it is due largely, if not entirely, to the expansive force of the associated gas. When the oil rock is penetrated by the drill it is usually necessary to remove the water from the casing by bailing. When the pressure is thus relieved there is first a rush of gas, followed by a stream of oil, which is expelled with great violence. The oil, however, never flows in a steady stream, like water from an artesian well, but by a series of jets or pulsations. These may be relatively slow, each flow lasting for several minutes, followed by an equal or longer period of quiescence in which only gas escapes; or they may be rapid, several pulsations occurring in a single minute. The rapidity of the pulsations appears to depend, among other things, upon the depth to which the well is drilled into the oil rock. Their rapidity and consequently the yield of the well is generally increased by deeper boring.

In addition to the expansive force of the gas there is also probably some hydrostatic pressure in this field, but its influence in producing the phenomena of a gusher must be relatively insignificant. The existence of a slight hydrostatic pressure in the Spindletop pool is shown in the invasion of some wells by salt water, which was first noticed after the pool had been producing about eighteen months. This invasion will continue as the oil is removed, though the head may not be sufficient to bring the salt water to the surface.

If the pressure producing the gushing in an oil pool is due chiefly to the expansive force of gas, it follows that this force will expel only a part of the oil, and the remainder will necessarily be won by pumping or by supplying the place of the natural gas by compressed air. It is evident, therefore, that the gas should never be allowed to escape freely from an oil pool, for, aside from the waste of a valuable fuel, the force needed to expel the oil is at the same time being lost.

The history of the Spindletop pool is very instructive in this connection. The Lucas gusher came in in January, 1901, and was wild for nine days, during which the flow is variously estimated from half a million to a million barrels. Drilling at once became very active, and within a year about 200 wells had been completed within the productive territory, which was then well defined. The pressure undoubtedly began to decline within three months or less after the field was opened, though it was still so high that the decline was not readily noticeable. At the end of the first year of production the pressure, although still manifesting itself occasionally with almost explosive violence, was perceptibly lowered. New wells rarely gushed spontaneously, as at first, but required bailing to remove the entire column of water and oil in the casing. Wells which had been shut off did not generally flow when the valves were opened, but to induce a flow it was necessary to agitate the oil in the casing, either with a bailer or by conducting compressed air to the bottom of the well. This general decrease in pressure continued until in the latter half of the second year few wells had a natural flow, and in some the oil was cut off by the invasion of salt water. This fate awaits every well in the pool, and it is only a matter of time when even pumping will no longer be profitable.

The development of this pool has been accompanied by enormous waste in the drilling of a large number of unnecessary wells and the loss of great quantities of oil, which has been allowed to flow over the surrounding country and invite further loss by fire. The even greater loss which has been inflicted upon the commercial world by the overcapitalization of oil companies and the sale of worthless stock is a matter which might be dwelt upon at length, but is not germane to the present discussion.

CHARACTER AND UTILIZATION OF THE GULF COAST PETROLEUM.

The character of the oil found in various parts of the Texas-Louisiana Gulf Coastal Plain is practically the same, but it is very different from that found in other fields of the United States. It is dark reddish-brown, almost black, and has a disagreeably pungent sulphurous odor. It has a high specific gravity, varying from 0.904 to 0.963, Pennsylvania petroleum having a specific gravity from 0.800 to 0.817. In this, as in other respects, it is more nearly related to the California oils.

The flash point or the lowest temperature at which the oil gives off an inflammable vapor varies, according to different observers, from 110° to 180°. The wide variation is probably due to the different lengths of time the several samples on which the tests were made had been exposed to the air. Since the flash point depends on the proportion of the lighter hydrocarbons in the oil, it is gradually raised by exposure to the air, which permits these lighter constituents to escape.

The oil contains a large amount of sulphur, both as hydrogen sulphide, which largely escapes on standing and is more thoroughly expelled by blowing air or steam through the oil, and also as other sulphur compounds. After freeing it from the hydrogen sulphide it has been found by various chemists to contain from 1.75 to 2.4 per cent of sulphur. At least a part of this appears to be sulphur as such simply dissolved in the oil and not in chemical combination. It is probable that this high sulphur would not form a serious obstacle to the utilization of the oil for the preparation of illuminants. The chemical constitution of the distillates, however, appears to be such that with any refining process now in use the yield of illuminants is small and the quality poor.

It is as a fuel that the Coastal Plain oil has thus far been chiefly utilized, and this will probably continue to be its principal use in the future. Tested in various forms of calorimeter, this oil is shown to have practically the same heating value as Pennsylvania petroleum, which is regarded as the standard liquid fuel. Practical tests in steam raising have been made with the Texas oil, and it has been found to have an evaporative power of 15.29 to 15.55 pounds of water per pound of oil used. Of the steam generated 3.1 to 4.8 per cent was used by the burner in spraying the oil. There was thus left available for use the steam from 14.74 to 15.16 pounds of water per pound of oil used. In ordinary practice, without the use of special precautions to guard against waste, 13 pounds of water should be evaporated by 1 pound of Texas oil, as compared with 6 to 6.5 pounds by the bituminous coals of Indian Territory, 8.7 pounds by Pittsburg coal, and 9 by Pennsylvania anthracite. From these relative fuel values it appears that 3.1 barrels of Texas oil may be regarded as having the same fuel value as 1 ton (2,000 pounds) of Southwestern bituminous coal and 4.31 barrels of oil as 1 ton of Pittsburg coal.

It should be noted, however, that the conditions under which coal and petroleum are used in ordinary practice favor the obtaining of a larger per cent of the theoretical fuel value in the petroleum than in the coal. Also a deduction of at least 10 per cent should ordinarily be made from the fuel cost of petroleum on account of the economy in handling the liquid fuel as compared with coal.

As a locomotive fuel petroleum has many additional advantages over coal. Practical tests have shown that its use may add as much as 30 per cent to the efficiency of the boiler, while it weighs only 67 per cent as much as coal having the same heating capacity. From these tests it appears that with coal at $3 per ton petroleum should be worth 97 cents per barrel as a locomotive fuel.

ASPHALT DEPOSITS OF PIKE COUNTY, ARK.

By C. W. Hayes.

The Trinity group, which is the lowest member of the Cretaceous in Arkansas, Indian Territory, and Texas, consists largely of coarse unconsolidated sands with some beds of clay, and is overlain by highly fossiliferous limestones. In Arkansas the Trinity beds rest in an almost horizontal position upon sandstones and shales of Paleozoic age. These older rocks have been intensely folded, the dips being from 50° to 90°. After the folding, but prior to the deposition of the Trinity sands, much erosion took place, so that the Trinity beds were deposited on an uneven surface composed of these folded Paleozoic rocks. Both Trinity and Paleozoic were, at a still later date, covered by a thin and irregular deposit of coarse sand and gravel called the Lafayette.

At many points in the area under discussion the sands of the Trinity group contain notable quantities of bituminous matter, usually in the form of asphalt, though in Texas small quantities of petroleum are reported to occur at this horizon.

The most extensive of these deposits occurs in Pike County, about 2½ miles southeast of Pike City, on a branch of Wolf Creek. This has recently been developed by the Arkansas Asphalt Company, of Little Rock. Two hills south of Wolf Creek contain in their upper portions the fossiliferous limestones of the Lower Cretaceous, and around their bases and extending under them is the Trinity sand. The asphaltum deposit occurs in a depression between these hills, where only the lower portion of the Trinity formation remains, consisting chiefly of coarse sand, in some places quite calcareous, with beds of clay. The deposit is in the form of a sand stratum, which varies in thickness from 6 to 12 feet, more or less thoroughly saturated with asphaltum. The deposit was discovered by the escape of small quantities of asphaltum to the surface in a spring, and this led to prospecting for its source. A pit was dug about 12 feet in depth, passing through the bed, and the thick, viscous asphalt has slowly oozed out into this pit for the last thirty years.

The asphaltic rocks show considerable variation in character and in the amount of asphaltum which they contain. This variation is shown by the following analyses made for the Arkansas Asphalt Company by G. W. Howard, of New York City.

Specimen No. 1, known at the pit as brown cap sand, contains 5.06 per cent of bitumen, or 1.73 per cent of petrolene and 3.33 per cent of asphaltene. It is essentially a sandstone, since it contains 92.40 per cent silica.

Specimen No. 2 is a black sand rock containing 16.53 per cent bitumen, of which 14.13 per cent is petrolene and 2.40 per cent asphaltene. The percentage of silica in this rock is 81.20.

Specimen No. 3, a grayish rock exhibiting banding, contains 6.68 per cent of bitumen, 69.15 per cent of silica, and 20.35 per cent of carbonate of lime.

Specimen No. 4 is a black, gummy rock carrying 8.86 per cent of bitumen, 79.50 per cent of silica, and 6.14 per cent of carbonate of lime. The bitumen determined as petrolene amounts to 6.61 per cent, and the asphaltene to 2.25 per cent.

Specimen No. 5, which is a calcareous sandstone, contains 4.58 per cent bitumen, which equals 3.46 per cent petrolene and 1.12 per cent asphaltene. The carbonate of lime in this specimen amounts to 46 per cent, and the silica to 49.42 per cent. At the pit this rock is known as limestone.

No doubt specimens taken from these classes of rock would vary from place to place in the pit. The analyses, however, probably represent fairly the materials obtainable.

Like similar deposits in other regions, there can be little doubt that this asphaltum is merely the residuum from petroleum, the lighter and more volatile portions of which have escaped by evaporation. It has also doubtless undergone certain chemical changes, chiefly oxidation, during its long exposure to atmospheric conditions.

By means of test borings the asphaltum bed has been proved to extend over a number of acres, under a cover sufficiently thin to permit profitable mining by stripping. At the time the deposit was last visited, in November, 1902, a pit about 100 feet in diameter had been opened and a tramway built to the railroad, about half a mile distant.

It is proposed to use the materials in such proportions as will produce a good paving mixture. The occurrence of the limestone with the sandstone makes this possible without the addition of material from other sources. A practical test will be made at Little Rock, where a contract has been obtained for paving certain streets.

The utilization of this deposit is a technical matter which can not be entered upon here. Its chief value will doubtless be as a paving material. As stated above, some portions of the bed form a natural paving mixture, which hardens on exposure to the sun, and, so far as could be judged, would be fully as durable as the ordinary artificial mixtures made from Trinidad asphalt. Other portions are too rich to be used in a natural state. Tests of these portions in the preparation of a paving mixture have been made by the St. Louis Testing and Sampling Works, with excellent results.

The extent to which the deposit can be used for paving purposes in competition with other asphalts will be determined entirely by the matter of freight rates. It should easily control the market in near-by cities, such as Little Rock, Texarkana, and Fort Smith, and the richer portions of the deposit should compete advantageously with other asphalts in cities as distant as Memphis and St. Louis.

No experiments have yet been made in refining the asphaltic sand for the preparation of pure asphaltum, and this may be found to be more profitable than shipping the crude product.

From the large amount of bituminous matter in these sands, it was inferred that petroleum in commercial quantities might be found by deep boring, and two wells were drilled for oil. The wells penetrated from 100 to 120 feet of the Trinity formation, consisting chiefly of sands and clays, with a few thin seams of limestone, and then entered the Paleozoic sandstones and shales. The latter are highly contorted, dipping at angles of 45° to 55°, and are intersected by numerous fractures. No oil in commercial quantities has ever been discovered in rocks of this character, and it will readily be understood that, even if they had originally contained oil, it would, before the deposition of the Trinity, have had abundant opportunity to escape to the surface through the fractures which resulted from the folding of the strata. The expectation of finding oil, therefore, in this region at greater depth than 100 or 200 feet, that is to say, in the underlying Paleozoic rocks, has no rational basis. Also, it need not be expected that oil in commercial quantities will be found at shallower depths, since the conditions are not favorable for its retention in these sands.

In view of the foregoing considerations, deep drilling in this region is not justified by even a remote probability of finding oil in commercial quantities. On the other hand, the conditions for the accumulation of asphaltum are most favorable, and it is quite probable that other valuable deposits will be found in this region, similar to that above described and at the same horizon.

PUBLICATIONS ON OIL, GAS, AND ASPHALT.

The following list contains the more important papers relative to oil, gas, and asphalt published by the United States Geological Survey or by members of its staff:

ADAMS, G. T. Oil and gas fields of the western interior and northern Texas coal measures, and of the Upper Cretaceous and Tertiary of the western Gulf coast. Bulletin U. S. Geol. Survey No. 184, 64 pp. 1901.

ELDRIDGE, G. H. The Florence oil field, Colorado. In Trans. Amer. Inst. Min. Eng., Vol. XX, pp. 442–462. 1892.

——— The uintaite (gilsonite) deposits of Utah. In Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 909–949. 1896.

——— The asphalt and bituminous rock deposits of the United States. In Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 209–452. 1901.

FULLER, M. L. The Gaines oil field of northern Pennsylvania. In Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 573–628. 1902.

GRISWOLD, W. T. The Berea grit oil sand in the Cadiz quadrangle, Ohio. Bulletin U. S. Geol. Survey No. 198, 43 pp. 1902.

HILGARD, E. W. The asphaltum deposits of California. In Mineral Resources U. S. for 1883–1884, pp. 938–948. 1885.

McGEE, W J. Origin, constitution, and distribution of rock gas and related bitumens. In Eleventh Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 589–616. 1891.

PHINNEY, A. J. The natural gas field of Indiana. In Eleventh Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 617–742. 1891.

RICHARDSON, C. Asphaltum. In Mineral Resources U. S. for 1893, pp. 626–669. 1894.

VAUGHAN, T. W. The asphalt deposits of western Texas. In Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. V, pp. 930–935. 1897.

WILLIS, B. Oil of the northern Rocky Mountains. In Eng. Min. Jour., Vol. LXXII, pp. 782–784. 1901.

STONE.

Several brief papers on building stone are here presented. During the last year other extensive investigations in various important quarry districts have been commenced by the Survey, the results of which are not yet in form for publication here. The slate industry has been given particular attention, reports being published or in preparation on the slates of Vermont, New York, Pennsylvania, West Virginia, and Georgia.

THE STONE INDUSTRY IN THE VICINITY OF CHICAGO, ILL.[a]

By William C. Alden.

LIMESTONE.

The supply of limestone within the Chicago district, so exposed or so thinly covered as to be easily reached, seems to be quite adequate to the demand; at least, not all the exposures are utilized for the production of the commodity. The exposures are so distributed as to be convenient to Chicago and its nearest suburbs, but the country districts lying in the morainal track are not so well supplied.

BUILDING STONE.

The strata considered by Dr. Bannister as the lower division of the Niagara group afford one of the best building stones in the State. These are exposed on the floor of Desplaines Valley northeast of Lemont. The location, being formerly known as Athens, gave the name "Athens marble" to the rock, by which name it is known wherever used. The same beds are seen in the western end of the Sag, at its junction with Desplaines Valley. The rock at the Western Stone Company's quarries, Lemont, is a fine-grained, even-textured limestone, of an agreeable light-drab color when first taken from the quarry. On exposure to the air the color changes to a buff or yellow. The rock rubs well, though not capable of receiving a very fine polish.

[a] Abstract from Geologic Atlas U. S., folio 81, Chicago.

It is regularly bedded, the layers ranging from 6 inches to nearly 3 feet in thickness, thus affording fine cut and sawed dimension stone and flagging.

The quarries of the Illinois Stone Company in the same vicinity show the same even-bedded limestone and produce dimension and rubble stone and flagging.

At Sag Bridge the quarries of the Phoenix Stone Company produce a fine grade of even-grained, solid limestone. The courses increase in thickness downward, becoming nearly 8 feet thick at the bottom, with little or no fracturing. The product is fine cut and sawed dimension stone, rubble, and five grades of crushed stone for macadam.

The quarry of the Calumet Stone Company, 1½ miles east of Sag Bridge, shows stone of excellent quality. A small quarry on the north side of the Sag has turned out a small amount of a dense, fine-grained rock of very good quality.

These are the principal localities yielding good dimension stone, as here the strata have suffered little or no disturbance and hence show little fracturing. The facilities for transportation by railroad and by canal are excellent.

The quarry 1 mile west of Elmhurst, on the Chicago and Northwestern Railway, puts out building stone, including some dimension stone.

RUBBLE, MACADAM, AND LIME.

As most of the quarries furnish crushed stone for macadam and rubble for foundations, and some furnish lime, they will be noted in order, beginning with those in Chicago. The rock at all the quarries is well adapted for macadam, as it is a hard, gray dolomite, in places very siliceous, and the fractured condition of the strata makes it comparatively easy to remove. At the intersection of Chicago and Western avenues, about three-fourths of a mile southeast of Humboldt Park, the quarries of the Artesian Stone and Lime Works Company produce crushed stone for macadam and lime.

The quarries of the Chicago Union Lime Works Company at the intersection of Nineteenth and Lincoln streets, about a mile east of Douglas Park, have been excavated to a depth of 175 feet. The limestone is a dolomite containing about 54 per cent carbonate of lime and 44 per cent carbonate of magnesium.

The quarries of the Stearns Lime and Stone Company at Bridgeport, near Twenty-seventh and Halsted streets, produce lime and crushed stone for macadam.

The quarries of Dolese & Shepard, at Hawthorne, on the Chicago, Burlington and Quincy Railway, produce building and dimension stone, crushed stone for macadam and concrete, and limestone for flux.

At Thornton, on the Chicago and Western Indiana Railroad, the quarries of the Brownell Improvement Company produce crushed stone for macadam containing about 36 per cent of silica, giving it a very durable quality. Their quarries at Gary, Ill., on Desplaines River, produce a dense, even-grained limestone in little-fractured strata. Some foundation stone is gotten out, but the rock is rather hard to dress. The product is largely crushed stone for paving.

At the outcrop, 1 mile southwest of Blue Island, considerable rock has been removed for foundation stone. It is stated that a bed of bluish, impure limestone has been worked here for hydraulic cement. Mr. J. V. Q. Blaney reports the following analysis of this limestone:

Analysis of limestone 1 mile southeast of Blue Island.

Clay and insoluble matter	43.56
Carbonate of lime	31.60
Carbonate of magnesium	22.24
Peroxide of iron	1.20
Soluble silica	.16
Alkalies, loss, etc	1.30
Total	100.06

At his place about 2 miles southwest of Blue Island, Mr. Henry Schwartz has quarried a limited amount of good foundation stone. There is abundant rock here, easily accessible.

The quarry 1 mile west of Elmhurst, on the Chicago and Northwestern Railway, produces crushed stone.

The quarry of Kogle & Smith, about 3 miles southeast of Elmhurst, yields crushed stone. Some building stone is also taken out.

At the outcrop, 1 mile northwest of Lagrange, on the bank of Salt Creek, a quarry has been opened which is turning out crushed stone for macadam.

Mr. Fred Schultz puts out crushed stone and lime from his quarry at Lyons.

At McCook, on the Santa Fe Railway, near the canals, are the quarries of the Chicago Crushed Stone Company. Rubble for foundations is also produced.

Not all of the rock exposures have been utilized for economic purposes. The following may be noted as affording productive sites should the demand require: One mile northwest of Humboldt Park; corner of North Central Park avenue and Humboldt avenue; two blocks west of Humboldt Park; in the vicinity of Robey and Twenty-third streets; on the lake shore in Windsor Park, at the foot of Cheltenham place; on either side of Railroad avenue, between Ninety-fourth and Ninety-fifth streets, and six blocks west, between Ninety-fifth and Ninety-sixth streets.

At "Stony Island" two quarries have produced considerable rock, but are now unused. There is abundant rock thinly covered north and west of Thornton. Two miles south of Glenwood and three-fourths of a mile east of the Chicago and Western Indiana Railroad the rock is rather thinly covered in the hill slope. Three and one-half miles south of Elmhurst rock can be obtained in the west bank of Salt Creek. Abundant rock is thinly covered south and east of Lyons; also down Desplaines Valley from McCook, along the north side of the river. At Sag Bridge and at Lemont abundant rock is easily quarried. The southwestern part of the area is most poorly supplied, though the proximity of Joliet may counterbalance this deficiency. Only two exposures were noted in this part of the area, one 5 miles east of Orland, along the banks of a small creek; the other along the bed of Hickory Creek, near New Lenox.

Where the bituminous limestone has been used for building purposes the staining gives a peculiarly venerable appearance to the structure. There is, however, the disadvantage that the melting and running out of the bitumen may give a disagreeable streaking to the walls.

The abundant drift bowlders of limestone, sandstone, igneous and metamorphic rocks have furnished material for many picturesque and beautiful buildings within the district and could supply a further demand. These are also of value in the construction of piers and breakwaters.

SAND AND GRAVEL.

The wide distribution of sand and gravel over the Chicago Plain has afforded abundant material for building sand, roofing and road gravels, and for filling. The extensive deposits of dune sand along the present lake shore, along the west side of the Blue Island ridge, southwest and south of Hammond, Ind., and east of Thornton, furnish abundant fine, clean sand. The deposits of glacial gravel furnish the coarser gravels, with some sand and fine gravel. Several large pits have been opened about a mile north of Willow Springs, in the north slope of Desplaines Valley. The deposits here are assorted into several grades of gravel for building, paving, and ballast purposes. The output at these pits is 20 to 25 carloads per day. Numerous pits have been opened at various points along Desplaines Valley, showing material grading from sand and gravel to very stony till, composed almost entirely of well-worn limestone pebbles and bowlders. In places this limestone is partially cemented into a conglomerate, so as to come out in large masses. One-half mile southwest of Worth Messrs. Henke & Read have opened a large gravel pit. The gravels here are assorted into grades of two sizes. Ten to twelve thousand cubic yards have been taken out per annum. At Blue Island, just north of the Chicago, Rock Island and Pacific Railway station, there is an extensive deposit of the coarser beach gravel. The entire south end of the ridge seems to be composed of these gravels.

THE SLATE INDUSTRY AT SLATINGTON, PA., AND MARTINSBURG, W. VA.[a]

By T. Nelson Dale.

SLATINGTON, PA.

The basis of the slate industry here is a belt of Lower Silurian (Hudson) slates, shales, and grits which stretches along the southern side of the Blue or Kittatinny Mountain from east-northeast to west-southwest. This formation is about half a mile thick, overlying the great magnesian limestone formation on the south and underlying the Upper Silurian conglomerate and sandstone on the north. The structure of this formation is a succession of minor folds generally overturned to the north, and in places crossed by a southward-dipping slaty cleavage.

Although the formation covers many square miles of Lehigh County, west of the Lehigh River, and prospects have been made at many points, yet the Slatington industry is confined to an area of 3 to 4 square miles along Trout Creek and its branches. Within that area about 100 openings have been made, of which only about 45 are now being worked. These range from 50 to 300 feet in depth.

The slate is black and has a very fine cleavage. It is calcareous, as shown by its effervescing in cold dilute hydrochloric acid, and contains carbonate of iron, as shown by its discoloration after continued exposure. Under the microscope it is found to consist of a matrix of muscovite (potash mica), with much carbonate, carbonaceous matter, and pyrite, some angular quartz and feldspar grains, chlorite scales, and the usual slate needles (rutile, TiO_2). It is geologically between a phyllite and a clay slate. The roofing-slate industry here seems to owe its success largely to the fine cleavage, which enables the producers to undersell slates of more durable character, but of poorer fissility. Some beds unsuitable for roofing are made into school slates. A large establishment for the manufacture of school slates has just been erected.

The slate beds vary in thickness and alternate with grit beds from a fraction of an inch to several feet in thickness. The grit consists mainly of quartz grains, carbonate, carbonaceous matter, and pyrite. It represents coarser marine sediments, brought in possibly by shift-

[a] Detailed reports on these areas are in preparation.

ing currents, while the slate is the finer off-shore material powerfully compressed and largely altered to mica.

The chief difficulty attending the Slatington slate industry is the complex structure of the slate beds. The frequency of the grit beds, "rock" or "ribbon" of the quarrymen, is one element in this. Then the folds vary greatly in width. One limb of a trough (syncline) may measure over 200 feet at the horizon or the arch (anticline) may be so sharp as to measure scarcely 25 feet across. These folds are more or less overturned, so that the ribbon intersects the cleavage at different angles on the sides of the fold, thus differently determining the size of the slate blocks and to some extent the quality of the slate. The axes of these overturned folds pitch alternately east-southeast and west-northwest at from 5° to 10° or bend 10° laterally, i. e., north-south. The folds have all been truncated at the surface by erosion, so that it is difficult to trace any one bed across the strike. The rock surface may be but a few inches below the turf or may be buried beneath 30 to 40 feet of glacial deposits. There is frequently a flexure of the cleavage ("curl") for a few inches near the ribbon; more rarely there is a curvature of the cleavage across the entire bed. Slates cut from such beds are called "bents," and are used for covering curved or conical roofs. At the old Hughes quarry this curvature in 25 feet along the dip of the cleavage amounts to a change of 20° in the dip, the dip at the top being 45°, but 65° below. Exceptionally the joints, instead of crossing bedding and cleavage at a certain angle, undulate like bedding planes. Faulting seems to occur rarely.

It would seem that nothing less than an exhaustive study of the stratigraphy of the region with the aid of a perfectly reliable large-scale topographic map would suffice to furnish a safe basis for such an industry, but in fact the industry has attained its present prosperity without such aid, and it is even doubtful whether a pocket compass could be found on the person of any foreman in the quarries. In view of the very small collective area of all the openings about Slatington compared to the extent of the slate beds as shown by the location of these openings, and in view also of the financial risks growing out of the difficult stratigraphy, it is surprising that the diamond drill, used so effectively in marble and other regions, has not been brought into requisition here also. The core from such a drill would not only show the quality of the slate but its thickness, in many cases, as well as the dip of the cleavage and ribbon. A less costly drill, which secures a core by the rotation of a wrought-iron pipe upon steel shot, has been successfully used in the Vermont slate belt.

Attention ought to be called to certain outcrops of dark reddish shales a mile southeast and southwest of Werleys Corners in Weisenberg, or about 10 miles southwest of Slatington. A microscopic examination of a surface specimen from the first of these places shows it to be almost a slate. It is possible that a dark red clay slate, suitable for roofing, occurs below the top rock in that vicinity.

MARTINSBURG, W. VA.

This recently prospected slate district lies in Berkeley County, W. Va., within the geologic belt designated Martinsburg shale in the Harpers Ferry folio. This belt lies about 13 miles west of the Blue Ridge and mostly on the western side of Opequon Creek, a tributary of the Potomac. It measures at least 14 miles in length, from north-northeast to south-southwest, and from 2 to 4 in width. Martinsburg lies just beyond its western edge.

This shale and slate formation, estimated to be from 700 to 1,000 feet in thickness, is of Lower Silurian age, and overlies the Siluro-Cambrian Shenandoah limestone in a series of folds represented in the folio as overturned to the west. The rock is generally a dark grayish shale, weathering into a yellowish or white clay, known locally as "soapstone." The general character of this rock and its appearance when weathered would hardly be regarded as good indications of the presence of roofing slate. But at several points, usually near the Opequon or its tributary "runs" or creeks, where the mass has been denuded of its weathered portions, it has a well-marked easterly dipping (in one case, westerly) slaty cleavage crossing the bedding at various angles; and pieces, when struck with the hammer, give the typical ring of a slate. A superficial examination of this slate shows that its cleavage is far from being as fine as that of the Slatington quarries and that the cleavage surface, although quite as black, yet lacks the smoothness and luster of the Slatington product. On the other hand, it effervesces far less readily or not at all with cold dilute hydrochloric acid. Its relative commercial value will be soon determined scientifically by the usual physical and chemical tests and by comparing the results of these tests with those obtained from tests of "Peach Bottom" slates. Meanwhile preliminary microscopic examinations of specimens taken from several localities have been made with the following results.

All the transverse sections show a rather coarse and poorly defined cleavage and a very faint polarization of the matrix, in some cases none at all, indicating incomplete sericitization. All the sections show carbonate, some in very small amount, others in large. Carbonaceous matter is present in all the sections, but is less conspicuous than in the Slatington slates. The following minerals are also present: pyrite in spherules, angular quartz grains, plagioclase grains very rarely, rather large muscovite scales, chlorite usually interleaved with muscovite, and the usual slate needles (TiO_2), but these are not as abundant as in other slates.

The above suffices to show that these slates are neither true phyllites nor midway between phyllites and clay slates, like the Slatington and Vermont slates, but are closely related to clay slates. They resemble in structure, but not in composition or color, the Welsh Penrhyn dark purple ("red") slates.[a]

Microscopic examination shows that the slates will cleave less readily than the Slatington or Vermont "sea-green" slates, and that they will be liable to lose some of their blackness on continued exposure, and that the amount of discoloration will vary in different beds and localities. Although a clay slate even with a small amount of carbonate could hardly prove as durable as a phyllite without any, yet it may compare favorably with slates intermediate between phyllites and clay slates and containing much more carbonate.

Slate has been found at the following points in the Martinsburg belt: Two miles north 10° west of Middleway, or about 9 miles south of Martinsburg, 5 miles northeast, 3½ miles northeast, 2½ miles southeast, 2½ and 5½ miles south-southeast, 6½ miles south-southwest of Martinsburg. Numerous other localities will probably be found. The cause for the development of slaty cleavage at one point in the shale belt and not at another is not yet clear. Thus the railroad and highway cuts east of Martinsburg along Tuscarora Creek, which bisects the belt, are in shale, but slate occurs north-northeast and south-southwest of this along the strike.

What is needed to develop the industry is to thoroughly open one experimental quarry and introduce its product into the market. Should that experiment prove successful the growth of the industry will be assured.

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[a] See Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 262.

LIMESTONE OF THE REDDING DISTRICT, CALIFORNIA.

By J. S. Diller.

More limestone occurs in the copper region of Shasta County, Cal., than in an equal area of any other part of the State. A thick limestone of Triassic age occurs along the stage road east of Furnaceville, and subordinate masses crop out around the upper slope of Bear Mountain a few miles northwest of Sherman, but the principal mass of this belt forms Brock Mountain, on Squaw Creek, and may be traced for many miles to the north. This limestone is full of fossils and is especially noted for the large lizard-like animals it contains. It is generally pure, and at Brock Mountain is used for flux in the Bully Hill smelter.

A belt of more prominent limestone ridges and peaks extends from near Lilienthals north by Grey Rock, the Fishery, and Hirz Mountain, along the McCloud for many miles. The limestone where best developed is over 1,000 feet thick, and until recently has been used for flux at Bully Hill. It is cut by numerous irregular dikes of igneous rock, which locally interfere with quarrying. If the projected branch railroad up Pit River is ever built, it would pass near this great limestone.

A third belt of limestone occurs near Kennett, within a few miles of the railroad, and furnishes not only flux for the Mountain Copper Company at the Keswick smelter, but also lime, which is burned at Kennett and shipped to many points on the Southern Pacific Railroad. This limestone is of Devonian age, and consequently much older than the others. Although the limestone is not nearly as large as the others, and isolated on ridge crests by igneous rocks, it is more valuable because more accessible. Smaller masses occur near Horsetown and at several points on the plain northeast of Buckeye where lime has been burned, but since the Kennett locality has been opened they are of little importance.

TENNESSEE MARBLES.[a]

By Arthur Keith.

STRATIGRAPHY.

Beds of workable marble are found in a belt in the center of the valley of East Tennessee, extending nearly across the State. The general belt is composed of a number of nearly parallel bands or lines of outcrop of the marble formation. They were brought into their present attitudes during the folding of the strata of that region, and bear their present relations to the surface in accordance with the progress of erosion of the rock materials. The exposures of the marble are to be seen in the following counties, beginning at the northeast: Hawkins, Hancock, Hamblen, Grainger, Claiborne, Union, Knox, Sevier, Blount, Roane, Loudon, Monroe, and McMinn.

All of the marble is found in the strata of Silurian age, much the greater part of it in the Chickamauga limestone. On account of the prominence and extent of the marble in that formation near Holston River, it has been called "Holston" marble in the folios of the United States Geological Survey. A considerable development of marble is also seen in the lower portion of the Sevier shale in Sevier, Knox, Blount, and Monroe counties. Practically all the quarrying has been done in the Chickamauga limestone, although in Knox and Blount counties some of the higher beds have also been used to a small extent.

In the lower part of the Chickamauga formation are many beds of more or less coarsely crystalline marble. These do not appear, except in a most local way, northwest of the synclinal fold from which Clinch Mountain rises. In that syncline and southward, however, marble is usually well developed in all the areas of the formation. It is from 600 to 650 feet thick near Clinch Mountain and thins in all directions from that area. Its average thickness is 300 to 400 feet, where well developed. The position of the marble beds in the limestone varies much from place to place. Usually there is a considerable thickness of blue and gray limestone below the marble; north of Clinch Mountain, however, this is not the case, as the marble beds are thicker and rest directly upon the Knox dolomite. The same condition was observed on the south side of Black Oak Ridge.

[a] A résumé of material presented in folios of the Geologic Atlas of the United States.

The marble differs from most of the rocks of the formation in being coarsely crystalline. It may have been altered after its formation by the passage of water through the rock, dissolving and recrystallizing the carbonate of lime, or it may have been deposited in its present form. The shaly parts containing less lime are not crystalline. The forms of the fossils inclosed in marble are plainly visible, although wholly recrystallized. The marble varies considerably in color, most of the rock, however, being of two types, a dark bluish gray and a variegated reddish brown or chocolate. Of these two varieties the latter or reddish marble is considerably more common. Both are extensively quarried for ornamental stone.

Workable beds are rarely over 50 feet thick, and usually in that thickness there is a combination of several varieties. Quarries far separated from one another have quite distinct series of beds, and each quarry has its special variety of marble. All marbles of this region are free from any siliceous impurity, and all of reasonable purity take a good polish and are unaffected by weather.

The total thickness of the marble beds is by no means available for commercial use. The rock must be of desirable color, must quarry in blocks of large size free from cracks or impure layers, and must be of fine, close texture.

The variations in all of these characters are due to differences in the sediment at the time of its deposition. Carbonate of lime, iron oxide, and clay were deposited together with shells of large and small mollusks. The firmness of the rock depends upon a large proportion of the lime, while the dark, rich colors are due to the oxide of iron; but if the latter be present with clay in large proportion the rock becomes a worthless shale. The colors vary from cream, yellow, brown, chocolate, red, and pink to blue, in endless variety. Absence of iron oxide results in gray, grayish white, and white. The colors are either scattered uniformly through the rock or are collected into separate crystals or patches of crystals; forms such as fossils are usually of pure, white calcite. The curious and fantastic arrangement of the colors is one of the chief beauties of these marbles. Like the shaly matter, the iron oxide is an impurity, and the two are apt to accompany each other. The most prized rock, therefore, is a balance between the pure and impure, and slight changes in the form of sediment result in deterioration or better quality. Such changes are common in most sediments and must be expected in quarrying the marble. Not only may a good bed become poor, but a poor bed may develop into good marble.

Tests for absorption of water show a high resistance in the better grades of marble, and the rock is very well fitted for withstanding weather. Its crushing strength is also very high in the purer layers. Tests of a number of samples gave an average strength of 16,000 pounds per square inch.

The nature and associations of this marble are subject to great variations. An instance of this is the disappearance of red marble northeast of Thorn Hill in the belt running north of Clinch Mountain, its place being taken by blue and gray marbles. These latter beds are of good body, but lack the most prized color. More marked changes are seen in the disappearance of the massive marble and the increase of shale in the same belt after it passes southwest from Luttrell. Similar changes are seen east and south of McMillan and Strawberry Plains. The position of the marble in the Chickamauga limestone also varies. Near the northeast end of Black Oak Ridge, and also northeast from Luttrell, the Chickamauga limestone appears only above the marble. Along Holston River, however, the limestone appears only below the marble, above the latter being the Tellico sandstone. In other places the marble occupies an intermediate position. In the next basin north of the Clinch syncline no marble appears except northeast of Maynardville, where some unimportant beds of gray marble occur. North and west of this no marble has been observed, nor does any of consequence occur along the southern border of the Maynardville quadrangle.

The marble above the Tellico sandstone in the base of the Sevier shale is comparatively thin and shaly. Occasionally, however, a local thickening takes place and the beds resemble the Holston marble in all respects. This is notably the case in the area of Sevier shale extending southwest from Strawberry Plains past Knoxville. The Sevier marble beds are much more variable than those of the Chickamauga, and there is a smaller amount of workable material in them; consequently they have not been successfully quarried.

Other variations in the marble are shown in the disappearance of good marble for a few miles in the belt running through the northern portion of Knoxville. The belt which is productive south of Knoxville becomes of minor importance 8 miles northeast of Knoxville; and the bed at the bottom of the Sevier shale is the productive one in that locality. These latter marbles in the region of Knoxville are usually shaly and of less value, although they contain many beds of good body and color. Workable beds are rarely over 10 feet thick, and usually there are several varieties in close proximity.

Southwest of Knoxville the Holston marble varies in similar fashion. It disappears in the belt northwest of Madisonville and shifts downward into the beds next to the Knox dolomite at Marble Bluff, west of Loudon. As a rule, however, the marble in this region remains very constantly in the upper part of the Chickamauga limestone. The different belts continue southwestward to the vicinity of Sweetwater. They then disappear rather abruptly and are not found in areas farther southwest.

The marbles of the Sevier shale are prominent at the bottom of that formation, but occasionally occur in the upper strata as well. They are similar to the Chickamauga marbles, but usually have not such rich colors, being oftenest of a gray color; and they contain more shaly beds. The belts passing south of Loudon and Louisville have this marble more highly developed than the other belts. It has been quarried only in the southeastern belt, near Mountainville, and farther southward at the Tellico River, and its beds are not now worked, for want of transportation facilities. These marbles extend a little farther southwest than the Holston marble.

QUARRY LOCATIONS.

Owing to the soluble nature of the pure marble, it is either completely unaltered and fresh or it is entirely reduced to red clay. The best marbles, therefore, are nearly as solid at the surface as at great depths. Marbles which are shaly at the surface become less weathered in going down, and appear solid; but when these are sawed and exposed to the weather their inferiority appears in splits along the argillaceous seams and in cracks through the thicker masses. Solution of the pure beds has produced holes and caves down to the adjacent stream levels. Through these openings the quarrymen attack the rock more easily, but much valuable stone has been lost by solution.

The available localities for quarrying are limited in part by the attitude of the marble beds. At the northeast end of the marble belt the best situations are those just north and northwest of Rogersville, where the strata dip at a high angle and there is little stripping to be done. Here the location of the marble, well above drainage, is an added advantage. In the areas north of Clinch Mountain the dip is such as to carry the marble beneath the surface with narrow outcrops, but is not steep enough to avoid considerable stripping.

In the same belt southwest of Clinch Mountain the dip is usually steep, so that the amount of earth to be stripped is not great. Near Holston River, owing to the recent cutting of the streams, the marble is usually at some distance above the water level. In the more northern areas, where the streams have not cut their valleys deeply, the marble usually occupies the lowest portions of the valleys, being the most soluble of the formations, and the drainage of the quarry becomes an important problem. This is also the case even in areas well above drainage level, when springs and underground streams are encountered, as frequently happens.

The best situations are those in the belt immediately south of Knoxville, where the strata dip at small angles and cover a greater surface. Most of the marble is well above the drainage level. Similar advantages of dip favor the belt 5 miles northwest of Knoxville. In most of the areas of marble southeast of Knoxville the beds are more folded and dip at greater angles, so that prolonged quarrying will necessitate a great deal of stripping and deep cutting.

In the extension of the marbles southwest of Knoxville fine quarry sites are to be found 10 or 12 miles from Knoxville. In that vicinity the strata dip at small angles and cover a great surface. Conditions of drainage are also excellent there. In most of the other areas of marble the beds are more folded and dip at greater angles, so that prolonged quarrying will necessitate a great deal of stripping. Also, in districts far from the Tennessee River, the marble is likely to be in low ground, so that quarries would be near the drainage level. At present the great bulk of marble quarried comes from the vicinity of Knoxville. It is here well situated with respect to transportation over different railroads, besides being of the best quality. Good marble exists in immense quantities, however, in the other regions, and will become available as more favorable places are exhausted, as new means of transportation are found, or as the fashion in color changes.

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CEMENTS.

During the forthcoming field season all the important cement plants in the country will be visited, and a report on the cement industry in the United States will be published by the Survey.

In addition to the paper presented below, a discussion of slag cements will be found on pages 221 to 223 of the present bulletin; while the manufacture of Portland cement from slag is discussed on pages 223 to 224.

CEMENT INVESTIGATIONS IN ARIZONA.

By EDWARD DURYEE.

INTRODUCTION.

Investigations were made under instructions from Mr. J. B. Lippincott, of the U. S. Geological Survey, in order to ascertain means of lessening the cost of Portland cement in the construction of dams on the Gila River in Arizona. Owing to the remoteness of these proposed dams from lines of transportation, the expense of bringing cement to the sites makes a notable addition to the cost over construction elsewhere, and it is therefore of great importance to reduce the quantity of cement to the smallest allowable amount.

Portland cement is considered an essential element in the construction of dams subject to severe and sudden strains due to floods. It is valuable not only in giving great strength and homogeneity to the structure, but also because of the fact that exposure to moisture, which deteriorates many materials, serves to increase the strength of Portland-cement mortars. It is thus being largely used for this purpose. For example, the new dam under construction on the Nile at Assuan will require 3,000,000 barrels of Portland cement, costing, in round numbers, $12,000,000.

The investigation of cement for the Gila River dams has been along three lines: (1) To ascertain whether by unusually fine grinding of the cement its strength can be appreciably enhanced and the quantity correspondingly reduced; (2) whether it is feasible to use the rocks found at the dam sites for making a sand cement; (3) whether Portland cement can be economically made at these sites.

SAND CEMENT.

Sand cement is a term applied to a mixture of cement and sand ground together in a dry state to an impalpable powder. As a rule Portland cement and quartz sand are the materials thus used. This mixture is then used with ordinary sand and gravel, as in the customary practice. The proportion of pure cement is thus considerably reduced, but the strength and durability of the concrete has been found to be nearly as great as that made with the undiluted cement. The explanation offered for the remarkably good results obtained with sand cement when used with ordinary coarse sand is that the voids in the coarse sand are nearly filled with the finely ground sand. The grains are thus bonded together and to the coarse sand by the uniformly diffused particles of the fine cement. The amount of voids in the ordinary sand, in other words, is greatly reduced by the fine sand, fulfilling the requirement for a strong mortar that must be of dense character, the grains being of such graduated size and so well mingled as to afford the maximum contact of the surfaces of the particles.

In sand-cement mortar the grains of sand are extremely minute, the mixture being so fine that only 5 per cent residue is left on a screen of 200 meshes to the linear inch or 40,000 meshes to the square inch. The great density thus obtained contributes to the impermeability to water and increases the compressive strength and load-bearing capacity, thus rendering the mass of value for constructing foundations, dams, and sea walls.

In the tests made in this investigation a rock known as pearlite, an acidic lava or rhyolite from the Buttes dam site, was used, and also samples of quartzite from the San Carlos dam site. These were chosen because of the abundance of these rocks at the localities named and their superior hardness. The Portland cement used was that manufactured at Colton, Cal., this being made nearest to the place where it will be used and being sold at a lower price than other Portland cement in the local market. All of the tests were made with the same sample of cement, portions of this being taken for the several mixtures with crushed pearlite and quartzite. The sand used with the foreign cement in making sand cement was clean beach sand from dunes along the coast.

TESTS OF SAND CEMENTS.

Results of the tests of the sand cements and comparisons with other mixtures are given in the following table. In each case the crushed pearlite was mixed with an equal weight of cement, and the mixture was ground in a mortar until it all passed through a screen having 200 meshes to the linear inch. The same method was pursued with the quartzite from San Carlos, thus making sand cements composed of equal parts of Portland cement and pulverized rock ground to an exceedingly fine condition.

The coarse sand used in making the mortar with the sand cement and with the pure (Portland) Colton cement was of the ordinary grade of fineness used for making cement tests. It was screened from ordinary gravel, all residue on the 20-mesh screen being rejected and all left on the 30-mesh screen being retained.

The briquettes for testing were made according to the specifications recommended by the American Society of Civil Engineers. After the briquettes were made they were kept under a damp cloth for twenty-four hours, then placed in vats of water, where they were left until the time for breaking arrived, namely, seven days or twenty-eight days. The fine grinding and diluting of the Portland cement with fine sand did not materially affect the time of hardening or setting. The beginning of the setting process of the ordinary Colton cement mortar, or initial setting, was thirty-three minutes, and the time of final setting was eighty-five minutes. This applies to samples Nos. 3, 4, and 9 of the following list. The corresponding periods for the sand cement were thirty and eighty minutes. The cement mortar continues to harden and increase in firmness for a year or longer.

Results of tests of Portland sand cements.

No.	Material.	Sand.	Portland cement to sand.	Fineness.			Water.	Strength.	
				50 mesh.	100 mesh.	200 mesh.		7 days.	28 days.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*
1	Colton and Buttes pearlite, 1 to 1	2	1 to 5	0.00	0.00	0.00	10	80	300
2	Colton and San Carlos quartzite, 1 to 1	2	1 to 5	.00	.00	.00	10	90	345
3	Colton, regular	2	1 to 2	.42	7.20	33.20	10	170	385
4	....do	3	1 to 3	.42	7.20	33.20	10	140	240
5	Colton, fine ground	2	1 to 2	.00	.00	(*a*)	12	370	465
6	....do	3	1 to 3	.00	.00	(*a*)	12	170	260
7	Colton and Butte pearlite, 1 to 1	3	1 to 7	.00	.00	.00	10	75	155
8	Colton and San Carlos quartzite, 1 to 1	3	1 to 7	.00	.00	.00	10	55	185
9	Colton, regular	0	1 to 0	.42	7.20	33.20	18	615	660
10	Imported	0	1 to 0	.80	7.80	29.33	18	345	525
11	Imported and sand, 1 to 1	2	1 to 5	.00	.00	.00	10	115	190
12	....do	2	1 to 5	.00	.00	(*a*)	10	125	185
13	....do	3	1 to 7	.00	.00	(*a*)	10	55	90
14	....do	3	1 to 7	.00	.00	.00	10	90	140
15	Imported, regular	2	1 to 2	.80	7.80	29.33	10	210	270
16	....do	3	1 to 3	.80	7.80	29.33	10	120	175

a Some left on 200-mesh screen.

NOTE.—The above cement stood the boiling test for free lime satisfactorily.

Comparison of test No. 3 with No. 5, and of No. 4 with No. 6, shows that increased fineness of grinding very materially increases the strength and sand-carrying capacity of cements. The ordinary Colton cement of tests No. 3 and No. 4 was ground finer than commercial Portland is usually ground. Recent improvements in mills for grinding render possible a reduction in size of cement grains at a cost which is small when compared with the great increase in the value of the resulting material. Where the freight charges are high, as is the case at the locations under consideration, it is especially important to take advantage of this improvement, and there is no doubt that if the specifications call for a fineness such that only 1 per cent is to be left on a 100-mesh screen, the manufacturers will respond to the requirements. Engineering specifications have ordinarily allowed a residue of 5 per cent on a 50-mesh screen, although manufacturers have for some years permitted a residue of only 1 or 2 per cent on a 50-mesh screen.

CRUSHING TESTS.

In order to obtain the crushing strength of the various cements and concrete considered, two 1-inch cubes of each were broken. The results given are the averages of the crushing strength of the two cubes. The cubes were allowed to remain thirty days in water and then thirty days in the air.

Crushing tests of 1-inch cubes.

Character of mixture.	Water.	Average crushing strength.
	Per cent.	*Tons.*
Standard Colton cement	18	3.25
Colton cement, 1 part, and ordinary testing sand, 2 parts	8	1.75
Colton cement, 1 part, and marble sand, 2 parts	8	2.38

Crushing tests were also made of 6-inch cubes of concrete after these had been immersed for thirty days in water. The portions of the mixture and the breaking strain in tons are given in the following table. In the mixture the proportions are given by volume and not by weight.

Crushing tests of 6-inch cubes.

Character of mixture.	Breaking strength.
	Tons.
Colton cement, 1 part; ordinary sand, 3 parts; pebbles from gravel, 6 parts	38
Colton cement, 1 part; sand, 3 parts; crushed marble, 6 parts	30
Colton cement, 1 part; sand, 2 parts; crushed marble, 5 parts	20

It is believed that concretes of approximately equal value can be obtained by using cements in the following proportions, measured by volume:

Portland cement, 1; sand, 3; broken stone, 7.
Sand cement, 1; sand, 2; broken stone, 6,

COST OF SAND CEMENTS.

In the Portland-cement concrete made in the proportion of cement 1 part, sand 3 parts, and broken stone 7 parts, it has been found that 270 pounds of cement will be required for a cubic yard of concrete. This, at 2.12 cents per pound, will cost $5.72 per cubic yard.

In the sand-cement concrete of the proportions 1 cement, 2 sand, and 6 stone, 340 pounds of cement would be required for each cubic yard of concrete. This, at 1.2 cents per pound, would cost $4.08.

The saving in the cost of cement to be effected by using sand cement instead of the Colton Portland will be the difference between $5.72 and $4.08, or $1.64 per cubic yard of this concrete entering into the construction of the dam. From the total saving thus realized should, however, be deducted the cost of the plant required for grinding the sand cement.

Concrete blocks composed of the above proportions were crushed at McGill University in 1898, with the following results:

Sand cement, 1; sand, 2; broken stone, 6; water, 20 per cent.

Weight per cubic foot, 154 pounds. Crushing load, in pounds per square inch: Seven days, 521 pounds; twenty-eight days, 639 pounds; sixty days, 670 pounds.

A concrete of German Portland of the proportions of 1 cement, 2 sand, 6 broken stone, and 20 per cent water stood a load of 728 pounds per square inch in twenty-eight days, and one of the same proportions made from English Portland stood 698 pounds in twenty-eight days.

Tests for crushing strength on 6-inch cubes of concrete, made of 1 part sand cement, 2 sand, and 3 parts gravel, were made on concrete that was taken from the bucket just as it was ready to be laid in the foundation of the Cathedral of St. John the Divine, in New York City. Each result is the average of the crushing strength of four separate cubes, made under exactly the same conditions at different periods:

	Pounds.
7 days old crushed at	77,162
14 days old crushed at	83,225
30 days old crushed at	92,465

Approximate cost of plant for making sand cement; capacity, 240 barrels per twenty-four hours.

Crusher (required also for crushing rock for concrete)	$2,000.00
Mill for coarse grinding	2,000.00
Tube mill for finishing	2,500.00
Engine and boiler	1,500.00
Setting up machinery	1,000.00
Buildings and bins	1,000.00
Total	10,000.00
Cost of mill per barrel of cement	.20
Add, for concrete making, a power mixing machine	1,500.00

In making concrete, if a good quality of stone be used and the rock be crushed so as to be well graduated as to sizes, thus securing a minimum of voids, the compressive strength of the concrete increases as the proportion of stone increases and as the volume of voids between the stone decreases, and decreases as the proportion of sand in the mortar increases. The rule, therefore, holds: to secure the greatest strength mix the maximum quantity of stone with a minimum of sand mortar sufficient to bond the stone together, the sand mortar being rich in cement. An extensive bed of exceptionally good sand for mortar was found near the Buttes, the grains graduating in size from very small to large sizes. It shows only 35 per cent of voids, while the standard cement-testing sand used in laboratories has 45 per cent of voids.

A large tube mill will grind 10 barrels of sand cement per hour to the requisite degree of fineness, at an estimated cost of 20 cents per barrel. The cost of power for grinding is calculated at 3 cents per horsepower per hour at the dam site.

Cost of sand cement with Portland cement at $8 per barrel.

One-half barrel Portland	$4.00
One-half barrel crushed and coarse-ground quartzite	.18
Grinding same in a tube mill	.20
Royalty on account of sand-cement patent	.05
Total cost of sand cement per barrel (375 pounds)	4.43

The cost of sand cement per pound, quartzite being used as the source of the sand cement, would therefore be 1.2 cents.

The cost of the mill per barrel of cement, 20 cents, is not included in the above.

It is estimated that the cost per barrel of Colton Portla cement delivered at the dam site will be $8. This, for 375 pounds weight cement, would make the cement cost 2.12 cents per pound.

USE OF ROCKS AT THE DAM SITES.

For the purpose of ascertaining whether the rocks at the dam sites could be used in the manufacture of Portland cement the localities were visited and samples were obtained of those rocks which occurred in sufficient quantities to furnish the supply necessary for manufacturing the large amounts of cement needed. In looking for the raw materials it must be borne in mind that, chemically considered, Portland cement consists of a compound of tricalcium silicate and dicalcium aluminate, accompanied by small percentages of ferrate and sulphate of lime and traces of alkalies. It is made by grinding and burning together either natural or artificial mixtures of carbonate of lime and silicate of alumina. Limestones, chalks, or marls usually furnish the carbonate of lime, and clays are the ordinary source of the alumina and silica. The mixtures are burned at a high temperature to a blackish clinker of a semivitrified character. After cooling, this clinker is reduced by grinding to an impalpable powder, in which form it is known by the generic name of Portland cement.

ROCKS AT RIVERSIDE DAM SITE.

Limestone (No. 3 in the following table) was obtained near Riverside, on the road to the Pioneer mill, where it is found in large quantities along the roadside. The rhyolite (No. 4 in the following table) was found 2 miles south of the Riverside site. It offered the closest approach to a suitable silicate of alumina that could be found.

The source of elements of silica and alumina in the crude materials should, however, be sedimentary in character, not igneous or metamorphic. The analysis justified a trial mixture, and therefore one was calculated and made, but on burning the materials failed to effect the requisite combination for a Portland cement. Too large a percentage of the silica was in the free or uncombined condition. Fuel was not to be found near the Riverside site, and the manufacture of cement at this place is considered impracticable.

ROCKS AT SAN CARLOS DAM SITE.

The limestone from San Carlos site (No. 2 in the following table) was found to be admirably adapted to the purpose of the dam construction on account of its good specific gravity (which was 2.7), freedom from flaws, and siliceous character. It occurs in vast quantities, forming the abutments of the dam site. It forms bluffs, extending for several hundred feet, well located for quarrying. Large masses may be embedded in the concrete, care being taken that they be laid irregularly in the mass of the dam, and are well placed so as to bond into a monolith.

Analyses of rocks from the vicinity of the dam sites.

[Chemical composition, in percentages.]

No.	Name.	Color.	Locality.	Sp. gr.	Carbonate of lime, $CaCO_3$.	Carbonate of magnesia.	Silica (SiO_2).	Alumina and ferric oxide.	Moisture.	Lime per cent in the carbonate of lime.
1	Limestone	Gray	San Carlos		96.65	0.00	1.4	1.3	0.65	54.124
2	do	Pink	do	2.709	55.92	31.00	3.7	6.0	1.00	31.315
3	do	Blue	Riverside		93.10	0.00	4.7	1.4		52.136
4	Rhyolite	White	do	1.541	9.60		60.9	12.6	16.90	5.376
5	do	Pearl	Buttes	2.361						
6	Limestone	Blue	Queen Creek[a]	2.81	90.10	0.00	4.1	5.8		
7	do	Gray	do	2.678	55.50	0.00	34.6	1.3		31.08

[a] From about 1½ miles above dam site.

The analysis of the gray or bluish limestone (No. 1 in the above table) shows from its freedom from magnesia and the small percentage of free silica that it is possible to make a Portland cement with it, provided a suitable clay can be found to furnish the requisite elements of silica, alumina, and ferric oxide.

FUEL.

An extensive but undeveloped deposit of bituminous coal is located about 17 miles from the San Carlos dam site. There is a wagon trail to within about 6 miles of the coal beds, but after leaving the wagon trail the only means of access was found to be a bridle path over the hills. About ten years ago numerous prospectors' locations were made in the district, and shafts were sunk at a sufficient number of localities to prove the deposit to be of considerable extent. Most of the shafts have become filled with débris, but several were entered to depths of 15 to 30 feet. They showed the body of coal to be in beds having a dip of about 60°, the beds being from 5 to 10 feet in thickness, not of solid fuel, but showing seams of good coal interlaid with seams of slate and waste. In the bottom of the deepest shafts was found a good body of coal in a solid bed perhaps 5 feet thick. It was reported that at the time the prospecting was done on the claims some 30 tons were transported by wagons to the Southern Pacific Railroad and used in the locomotives, but that the cost of mining and transporting it to the railroad, with the crude means available at the time, was about $20 per ton.

Cement could be burned with the coal. The right to mine the coal for the use of the Government in this work could be secured readily and at a nominal cost. The cost of mining and transportation to San Carlos would, however, be high. In general practice 120 pounds of coal dust are used in burning 1 barrel of Portland cement.

Taking as a basis coal delivered at the dam site at $10 per ton, limestone at 40 cents per ton, and clay at $1.25 per ton, the cost of manufacturing Portland cement at the dam site would approximate $2.75 per barrel. The cost of erecting a plant with an output of 300 barrels of cement every twenty-four hours would be $75,000. Supposing the amount of cement to be required in the construction of the dam to be 50,000 barrels, the cost per barrel, if made at the site, would be approximately as follows: First cost of plant, $75,000; cost of manufacturing 50,000 barrels, at $2.75, $137,500; total cost, $212,500; cost per barrel, $4.25.

With reference to the degree of reliability to be placed upon Portland cement made in new localities, it may be said that the manufacture of this material has been put upon a scientific basis, such that the manufacturing chemist can predict the grade of cement to be made from the given materials, and, by means of analyses of various rocks, can calculate suitable mixtures to produce the required result. The uniform system of testing cements recommended by the American Society of Civil Engineers affords a reliable means of determining the intrinsic merits of the product. The old method of buying cements on the reputation of the maker has been succeeded by tests for determining the actual value. Portland cements of American make are being extensively manufactured and are of equal or even superior quality to the foreign-made cements. During the year 1899 it is estimated that 6,000,000 barrels of Portland cement have been used, of which four-fifths were of home manufacture. In spite of this fact, on account of the failure to find suitable clays at the various localities and also the difficulty of obtaining fuel, it is impracticable to manufacture Portland cement at the dam sites.

It is important, if Portland cement is used at the localities under consideration, that the specifications should require it to be ground so fine that not over 1 per cent residue shall remain on a 100-mesh screen.

Reliable sand cement can be made from the quartzite at San Carlos or the pearlite at the Buttes dam site by grinding with Colton (Portland) cement. A saving will result at the San Carlos dam site of $1.64 per cubic yard by making sand cement on the ground, this being exclusive of the cost of the plant for grinding.

PUBLICATIONS ON CEMENTS.

The following list includes the principal publications by the United States Geological Survey, or by members of its staff, on cementing materials.

CUMMINGS, U. American rock cement. A series of annual articles on natural cements, appearing in the volumes of the Mineral Resources, U. S., previous to that for 1901.

ECKEL, E. C. Slag cement in Alabama. In Mineral Resources for 1900, pp. 747–748. 1901.

——— The manufacture of slag cement. In Mineral Industry, Vol. X, pp. 84–95. 1902.

NEWBERRY, S. B. Portland cement. A series of annual articles on Portland cements, appearing in the various volumes of the Mineral Resources, U. S., previous to that for 1901.

RUSSELL, I. C. The Portland cement industry in Michigan. In Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 629–686. 1902.

TAFF, J. A. Chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements. In Twenty-second Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 687–742. 1902.

CLAYS AND FULLER'S EARTH.

The clays of the eastern United States will be the subject of a bulletin to be issued by the United States Geological Survey during the present year. Owing to its comprehensive character, no abstract of this important work has been attempted for the present publication. The results of recent field work by the Survey on the clays of western Tennessee and northwestern Mississippi, and on the fuller's-earth deposits of Florida and Georgia, are given in the following papers:

STONEWARE AND BRICK CLAYS OF WESTERN TENNESSEE AND NORTHWESTERN MISSISSIPPI.

By Edwin C. Eckel.

INTRODUCTION.

A preliminary report on the clay resources and industries of this region is here presented. Owing to the short time available for the field work, the writer's investigations were practically confined to an examination of the stoneware clays of the area. A few plants making common brick were visited, and notes on this industry have been appended.

STONEWARE CLAYS AND MANUFACTURE.

The stoneware clays of the region under discussion appear at the surface of a belt of country averaging 10 miles or more in width and extending from Holly Springs, Miss., through Grand Junction, Jackson, and Paris, Tenn., into Kentucky. No field work was done on these clays south of Holly Springs or north of the Kentucky-Tennessee line, though the clays are known to be of economic importance both south and north of these limits.

The age of the clays has been discussed by Safford, Hilgard, Loughridge, Smith, and McGee, the principal question at issue being whether or not they are to be included in the Lafayette. While the work of the present writer can not be regarded as conclusive, certain facts of interest have been developed. As described by McGee, the series shown in this area, from the top downward, is as follows:

1. Columbia brown loam.
2. Lafayette orange sands.
3. Lafayette (stoneware) clays.

There seems to be no doubt about the order of this series, but from the examination of a large number of exposures it would seem probable that a very marked geologic break occurs between the orange sands and the stoneware clays. The stoneware clays are normally accompanied by and interbedded with a series of fine white and light yellow sands, commonly very thinly and evenly bedded. At a few pits the contact between the clays (and interbedded sands) and the orange sands of the Lafayette seemed regular and conformable, but in most places, notably near Grand Junction, very marked erosion appears to have taken place before the deposition of the orange sands.

A few of the pits visited near Pinson and Paris seem to have penetrated to a horizon lower than that of the stoneware clays. The pits in question produce a very dark, lignitic clay, used in places as a ball clay. It seems probable that these dark-colored ball clays are of Lignitic (Tertiary) age.

The clays used in the stoneware industry are in general obtainable in clean masses, free from (extraneous) sand and gravel. So far as known no mechanical analyses of these clays have been made, so that it can not be ascertained just how much of their silica is really present as fine sand and chert. The fusing point of the clays is very high, and is proved by the fact that most of the potteries use, in addition to the usual Albany slip clay, slip clay from Seneca Falls, N. Y., or slips made up from feldspar and quartz. As both these latter fuse only at a high temperature, their use proves the relative infusibility of the stoneware clays.

Many improvements in the stoneware industry in this district are possible. First of all, the method—or lack of method— in excavating is very wasteful and extravagant. By systematic work all the clay in the banks could be extracted, and that at a lower cost per ton than now obtains. In some cases observed the selection of spots in which to work is left entirely to the caprice of the negroes who do the digging, and in consequence the area is covered with small pits. As soon as these become inconveniently deep another excavation is started in another place. The stripping, when there is any, is thrown carelessly to one side, thereby covering up and rendering useless a certain amount of clay.

In the second place, it would seem advisable to season the clays somewhat, instead of sending them direct from the pit to the mill. By a little extra care, which might necessitate supervision of the negroes working the clay pits, the average quality of the material sent to the mill could be raised. Frequently the mixture of clays from different pits would greatly improve the product. Finally, it would seem advisable to push the fire-brick industry in every possible way. At present this product is manufactured on a very small scale, and little attention is devoted to the technology of the subject. It seems probable that it is in this direction, rather than in the line of stoneware, that the clay industry of the district will progress.

The clay pits and stoneware plants visited will be described in order, from those near Holly Springs, Miss., at the south, to those near Paris, Tenn., at the north.

HOLLY SPRINGS, MARSHALL COUNTY, MISS.

The plant of the Holly Springs Stoneware and Firebrick Company is located near the tracks of the Kansas City, Memphis and Birmingham Railroad, and within 100 yards of the station. Little fire brick is made, the principal product being stoneware. The clay used at this plant is obtained from the pits described below. On arrival at the works it is ground, after the addition of sufficient water, in a "chaser mill" (i. e., edge-runner mill), no seasoning at all being given the clay. Four kilns are in use, two downdraft and two updraft, the former having been, of course, installed at a later date than the latter. Eighteen hands are employed in the plant, four of whom are potters; and the product of the establishment is about 8,000 "gallons" of stoneware per week. Two slips are used. One is the usual Albany slip clay, which gives a brown glaze, the other a slip made up of "flint" (pulverized quartz) and "spar" (pulverized feldspar), both the ingredients being purchased at East St. Louis.

The clay pits of this firm are in two widely separated groups, located 2½ miles west and 1 mile east of the railroad station.

The west pits furnish the best grade of clay. About 65 acres of land are owned (on which these west pits are located). Of this area about 10 acres have been worked in the usual fashion.

The usual size of these pits is 8 to 10 feet in depth, with an area of from 4 by 6 to 8 by 15 feet. One negro with one team of horses does the hauling. Three trips a day can be made.

No Lafayette (orange-red sands) was in this area. A typical pit showed from the top downward—

	Feet.
Clayey and sandy soil	3
Yellow sand and clay in alternate 2–4 inch bands	3
Gray clay	6

The eastern pits, located a mile east of the station, show (in pits and gullies) about 20 feet of clay, with much interlamination of white and yellow sands. Six trips per day can be made to these pits.

Peyton Allison runs a small pottery, with one updraft kiln, about one-half mile east of the station, obtaining his clay from very near the east pits of the preceding firm.

GRAND JUNCTION, HARDEMAN COUNTY, TENN.

The plant of the Grand Junction Pottery Company, controlled by Mr. W. T. Follis, is located near the station. Clay is bought from various pits in the vicinity and manufactured mostly into stoneware, though fire brick is occasionally made. One downdraft kiln, with a capacity of 6,000 gallons of stoneware, is in use.

The Hancock pits are located three-fourths of a mile southwest of town, reaching for several hundred yards along both sides of the Illinois Central tracks. The clay begins to outcrop about 200 feet south of the Fayette-Hardeman county line, and the deposits therefore lie in Fayette County. These pits are worked occasionally to supply the local pottery noted above, but were idle at the time of visit. The clay is said to be the best obtainable near Grand Junction. The section shows orange-red sands above, belonging to the Lafayette formation. The lower 6 inches to 4 feet of these sands have been cemented into a conglomerate by infiltrating waters carrying iron. Below the sands is exposed 20 feet or more of clay, which is light gray on a fresh surface, but weathers, on exposure, to a chalky white. The clay contains no apparent partings of sand. At this point the top of the clay beds is just at the level of the railroad tracks.

The extensive pits of the Irwin Clay and Sand Company are located 1¼ miles east of the station, along the south side of the Southern Railway tracks. These pits were opened in April, 1901. Little has been done with the clay, but extensive shipments of sand have been made. The pits are about 60 feet below the track level, the material being brought up on an inclined tramway. Several small pits, filled with water at the time of visit, had been sunk below the level of the main excavation. The complete section from the top of the bank down, including the section reported as appearing in these small pits, is as follows:

Section of Irwin clay bank, Grand Junction, Tenn.

Red sand	40 feet (to top of bank).
White sand, evenly stratified	8 feet.
White clay	8 feet.
Gray, lignitic, clay	8 inches to 10 inches.
White clay	20 inches.
White sand	1 foot (to bottom of deepest pit).

The clay deposits, as seen at this extensive series of exposures, are very irregular, and apparently occur as overlapping lenses in the white and yellow sands. The overlying red sands of the Lafayette formation would seem to have been deposited after extensive erosion had taken place in the clay and white sand series.

Three-fourths of a mile west of Grand Junction station are located the clay pits of Mr. J. H. Prewitt, at a point about 200 yards north of the Southern Railway tracks. The clay is said to be of good quality, though carrying somewhat more iron than does that from the Hancock pits. The excavations are small, only about 10 feet or so of clay being shown. The clay is overlain immediately by a dull brown loam (Columbia formation), the red sands of the Lafayette being absent.

The Stinson pits are small openings located on the south side of the Southern Railway tracks, about one-half mile west of Grand Junction station. The clay is said to be as good, if not better, than that from the Prewitt pits.

Stoneware clays of the same general type as those described above are well exposed, and have been worked rather extensively, near Lagrange, 3 miles west of Grand Junction. About 5 miles east of Grand Junction, at Saulsbury, clay is also worked; but the material from this locality may be the dark-colored ball clay (of the Lignitic Tertiary), described later as occurring in a belt bordering the stoneware-clay region on the east and outcropping near Pinson and Paris, Tenn.

TOONE, HARDEMAN COUNTY, TENN.

A large pottery located at this point could not be visited during the course of field work, and no information concerning it was obtainable by correspondence.

PINSON, MADISON COUNTY, TENN.

A large pottery located near Pinson station is operated by Messrs. Robins and Henderson. The plant, which is run entirely by steam, is by far the best equipped that was seen on this trip. Fire brick, tiles, and stoneware are manufactured, and, to a small extent, common brick. The engine supplies about 35 horsepower to the plant. It should be recollected that usually part of the machinery is idle, as it is but rarely that both stoneware and fire brick are in process of manufacture.

The clay for stoneware passes through the following processes in order:

1. Crushing (crusher).
2. Grinding (wheel).
3. Turning (hand work, wheel run by steam).
4. Drying (on heater).
5. Burning.

The kiln used is down draft of the Stewart pattern, the rights being owned by the Stewart Patent Kiln Company, of Findlay, Ohio. The right to erect one kiln costs $100. It is fired entirely with wood. One burning requires about 15 cords, costing here about $1.50 per cord. The production of stoneware is about 2,500 gallons per day.

The same clay is used for fire brick, in which case it passes through the following machines:

1. Disintegrator.
2. Pug mill.
3. Brick machine.

The mixture used for fire brick is—

3 parts clay.
1 part white sand.
1 part sawdust.

The mixing is effected in the disintegrator. The brick machine requires 8 men to operate it, as follows: 2 "off-bearer," 1 "take off," 1 "cut-off," 3 "fill," 1 engineer. The product is about 30,000 fire brick or 35,000 common brick per day.

The slip clays used come from Albany, N. Y., and from Seneca Falls, N. Y. The Albany clay is of course often used alone, but the Seneca Falls slip is very hard to fuse, and in consequence Albany slip is usually added to it, the proportions of the mixture being one-third Seneca Falls, two-thirds Albany. The Seneca Falls slip costs somewhat more than the Albany clay. It is not so easy to dissolve as the Albany slip clay, but when dissolved covers the ware more evenly. When used alone it gives a beautiful bright olive glaze. Used in combination with Albany slip, it brightens the coloration of the latter and also gives a somewhat greenish tint.

The Robins & Henderson clay pits are located about 2½ miles southwest of Pinson. A considerable area of clay has been uncovered at this point, but the actual pits are not very large. The excavations show about 20 feet of light-yellow sand, underlain by 15 feet or more of white clay.

Three miles southwest of Pinson are the clay pits of Mr. R. M. Davis. The section could not be made out clearly, as the sides of the pits have been washed in and gullies cut by the rain. About 20 feet of white clay is shown, overlain by reddish sands, these latter containing little streaks of white sand.

The pits belonging to Mr. Henry Weiss are located about 200 yards from Davis's pits. The freshly exposed area is very small, as the overlying material has been washed down by the rain, and the section is therefore doubtful. Some clay from these pits has been shipped to the pottery at Memphis, and occasional shipments have been made to the Chattanooga potteries.

About 3½ miles southwest of Pinson are the pits of Mr. C. M. Morrow. These showed the most solid clay seen in the Pinson district. At the top of the pits are 2 feet or so of reddish-yellow weathered clay, overlying a very dark grayish-black clay, without grit or sand. Clay from these pits is now used in the pottery at Jackson, Tenn., as noted later.

As can be seen, the clay pits are all located southwest of Pinson, and from 2 to 4 miles distant from the station. On the way to the clay pits, sections were seen containing members not met with previously. They almost certainly belong to a series lower in horizon than the stoneware clays, but the exact relations were not determinable, as they were not seen anywhere in contact with the pottery clays, and no good maps or levels were available. The sections in question showed 6 feet of yellow, micaceous, slightly indurated sands, underlain by 5 feet of greenish-black sands, also micaceous and somewhat indurated. These latter pass downward into harder material, which is often trimmed with an ax or saw, and used as building stone. It is said to be a durable material, hardening on exposure. The clay shown at several of the pits was too dark in color, and too free from sand or grit, to resemble closely the typical stoneware clays. It seems probable that Morrow's pits at least are in the ball clays of the Lignitic (Tertiary).

JACKSON, MADISON COUNTY, TENN.

The plant of the Jackson Pottery Company is located near the intersection of the Mobile and Ohio and Nashville, Chattanooga and St. Louis railroads. Only stoneware is manufactured. The clay is ground in one mill, worked by two horses, the amount ground per day being $1\frac{1}{2}$ to 2 tons. One down-draft kiln is used, fired with Kentucky coal, and holding 5,000 gallons of ware. The clay used is a mixture, in equal parts, of clay from pits near Jackson and of that from Morrow's pits near Pinson. The slip used is from Albany, N. Y., and from East St. Louis, the latter being a "flint" and "spar" mixture.

The clay pits near Jackson, from which the Jackson Pottery Company procures its material, are located about 1 mile from Jackson along the road to Claybrook post-office. The section shown in these pits is as follows:

Red sands (Lafayette formation)	?
White sands	6 to 10 feet.
Yellow, red, gray, and whitish sands in irregular streaks	4 to 5 feet.
Clay	5 feet.
White sand	1 foot.
Clay	8 inches.
White sand for at least 1 foot; no deeper exploration.	

The 5-foot bed of clay is separated into layers 4 to 6 inches thick by thin partings of sand, which is cleaned off before loading. The contact here between the upper white sand and the red Lafayette appears to be conformable and very regular. These clays are poorer than those from Pinson, and can not be used without mixing with the latter.

HOLLOW ROCK, CARROLL COUNTY, TENN.

Clays from the vicinity of Hollow Rock are shipped to Nashville, Tenn. These pits, however, could not be reached during the field work.

HICO, CARROLL COUNTY, TENN.

Clay is now being dug from pits located about 3 miles southeast of McKenzie, and shipped from Hico station to potteries at Akron, Ohio; East Liverpool, Ohio, and Louisville, Ky.

M'KENZIE, CARROLL COUNTY, TENN.

A pottery located in this town is now shut down. The clay used when it was in operation was obtained from pits east of McKenzie.

HENRY, HENRY COUNTY, TENN.

A plant is now in process of erection at Henry. It is said that local clay will be used, and that the principal product will be fire brick.

PARIS, HENRY COUNTY, TENN.

J. T. Currier operates two potteries near Paris. The principal plant is located about 1½ miles east of Paris station. A two-horse pug mill is used for grinding the clay and is capable of tempering about 11,000 pounds a day. Three turners are employed. Two kilns are in operation—one, a down draft, 16 feet inside diameter, with a capacity of 3,000 gallons; the second a patent (Howard) kiln, with a capacity of 2,000 gallons of ware. (Seven pounds of clay are equivalent to 1 gallon of stoneware.) The down-draft kiln is fired with coal, taking 120 bushels; the Howard kiln uses wood, 5 cords being required. The slips used are Albany and a "flint" and "spar" mixture.

The second pottery is located about half a mile east of the other and employs two turners. One down-draft kiln, having a capacity of 2,000 gallons, is in use.

Currier's pits are located about 1 mile east of the principal pottery. The section shown there is—

Brown loam	2 to 3 feet.
Gravel	1 to 3 inches.
Sandy, yellowish clay	1 to 3 feet.
Grayish clay, not very uniform in color	5 feet.
No deeper excavation.	

I. Mandle (St. Louis, Mo.) has pits located about three-quarters of a mile east of the preceding, on the next road to the south. An area of about 60 feet by 50 feet has been opened up. The sections shown are as follows:

	Feet.
Section on east side of Mandle's pit:	
Reddish sands	2
Clay	4
Black clay, lignitic	1
Brown clay (ball clay)	5
Section on west side of Mandle's pit:	
Light-gray clay	15
Black clay	1
Ball clay	5

As will be seen from the above sections, whose bases are at the same level and only about 60 feet apart, the top beds are very irregular. The light-gray clay is shipped to East Liverpool, Ohio, being used for saggers, while the ball clay is shipped to the same potteries, being listed there as Tennessee ball clay No. 3.

It seems probable that Mandle's pits show the contact between the stoneware clay series and the Lignitic clays, and that the lower beds in Currier's pits may also belong in the Lignitic series. The geologic question is in this case of great practical importance, as the Lignitic clays are mostly as satisfactory for use as ball clays, and are therefore of considerably greater value than the stoneware clays.

BRICK CLAYS AND MANUFACTURE.

The brick clays and brick industry of the region were only examined incidentally, and the brief notes taken at several points are here inserted, not as being in any sense a complete discussion of the industry, but as calling attention to some of its interesting features.

JACKSON, MADISON COUNTY, TENN.

Four brickyards are in operation in the vicinity of Jackson. All of them were visited.

Charles Owen's yard is located three-quarters of a mile east of the court-house, on the Claybrook road. Both common and fire brick are manufactured—the former being a surficial deposit near the yard 1 foot to 5 feet thick; the latter from stoneware clay, obtained from pits near those of the Jackson Pottery Company.

The clay goes from the pits to an iron tempering wheel (C. W. Raymond's pattern), which is a vertical wheel revolving in a pit on a horizontal axle, and so arranged that its distance from the center of the pit is automatically changed gradually and regularly. It is run by two horses; the pit holds sufficient clay to make 8,000 bricks, which requires two to two and a half hours' grinding. Three of these wheel pits are in the yard, only one being in use at present. The bricks are hand molded on a molding table, as a stiff mud, three bricks to a mold. Two molding gangs were at work, each consisting of four men—1 bringing mud in wheelbarrow, 1 molding, 1 sanding molds, and 1 putting the bricks on racks. Each gang turns out 6,000 bricks a day. The bricks are dried on pallets in racks and require about two days to dry thoroughly. Two kilns are in use holding 300,000 and 400,000 bricks. The time required is one month to fill a kiln, two weeks to burn, two weeks to cool, one month to draw.

W. M. Payne's yard is located near the Union station (Mobile and Ohio Railroad and Illinois Central Railroad). Clay is obtained near yard and is about 2 feet in thickness. The bricks are made in an "Iron Quaker" brick machine (Wellington Machine Company, Wellington, Ohio). This machine requires nine persons to operate it—2 men feed machine from soaking pit, 1 strikes and dumps molds, 1 sands molds, 1 (boy) washes molds, 1 (boy) puts bricks on slats, and 3 carry slats to racks. The output of the machine is 16,000 bricks per day. The bricks are usually dried on racks; occasionally on the ground. One kiln is used, holding 160,000 bricks.

F. A. Williams's yard is located 1 mile west of Jackson. Surficial clay, nearly 4 feet thick, found near the yard, is used. A little fire brick is burned, for which stoneware clay is obtained from pits near those of the Jackson Pottery Company. Four tempering pits are in the yard; only one is in use at present, and that is equipped with a Raymond wheel. Each pit holds material for 6,000 bricks, and requires four hours' grinding. Bricks are hand molded by a molding gang, consisting of 5 persons, 1 wheeler, 1 molder, 2 "off-bearer" (carrying from table to rack), and 1 sand boy. A gang turns out 6,000 bricks per day. Fire brick and tiles are hand molded and burned like common bricks. Some of the fire brick is pressed. Two kilns are in use, each holding 270,000 bricks. Product per year, 15,000,000 common bricks; 100,000 fire bricks.

E. R. McCabe's yard is located opposite Jackson Pottery Company's plant. Surficial clay, 4 to 8 feet thick, is used. The bricks are made in a soft-mud machine (Jonathan Gregor's Sons Co.). Persons required for operations are—4 truckers, 1 mold sander, 1 striker, 1 dumper, 2 temperers, 1 sand boy and mold washer, 4 men at bank digging and loading, 3 cart boys, and 2 slat boys. The product is 25,000 bricks per day of eight hours.

HUMBOLDT, GIBSON COUNTY, TENN.

Two brickyards are located here, one of which is not operated at present. The other was visited.

W. H. McKnight's yard is located 1 mile east of station. Reddish surface clay, 3 feet thick, is obtained near the yard. Common brick is the only product. The clay is tempered by a Raymond wheel, and hand molded. All operations save burning are paid for by the thousand.

	Per thousand.
Molding, 1 man, at	$0.30
Wheeling, 1 man, at	.18
Tempering, 1 man, at	.18
Off-bearer, 2 men, at	.12
Wheeling to kiln, at	.20
Setting in kiln, at	.12½

The bricks are dried on racks. The kiln requires one-third cord of wood per thousand bricks.

FULLER'S EARTH DEPOSITS OF FLORIDA AND GEORGIA.

By T. Wayland Vaughan.

INTRODUCTION.

The first fuller's earth discovered in the United States was at Quincy, Fla., in 1893. Since 1896 details regarding new occurrences have annually appeared in the volume on Mineral Resources, published by the United States Geological Survey. A discussion of the Florida and Georgia deposits is given in the present paper.

Extensive deposits of fuller's earth occur in Decatur County, Ga., and in Gadsden, Leon, and Alachua counties, Fla. With the exception of the Alachua County deposits, they are all of Upper Oligocene age, and equivalent with the Alum Bluff beds.

DECATUR COUNTY, GA.

Lester property near Attapulgus.—The material occurs in the southern and eastern slopes of the hills 1½ miles west of Attapulgus, where Mr. J. D. Lester has sunk ten pits, nine of them being on the south side of the road from Attapulgus to Faceville, and on the west side of Sanborn (or Little Attapulgus) Creek, and the remaining one on the east side of that creek. Martin Mill Creek runs east across the area in which the nine pits have been dug, and cuts below the level of the fuller's-earth stratum. Three of the prospects are on the north side of the creek, and six are on the south side. The first three extend from the road to the creek. The distance between the outer prospects is about 700 yards. The distance across the prospects on the south side of the creek is about 400 yards. Fuller's earth was encountered in all the prospects. The thickness on the north side of the creek at the foot of the hill was 2½ feet; on the south side it varies from 3 to 9 feet.

Section in deepest pit on Lester property.

		Feet.
5. Soil and red clay	about	2
4. Blue clay	do	4
3. Grayish sand and fuller's earth	do	5
2. Fuller's earth	do	9
1. Whitish or bluish sand mixed with fuller's earth and containing a few poor fossils		1+

Thirty yards north of this pit, stratum No. 1 of the section given above was penetrated. It was 4 feet thick, and beneath it was blue clay mixed with fuller's earth.

Analyses of fuller's earth from mines of Mr. J. D. Lester, Attapulgus, Ga.

[Analyst, H. Ries.]

Constituent.	1.	2.
	Per cent.	*Per cent.*
Silica	55.90	57.26
Alumina	12.40	18.33
Ferric oxide	2.40	1.87
Lime	1.00	2.58
Magnesia	8.12	1.06
Water	10.50	9.40
Moisture	9.40	9.00
	99.72	99.50

Two practical tests gave the following results: "In the first, mineral oils were bleached very nearly to the standard shade. In the second, the material showed with cotton-seed oil very fair bleaching qualities, but still was not quite equal to the English material."

In the well bored at Mr. Lester's house on the hill the fuller's earth was struck at a depth of 42 feet. It was also found on property belonging to Mr. G. P. Wood, immediately south of Mr. Lester's.

Connell property, near Whigham.—A pit sunk 1 mile south of the house of Mr. R. A. Connell showed 6½ feet of fuller's earth, with 19½ feet of overburden. An auger boring in the creek bed near by showed 1 foot of fuller's earth and 10 feet of overburden. Other pits sunk on Sears and Wolffs creeks showed several feet of fuller's earth, with 5 to 8 feet of overburden.

Near Withlacoochee Creek.—A mine on the west side of Withlacoochee Creek, about one-fourth mile northeast of the Georgia-Florida State line, was opened by John Howard in 1896 or 1897 and sold to the Owl Commercial Company in the same year. There was from 4 to 8 feet overburden of soil, clay, and white or brownish sand, and immediately above the fuller's earth a layer of bluish or reddish sandy clay; then 2 feet, or a little more, of fuller's earth, underlain by whitish argillaceous sandstone. The bed is not constant in character. On the north side of the road there is a sand seam in the fuller's earth. On the east side of the creek there is an exposure in the roadside. The overburden has been removed from an area of about 50 feet square. Several carloads of material have been piled up and placed under a shed.

This fuller's earth has not been analyzed, but has been practically tested by Dr. Heinrich Ries. It is of the same quality as that from the land of Mr. J. D. McPhaul, NE. ¼ sec. 16, T. 3 N., R. 4 W., Gadsden County, Fla. These two samples, when tested with cotton-seed oil, were found to bleach it as well as the Sumter material which was prepared and sent to Charleston. When tested with crude petroleum it was found not to bleach it quite so well as the original Quincy material.

Ries states that the Sumter (S. C.) material bleached cotton-seed oil as well as English earth, and bleached petroleum practically as well as that from Quincy.

Cohn property near Attapulgus.—On Messrs. Cohn & Co.'s property fuller's earth occurs at a point 2 miles east of Mr. Getzlow's house. It is overlain by a few inches of soil and 2½ feet of clay, and is at least 4 feet thick.

Fuller's earth also occurs on land in the NE. ¼ sec. 8, and E. ½ sec. 5, T. 3 N., R. 3 W., in Florida. Mr. Mark W. Munroe is interested in this property and in lots in Georgia.

GADSDEN COUNTY, FLA.

Near River Junction.—Four miles southeast of River Junction is the mine formerly worked by Mr. Hymeson.

Section beginning at the top of the hill on the Hymeson property.

	Feet.
4. Surface sands, beneath which are reddish sands containing some quartz gravel	60
3. Stiff blue clay, the top of the fuller's earth deposit	4
2. Fuller's earth. A considerable amount of the overburden had been thrown off, but due to weathering and wash there is no really good exposure. Judging from what can now be seen, according to a roughly leveled section, it seems that the deposit is at least 8 feet thick, and it may be thicker. There is no means of determining its horizontal extent. A box of the earth was collected from the best exposure.	
1. Immediately beneath the fuller's earth there appears to be a deposit of sandy, very stiff blue clay. Thickness unknown.	

Generalized section near River Junction.

	Feet.
Surface sands	60
Clay and fuller's earth	10
Not exposed, but probably argillaceous sands	17
Chattahoochee chalk or limestone with some layers of marl about	88
The rocks beneath the Chattahoochee formation are not exposed near River Junction.	

The inference from this section apparently would be that the Chattahoochee limestone is 88+ feet in thickness, separated by 17 feet of unexposed strata from the deposit of fuller's earth, which would come above. This would stratigraphically correlate the deposit of fuller's earth with the Alum Bluff beds.

Dr. H. Ries analyzed and tested fuller's earth from this property, with the following results:

Analyses of fuller's earth from the Hymeson mine.

	Per cent.
Silica	59.00
Alumina	15.05
Ferric oxide	2.95
Lime	.20
Magnesia	3.70
Water	11.40
Moisture	7.80
Total	100.10

Fuller's earth from the Hymeson mine, 3 miles south of River Junction, the sample having been taken from the crusher at River Junction, Fla. This exerted only a moderate bleaching action on the cotton-seed oil, and would not bleach mineral oils very well.

Mr. William Bruce states that there is fuller's earth halfway between River Junction and the Hymeson mine, near the top of the hill, and also near Rockbluff, back from the bluff, in the ravines among the hills.

Mosquito Creek.—There is an exposure of fuller's earth on the south bank of Mosquito Creek, near the foot of a bluff, on land belonging to Mr. John D. McPhaul. The overburden is here too great for working. The deposit is along a small stream running north into Mosquito Creek in the NW. ¼ sec. 16, T. 3 N., R. 4 W.

A section in the pit shows overburden (sand), 4 feet; fuller's earth, 6 feet. The bed was not completely penetrated.

The following is an analysis by Dr. Heinrich Ries of fuller's earth from the NE. ¼ sec. 16, T. 3 N., R. 4 W., Gadsden County, Fla., from land of Mr. J. D. McPhaul:

Analysis of fuller's earth from the McPhaul property.

Constituent.	Per cent.	Per cent.
Silica	58.50	62.85
Alumina	14.30	15.36
Ferric oxide	2.10	2.25
Lime	1.30	1.39
Magnesia	6.50	6.98
Alkalies	1.80	1.93
Water and CO_2	9.5	10.20
Moisture	7.00	-------
	101.00	100.96

Dr. Ries remarks: "As the moisture content of this sample was so large I have in the second column given the analysis with the moisture deducted and the percentages recalculated on the basis of the remainder being 100 per cent."

The material was also exposed nearby in the bed of a creek. The slope down to the creek valley is gradual. A strip several hundred yards wide and probably half a mile long could be worked. Fuller's earth occurs also on the land of Mr. A. J. Key, in sec. 15, T. 3 N., R. 4 W.; and on the land of Mr. Elias Howell, in sec. 10, T. 3 N., R. 4 W., and extends along the creek about one-half mile below Mr. McPhaul's.

Dr. Ries states that this earth is very similar to that on Withlacoochee Creek, 8 miles north of Quincy. Both bleached cotton-seed oil as well as the Sumter, S. C., material, but did not bleach crude petroleum quite as well as the original Quincy material.

Near Quincy.—The following is a section through the fuller's earth at the Chesebrough Manufacturing Company's mine, 1 mile south of Quincy.

Section of Chesebrough Manufacturing Company's mine.

	Feet.
5. Overburden of clay and sands	7
4. Fuller's earth (average)	4
3. White argillaceous sandstone containing fossils	5
2. Fuller's earth	9
1. Soft sandstone, sand, and fuller's earth	15

It is estimated that there are about 10,000 tons to the acre. About 2 acres have been mined, and 20,000 tons were taken out. Mr. T. L. Ward states that operations began in 1895, and stopped in December, 1899, because the Standard Oil Company had sufficient earth on hand.

An examination of the section at the mine of the Owl Commercial Company where stripping is practiced showed the following section:

Section at mine of the Owl Commercial Company.

	Feet.
4. Overburden	5 to 20
3. Fuller's earth	6 to 10
2. Sandstone with crystals and lumps of calcite	3 to 4
1. Fuller's earth	5 to 6

Fuller's earth occurs along Quincy Creek, above the preceding mine, on land belonging to Mr. William Bruce, and also on the property of Messrs. Taussig & Wedeles. The fuller's earth here seems to be of good quality and about 8 feet thick; the overburden is 4 to 5 feet, and transportation is near at hand. Analyses and tests by Dr. Ries follow:

Analysis of fuller's earth from land of Messrs. Taussig & Wedeles.

	Per cent.
Silica	60.70
Alumina	14.10
Ferric oxide	2.40
Lime	1.65
Magnesia	2.08
Water	9.70
Moisture	9.30
Total	99.93

Sample from the land of Taussig and Wedeles, sec. 2, T. 2 N., R. 4 W. This did not bleach very well.

Analysis of fuller's earth from land of Mr. William Bruce.

	Per cent.
Silica	60.80
Alumina	15.45
Ferric oxide	1.95
Lime	1.60
Magnesia	3.12
Water	9.90
Moisture	6.90
Alkalies	.70
Total	100.42

Practical tests gave the following results: Its bleaching power on cotton-seed oil was but moderate. It bleached the petroleum to the standard shade adopted by the Standard Oil Company.

Near the residence of Mr. Carmen, who lives 4 miles east of Quincy, outcrops of fuller's earth occur along the creeks and in the hillsides. Seven miles east of Quincy are other outcrops.

LEON COUNTY, FLA.

Twelve miles west of Tallahassee, on property belonging to Messrs. W. H. Allen & Sons, fuller's earth occurs. Several pits have been sunk by Mr. Rosendale. The overburden is about 6 feet, and there are about 8 feet of fuller's earth. The land lies rather flat, along a small creek running into the Ochlockonee River.

The following gives the results of two practical tests by Dr. Ries:

(1) Sample of fuller's earth from the land of Mr. W. H. Allen, 12 miles west of Tallahassee. I was not able to make this bleach mineral oil, or at any rate the bleaching action was slight, although I tried twice.

(2) Sample of fuller's earth from 12 miles west of Tallahassee, on the land of Mr. W. H. Allen. This bleached the cotton-seed oil fairly well, but was not equal to the English material.

A section on the Seaboard Air Line Railway, about 1 mile east of Tallahassee, at milepost 163, shows the following exposures:

Section on Seaboard Air Line Railway.

3. The upper 25 or 30 feet at the ends of the cut are reddish, yellowish sands.
2. Sands with clay partings, 5 to 10 feet.
1. Whitish or bluish clay resembling fuller's earth, in thin laminæ with sand partings, 4 to 5 feet.

Another cut, between mileposts 163 and 164, shows a similar section, in which the clay at the base resembles fuller's earth even more closely than that in the section first described.

ALACHUA COUNTY, FLA.

Devil's Mill Hopper.—This is a lime sink several hundred yards in diameter and over 100 feet in depth in the Vicksburg limestone. It is situated about 11 miles from Alachua, on the road to Gainesville, being 5 or 6 miles from the latter place. A thin stratum of fuller's earth, apparently interbedded with the limestone, was discovered in the side of this sink.

ANALYSES OF AMERICAN AND FOREIGN FULLER'S EARTHS.

A number of analyses are here reprinted, for comparison with those given in the preceding paper:

Analyses of fuller's earth in the United States.

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	H_2O.	Na_2O.	K_2O.	Moisture.	Loss on ignition.	FeO.	Volatile matter.	MnO.	Total.	Analyst.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
Gadsden County, Fla	62.83	10 35	2.45	2.43	3.12	7.72	0.20	0.74	6.41					96.25	P. Fireman.
Decatur County, Ga	67.46	10.08	2.49	3.14	4.09	5.61			6.41					99.28	Do.
Fairburn, S. Dak	58.72	16 90	4.00	4.06	2.56	8.10	2.11		2.30					98.75	E. J. Reiderer.
Southeast of River Junction, Fla	50.70	21.07	6.88	4.40	.30	9.60			7.90					100.85	Do.
Between Mount Pleasant and Norway, Fla.	58 30	10.63	6.72	1.71	3.15	9.05			9.55					99.11	Do.
Near Norway, Fla	54.60	10.99	6.61	6.00	3.00	10.30			7.45					98.95	Do.
North of Fairburn, S. Dak	68.23	14.93		2.93	.875					6.20	3.15			96.19	State School of Mines, Rapid City.
Custer City, Ind. T	55.45	18.58	3.82	3.40	3.50	8.8						5.35	Trace.		F. E. D. Heinault.
Do	57.00	17.368	2.362	3.00	3.027	9.5						5.85	Trace.		Do.
Do	63.50	14.97	4.48	2.40	2.882		7.20	1.116				{CO_2 & vol. 10.75}			J. E. Pilcher.
Hermosa, Ind. T	55.40	27.70	1.80	2.30	.703		4.87	.589					{Loss 13.00}		Geo. Boland.
Custer City, Ind. T	71.28	14.33	2.484	.33	1.199	{Alk. und.}						{Alk. und.}			A. M. Willard.
Three-fourths mile from Fairburn, S. Dak.	68.23	14.93	3.15	2.93	.875	6.20									Wm. Bodenner.
Fairburn, S. Dak	60.16	10.38	14.868	4.96	1.714	{Ign. 7.20}									M. Palmiter.
Fairburn, S Dak. (dried)	56.18	23.23	1.26	5.88	3.29	11.45									Do.
Fairburn, S. Dak	67.00	5.00	12.00			15.00									Wm. Bodenner.
"Glacialite," Enid, Okla	50.36	33.38	3.31			12.05						{Trace TiO_2}	{Org. trace}		
Tampa, Fla	70.78	11.38		2.18					15.71					100.05	F. W. Clarke.

Florida[a]	36.73	27.78	3.21	.81	.64	[b]7.38 [c]12.14	None.	.42	------	------	------	------	------	------	
Sumter, S. C	74.20	10.10	1.80	1.90	2.10	5.70	1.60		2.50	------	------	------	------	99.90	H. Ries.
Do	74.90	10.25	1.75	1.30	2.30	5.80	1.75		1.70	------	------	------	------	99.75	Do.

[a] In addition this specimen contained 5.54 per cent P_2O_5, 1.27 per cent TiO_2, and 3.61 per cent of organic matter. [b] At 110°. [c] Above 110°.

Analyses of fuller's earth from foreign countries.

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	H_2O.	Na_2O.	K_2O.	Moisture.	Loss on ignition.	Total.	Analyst.
Smectite from Cilly	51.21	12.25	2.07	2.13	4.89	27.89	------	------	------	------	100.44	Pogg. Ann., vol. 77, p. 591.
Fuller's earth from Reigate	53.00	10.00	9.75	.50	1.25	24.00	------	------	------	------	98.50	
Malthite from Steindorfel	50.17	10.66	3.15	.25	------	35.83	------	------	------	------	100.06	Dana, System of Min.
Fuller's earth: England	44.00	11.00	10.00	5.00	2.00	------	5.00	------	------	------	77.00	Geikie, 1893, p. 133.
Do	44.00	23.06	2.00	4.08	2.00	24.95	------	------	------	------	100.09	Dr. Thompson.
Woburn sands (yellow)	47.10	16.27	10.00	2.63	3.15	------	------	------	15.12	5.73	100.00	R. H. Harland.
Woburn sands (powdered)	47.20	15.66	10.64	2.24	2.00	------	0.46		15.44	5.36	99.00	Do.
Woburn sands (blue, undried)	40.50	12.20	6.80	1.57	1.00	------	1.15		33.50	3.25	99.97	Do.

GEOLOGICAL SURVEY PUBLICATIONS ON CLAYS, FULLER'S EARTH, ETC.

In addition to the papers listed below, references to clays will be found in the publications listed under the head of "Cements," on page 381. A bulletin will soon be issued by the United States Geological Survey, dealing with the clay deposits and industries of the entire eastern United States.

BRANNER, J. C. Bibliography of clays and the ceramic arts. Bulletin No. 143, 114 pp. 1896.

GOLDING, W. Flint and feldspar. In Seventeenth Ann. Rept., Pt. III, pp. 838–841. 1896.

HILL, R. T. Clay materials of the United States. In Mineral Resources U. S. for 1891, pp. 474–528.

———. Clay materials of the United States. In Mineral Resources U. S. for 1892, pp. 712–738. 1893.

RIES, H. Technology of the clay industry. In Sixteenth Ann. Rept., Pt. IV, pp. 523–575. 1895.

———. The pottery industry of the United States. In Seventeenth Ann. Rep., Pt. III., pp. 842–880. 1896.

SHALER, N. S., WOODWORTH, J. B., and MARBUT, C. F. The glacial brick clays of Rhode Island and southeastern Massachusetts. In Seventeenth Ann. Rept., Pt. I, pp. 957–1004. 1896.

WILBER, F. A. Clays of the United States. In Mineral Resources U. S. for 1882, pp. 465–475. 1883.

———. Clays of the United States. In Mineral Resources U. S. for 1883–1884, pp. 676–711. 1885.

GYPSUM, SALT, BORAX, AND SODA.

The mineral products grouped under the above heading, though applied to widely different uses, form a somewhat natural group so far as origin is concerned. Their close connection becomes obvious when their study in the field is attempted, for it is commonly the case that two or more of these salts will be found in adjacent and closely related deposits. This is due to the mode of origin of such deposits. The materials here grouped include certain sulphates, chlorides, carbonates, or borates of lime, magnesium, sodium, or potassium; and deposits of commercial value are due in almost every case to the deposition of these salts, by evaporation, from the sea or lake water in which they were contained in solution.

The most important, and fortunately the most widely diffused, of these materials is common salt, whose uses, both in the preparation and preservation of food and in the chemical industries, are rapidly increasing. For a report on field work by the Survey, during 1902, on the Virginia salt and gypsum deposits see pages 406–416. Appended to this report are tables of analyses of rock salts, brines, and commercial salts from various United States and foreign localities.

The next in importance of these materials is gypsum. In addition to the report on Virginia gypsum, noted above and presented in this bulletin, all the commercially important gypsum deposits of the United States will be described in a bulletin of the United States Geological Survey, now in preparation.

A report on the California borax deposits has recently been issued by the Survey. This, together with other Survey publications on the materials of this group, will be found listed on page 417. The parts of that paper dealing with the worked deposits are here presented under the title of Borax deposits of Eastern California.

BORAX DEPOSITS OF EASTERN CALIFORNIA.

By M. R. Campbell.

INTRODUCTION.

The occurrence of deposits of borax in the United States, so far as known, is limited to the States of California, Nevada, and Oregon. The industry has passed through several stages of development since its inception in this country. Originally borax was obtained by evaporating the waters of Clear Lake, about 80 miles north of San Francisco, where it was first produced on a commercial scale in 1864. Subsequently the lake water was enriched by the addition of crystalline biborate of soda, which was collected from the alkaline marsh surrounding the lake. The industry flourished at this and other lakes in California until, in the early seventies, borax in large quantity and in a very pure condition was discovered on many of the alkaline marshes of western Nevada and eastern California. Refining plants were established in the vicinity of Columbus, Nev., and at several points in California, the most important of the latter being in San Bernardino County, at Searles's marsh, west of the Slate Range; in Inyo County, near Resting Spring; and at the mouth of Furnace Creek in Death Valley. These plants flourished for a time, even though the finished product in many cases had to be transported by teams to the railroad, 100 miles distant; but the increased production of borax in this country, together with the importation of large amounts from Italy, so reduced the price that in a few years most of the plants were abandoned.

About 1890 it was found that the borax crust on most of the marshes is a secondary deposit, being derived from the leaching of beds of borate of lime in the Tertiary lake sediments that abound in the region. This discovery revolutionized the borax industry, for the bedded deposits are much more extensive, are more easily accessible, and are in a purer condition than the marsh crusts. The marshes were abandoned and a mine was established on a bedded deposit at Borate, 12 miles northeast of Daggett, San Bernardino County, Cal. At the present time this plant, owned by the Pacific Coast Borax Company, is the chief producer of borax and boracic acid in this country. The value of this deposit led to extensive prospecting in various parts of the region and to the discovery, in Death Valley, of enormous deposits that far excel those now being worked near Daggett.

The borax of Death Valley, as well as that near Daggett, occurs in a regular stratum, interbedded with the semiindurated sands and clays that make up the bulk of the strata. These beds are generally regarded as of Tertiary age, and they are supposed to have been deposited in inclosed bodies of water.

Since the bedded deposits of borax always occur in association with strata of this character, it is probable that careful study and search will reveal deposits of this nature in localities other than Death Valley and Daggett.

For the purpose of locating outcrops of lake beds, and studying their relations and contents, the writer made a rapid reconnaissance across southern California in the spring of 1900. The trip was too hastily made to permit of detailed examinations, or of observations much beyond the line of travel, but many facts were found which have a bearing upon the occurrence of borax and its distribution, and these are embodied in the following paper. Of necessity the writer does not enter into a systematic treatise of the subject, but presents, in the form of an itinerary, the data gathered during his trip.

BORATE.

The principal deposit of boron salts occurs at Borate, about 12 miles north of Daggett, in the vicinity of the old Calico mining district. The mineral found here is borate of lime, or colemanite, and it occurs as a bedded deposit from 5 to 30 feet in thickness, interstratified in lake sediments. These lake beds are composed of semiindurated clays, sandstones, and coarse conglomerates, with intercalated sheets of volcanic tuff and lava. The rocks are intensely folded, the axes of the folds lying in an east-west direction. The lake beds extend in the same direction across the mountains for a distance of about 8 miles. It has been supposed that these deposits probably continue westward under the Pleistocene drift of the desert, but there is no evidence at hand to prove such an assertion. In fact, the lake beds at Borate do not come down to the foothills of the mountain; they are cut off and infolded with the crystalline rocks of the Calico district. Lake beds are present west of Calico Valley, and a bed of colemanite has been struck in a shaft in this locality at a depth of 200 feet. Although the colemanite is interbedded with sand and clay, it is not coextensive with these strata. As a traceable bed it probably extends for a distance of a mile and a half; beyond this limit it is very thin, and in many places it is wanting in the section. At the Borate mine there are two outcrops of colemanite, either on parallel beds or on one bed that has been so closely folded as to give two parallel layers about 50 feet apart. The beds strike approximately east and west, and dip to the south from 10° to 45°. A railroad connects the mine with the mill which is located on the west side of the mountain, and also with the Santa Fe Railway at Daggett.

DEATH VALLEY.

The range of mountains on the east side of Death and Mesquite valleys is separated into two parts by a low gap formed on lake beds. The mass lying north of these sediments is known as Grapevine Mountain, and that to the south, including the lake beds, is called Funeral Mountain.

The lake sediments of this region are composed of clay, sand, and gravel, with many beds of volcanic tuff and intrusive lava sheets toward the base of the series. Coarse gravel abounds near the contact between these beds and the Paleozoic rocks of Grapevine Mountain, showing that at the time of deposition this was a shore or boundary wall of the valley in which the lake was located. The strike of the beds is parallel with the northeastern margin, and the dip is 20° to 45° toward the northeast. The beds maintain this attitude on both sides of the range, and they do not dip under the valleys on either side, as they have been supposed to do.

Interbedded with the rocks of this series is a bed of colemanite (borate of lime), which, though probably not continuous, shows in outcrop in a number of places across the mountain, a distance of at least 25 miles. This constitutes the largest deposit known in this country and presumably the largest in the world. The bed has been opened low in the foothills on the east side of the mountain 4 or 5 miles south of the Ash Meadows road. At this point the bed is visible for several hundred yards, and in the prospect pits it has a thickness of from 4 to 10 feet. It is said to exceed these figures, but no thicker sections were seen. The bed is composed of a mass of crystalline colemanite which mines readily and with little waste.

In the western foothills of Funeral Mountain a bed of this mineral is exposed in the ravines for a distance of a quarter of a mile, and along this outcrop it varies in thickness from a few inches to 20 feet. At no point is it a solid, regular bed, but it consists of irregular masses and stringers of colemanite embedded in clay. The crystals are small, seldom exceeding a quarter of an inch in diameter, and the large masses are nearly pure. According to Superintendent Roach, of the Pacific Coast Borax Company, the largest mineral deposit occurs about 9 miles up Furnace Creek, on a nearly direct line between the outcrops just described. At this point he reports a bed of boracite 60 feet in thickness. This was not seen by the writer, but there are strong indications of the presence of minerals of this character, and it is probable that large deposits occur in this locality.

Borax was once manufactured 2 or 3 miles north of the point where Furnace Creek emerges from the hills into Death Valley. The plant was situated on the margin of the alkaline marsh, and the crude material was derived from a certain part of the marsh where colemanite accumulated. It is now known that the mineral is derived by solution from the bedded deposit described above, and that its accumulation on a certain part of the marsh is due to the solution being carried to that place by a small stream.

Death Valley contains an immense salt field, which may in time become valuable. It extends south from above the old borax works at least 30 miles. At the place where it is crossed by the road from Furnace Creek to Bennett Wells it is nearly 3 miles wide, and it probably varies from 2 to 4 miles in different parts of the basin. The salt is not white, like the marsh at Salton, in Colorado Desert, but it is brown with dust and sand that is constantly being blown upon it.

The salt stands in pinnacles 2 to 3 feet in height, making a surface so rough that it is impassable for a horse until the projections are pounded down with a sledge. With the implements at hand the thickness of the crust could not be determined, but it can not be less than 1 foot of solid salt. A sample collected in the middle of the field on this road shows that the salt is composed of chloride of sodium, 94.54 per cent; chloride of potassium, 0.31 per cent; sulphate of sodium, 3.53 per cent; sulphate of calcium (hydrous), 0.79 per cent; moisture, 0.14 per cent; undissolved residue (gypsum and clay), 0.50 per cent; total, 99.81 per cent. The presence of the large amount of mechanical impurities as well as the large percentage of sulphate of soda would render refining necessary before the salt could be placed upon the market, a process that would be very expensive under present conditions of great scarcity of fuel and water and lack of railroad transportation.

SALT AND GYPSUM DEPOSITS OF SOUTHWESTERN VIRGINIA.

By Edwin C. Eckel.

INTRODUCTION.

The field work on which is based the following report on the Virginia salt and gypsum deposits was carried on by the writer during August, 1902, under the direction of Dr. C. W. Hayes. The writer's thanks are due to the gypsum producers of the region, who cordially cooperated with him in his investigations.

Though salt and gypsum are found elsewhere in Virginia, the only economically important deposits of these minerals occur in the southwestern portion of the State. These deposits are located along the valley of the North Fork of Holston River, and have been developed quite extensively in Smyth and Washington counties.

The occurrence of salt brines in the Holston Valley was known at least as early as 1781, as Jefferson mentioned the fact in his Notes on Virginia. Rock salt was not, however, discovered until 1840. Gypsum or "plaster" seems to have been recognized early in the nineteenth century, though the writer has not been able to ascertain the exact date of its discovery.

Though the salt and gypsum deposits have been long known and worked, and have been examined by many geologists, a wide range of opinion exists as to their age and origin, as will be seen on comparing the literature of the subject. It is sufficient in this place to note that, as to age, the deposits have been variously referred to the Silurian, Carboniferous, Triassic, Tertiary, and Pleistocene, while different authorities have considered them as originating from deposition from sea water, from deposition from lakes, by the decomposition of pyrite and resulting action on fragments of limestone, or by the action of sulphur springs on unweathered limestone.

The work of the last field season would seem to prove that both the salt and gypsum deposits originated from deposition, through the evaporation of sea water in a partly or entirely inclosed basin, and that they are of Lower Carboniferous age, being immediately overlain by the massive beds of the Greenbrier limestone and underlain by Lower Carboniferous sandstones.

STRATIGRAPHY AND STRUCTURE.

The areal geology and structure of the district have been carefully worked out by Professor Stevenson, and are described by him in the paper cited below.[a]

In the forthcoming bulletin on the gypsum deposits of the United States, to be published soon by this Survey, will be found a geologic map of the Virginia salt and gypsum region, with structure sections, modified very slightly from that published by Professor Stevenson. A summary of the more important geologic features will here be given.

The ridges (Brushy Mountain, Pine Mountain, Little Brushy Mountain, etc.) which border the valley of the North Fork of Holston on the northwest are made up of Upper Silurian, Devonian, and Lower Carboniferous rocks, dipping southeastward (or riverward) at angles of 20° to 40°, and striking approximately parallel with the course of the river. The southeastern slope of these ridges is generally formed by the shales and shaly sandstones of the Lower Carboniferous which underlie the Greenbrier limestone. The Greenbrier limestone itself occupies the interval between the foot of the ridges and the river, and extends, on the southeastern side of the river, to the great fault described as the Saltville fault by Stevenson, and farther south as the Rome fault by Hayes. This fault brings up Cambro-Silurian limestones on its southeastern side. The location of the fault in the salt and gypsum district may be described as follows: Beginning at the southwestern end of the area, the fault crosses the Saltville branch railroad at a point several hundred yards south of the plaster mill of the Buena Vista Plaster Company, runs a little above the foot of the ridges on the southeast side of the salt wells, and in a direction approximately north, 60° east, crossing the river near Broad Ford, and passing north of the settlement at Chatham Hill. The rocks on the southeastern side of this fault are limestones and shales of Cambrian and Lower Silurian age, dipping southeastward, and may be disregarded in a further discussion of the salt and gypsum deposits. Trilobite remains occur in these Cambro-Silurian limestones in a railroad cut south of the Buena Vista mill.

SALT AND GYPSUM DEPOSITS.

In describing the geologic and areal relations of the salt and gypsum deposits, the area southeast of the Saltville fault may, as above noted, be dismissed from consideration. The deposits are confined to a belt north of this fault, and extending from the fault line to the line of outcrop of the Lower Carboniferous standstones, which passes along the foot of Pine Mountain and Little Brushy Mountain. This intervening space is occupied by the massive limestones and shaly

[a] Stevenson, J. J., Notes on the geological structure of Tazewell, Russell, Wise, Smyth, and Washington counties of Virginia: Proc. Am. Philos. Soc., Vol. XXII, pp. 114-161.

limestones, with salt and gypsum beds, here included in the "Greenbrier limestone."

The Greenbrier limestone, as that term is here applied, consists of the following members, from the top down:

	Feet.
1. Blue limestone, usually heavy bedded, with some beds of cherty limestone, and with occasional beds of grayish, black, or greenish fossiliferous shales near its base	1,000+
2. Shaly limestones, with one or more beds of gypsum, followed below by blue shales or slates, which in turn are underlain by shales or shaly limestones carrying thick beds of rock salt	600 to 1,000

Of the two members the lowermost (2) alone requires attention here. While the uppermost member of the Greenbrier limestone appears to have a wide distribution, the lower, carrying the salt and gypsum, seems to be developed only locally, as it has not been recorded except in the region here described. As the salt and gypsum beds are too soluble to be well exposed at the surface, and the interbedded shaly limestones and shales weather rapidly, it is impossible to find a good natural section of this important group of beds. Well sections would be of great service, but unfortunately no well has passed completely through the series. By utilizing the records of various wells and borings, however, some idea of the stratigraphy may be obtained.

At various dates between 1815 and 1857 a number of wells were bored on the Robertson property, with the objects of ascertaining the thicknesses of the various gypsum beds, and also of determining whether or not brine or rock salt could be obtained on the property. Through the courtesy of Col. W. B. Robertson, of the Buena Vista Plaster and Mining Company, the writer is enabled to present the records of most of these wells.

The wells started in the gypsum-bearing section of the Greenbrier limestone about 200 feet below the massive blue limestones. Several of them penetrated through the gypsiferous beds, apparently stopping near the top of the salt beds.

Records of wells on Robertson property.

	Feet.
Well A, bored between 1815 and 1820:	
Red clay	0–14
Clay and plaster	14–120
Pure plaster [a]	120–160
Well B, bored in 1847:	
Red clay	0–10
Clay and plaster, buhrstones	10–30
Clay and plaster (deep red)	30–50
Pure plaster	50–95
Impure blue plaster	95–163
Hard blue slate	163–420

[a] Pure plaster is said to have extended 40 feet deeper than is above shown—i. e., from 160 to 200 feet in depth.

Well C, bored in 1847:

Red clay	0–10
Clay and plaster, with brown rocks	10–70
Pure plaster	70–100
Slate and plaster	100–200
Hard blue slate	200–360
Red slate	360–480
Gray slate	480–495
Red rocks, a little salty	495–505

Well D, bored in 1847:

Red clay	0–10
Clay and plaster	10–62
Plaster, with a little clay	62–200
Red clay, with a little plaster	200–385
Red clay, alkali, and salt	385–387
Pure plaster	387–590

Well E, bored in 1847:

Red clay	0–10
Clay and plaster	10–16
Impure plaster	16–50
Pure plaster	50–102
Slate and plaster	102–165
Nearly all plaster	165–210
Blue slate	210–320
Blue slate and plaster	320–390
Yellow soapstone	390–445
Pure plaster	445–490
Red rock, with a little salt	490–505

Well F, bored in 1853:

Clay	0–17
Clay and plaster	17–50
Pure plaster	50–83
Hard black flint rock	83–90
Pure plaster	90–96
Plaster and sulphur balls	96–105
[Record lost]	105–109
Red and yellow soapstone	109–120
Hard blue slate and red, blue, and gray rock	120–359
Yellow and blue slate	359–390
Yellow and blue slate, salty	390–460

Well G, bored in 1854:

Sand and gravel	0–20
Blue clay	20–30
Hard white sand rock	30–40
Clay and plaster	40–55
Buhrstone	55–60

Another well was bored in 1845. No record was kept and it is only known that salt water was struck.

It will be seen that none of these wells gave any appreciable amount of salt. This may be due to the fact that the salt beds do not occur at this point or to the fact that the wells stopped some distance above the salt horizon. In the writer's opinion the latter supposition is the more probable. Unfortunately it was impossible to obtain records of the strata passed through in drilling the salt wells. It is known, however, that these wells start near the base of the gypsum-bearing beds and strike rock salt at a depth of about 200 feet. The aggregate thickness of rock-salt beds passed through is said to be about 175 feet.

By combining all these data, some idea of the thickness of the lower (gypsum and salt-bearing) member of the Greenbrier limestone may be formed.

Section of lower member of Greenbrier limestone.

	Feet.
Top of gypsiferous series to top of Buena Vista wells	100
Gypsum-bearing rocks and shales in deepest well	600
Bottom of deepest Buena Vista well to top of salt beds, probably not over	100
Salt beds and inclosing rocks	175
Bottom of salt beds to Lower Carboniferous sandstones	?

The thickness of the series in the Saltville-Plasterco basin must therefore be in the neighborhood of 1,000 feet.

MINING AND TECHNOLOGY.

THE GYPSUM INDUSTRY.

The gypsum deposits in this area have been developed at a number of points along the trend of the belt. These developments will be described briefly in order from northeast to southwest.

The most northeasterly point at which gypsum has been found in the Holston Valley area is on the Buchanan property, located about 3 miles west of Chatham Hill post-office. Several small openings can be seen here, one of which was being worked at the time of visit. This quarry was about 30 feet deep and 50 feet in length, exposing gypsum of very good grade. The product is crushed for use as land plaster in a mill located near the quarry. Extensive exposures of gypsum occur in the vicinity, but the difficulty of marketing the product has prevented the development of these deposits, only about 300 tons per year being quarried.

About 3 miles east of Broadford post-office, and some distance north of the river, gypsum is worked on the property of Mr. John D. Barnes. The inclosing shaly limestone beds here strike N. 80° E. and dip 40° SE. Black powder and hand drills are used in extracting the gypsum. The workings, at first in open cut, are now mostly underground, a slope having been run down on the dip of the beds, with pillars of gypsum left at intervals to support the roof. The product, which may amount to 500 tons a year, is carried by wagon to a land-plaster mill located at Broadford, on Laurel Creek.

An analysis, by Prof. M. B. Hardin, of the gypsum rock from the Barnes property is as follows:

Analysis of gypsum rock from Barnes property, east of Bradford, Va.

Calcium sulphate	78.60
Water	20.79
Calcium carbonate	0.21
Calcium chloride	Trace.
Magnesium chloride	Trace.
Organic	0.12
Silica, alumina, etc	0.23

At several points between the Barnes property and Saltville gypsum deposits have been opened, but none have been worked recently.

At Saltville several large openings can be seen. One of these was worked during 1901 and the early part of 1902, part of the product being sold for use as land plaster, but most of it being sent to Glade Spring, at which point it was utilized in the manufacture of Keene's cement. This industry not proving as successful as had been anticipated, the plant was dismantled during 1902. The product, though fairly satisfactory, was not equal to the imported material or to the Kansas product.

The writer has recently[a] described this interesting gypsum product in some detail, and the following quotation may be of interest here:

Keene's cement is sharply distinguished from the other members of the group of hydrate cements (or "plasters"), not only by the properties of the product, but by its method of manufacture. In its preparation a very pure gypsum is calcined at a red heat, the resulting dehydrated lime sulphate is immersed in a bath of alum solution, and, after drying, is again burned at a high temperature. After this second burning the product is finely ground, and is then ready for the market. This sketch of the process is a general outline of the methods used, and in the essentials is followed in all plants, though slightly modified at different plants according to the experience gained by each manufacturer.

The gypsum used should be as pure as possible, and especially it should be free from such impurities as might tend to discolor the product, which should be a pure white. Nova Scotia gypsum has been tried and, for some reason, found to be unsatisfactory. Even the Virginia gypsum, which on analysis shows but a trace of iron oxide, is not entirely satisfactory, for on heating to the temperature necessary for the manufacture of Keene's cement, minute red streaks appear in the lumps of gypsum. The following analyses show the composition of gypsum from Virginia and Kansas, both of which have been used in a domestic Keene's cement:

Composition of gypsum used in manufacture of Keene's cement.

	Kansas.	Virginia.
Lime sulphate	77.46	99.58
Water	20.46	
Iron and aluminum oxides	.10	.036
Silica and insoluble	.19	.116
Magnesium carbonate	.34	.221
Lime carbonate	1.43	----------

[a] Plasters and hard-finishing cements in the United States: Engineering News, Vol. XLIX, pp. 107-108, Jan. 29, 1903.

It will be seen that both materials are very pure gypsum, and that there is no apparent reason why the Virginia material should not be as satisfactory as that from Kansas.

The calcination of the product is usually carried on in small vertical kilns closely resembling those which are in common use for lime burning. These kilns are charged with alternating layers of fuel (usually coal) and lump gypsum. Small rotary kilns have been used experimentally, but have not proved successful, as the calcined product from a rotary kiln is discharged in small fragments, which can not be treated satisfactorily in the alum bath. After burning to a red heat, the gypsum is submitted to the action of a 10 per cent alum solution. It is then recalcined, and finally ground in emery mills.

The product is a very fine-grained white powder. On the addition of water this cement hardens, but the hardening is slow, relative to that of other plasters. Another peculiarity of the material is that, even after the hardening has commenced, the partly set cement may be reworked with water and will take its set just as satisfactorily as if the process (of hardening) had not been interrupted.

By far the largest openings of the district are those at Plasterco post-office (Gypsum station), a mile or so southeast of Saltville. The gypsum mines at this point are worked by the Buena Vista Plaster and Mining Company. The bed now worked is about 30 feet thick, dipping northwestward at an angle of 50 degrees or more, and has been mined to a depth of 280 feet. The shaft at present used is 180 feet deep. Part of the product is ground for land plaster at the mill of the company, located a short distance from the shaft, and part is calcined at the same plant, the total product being about 11,000 tons per year. The crude gypsum is reduced to 5 inches in a nipper, and then to about $\frac{1}{4}$ inch in a rotary crusher, receiving its final reduction in a Sturtevant rock-emery mill. The material used for land plaster is then sent to the bagging machines, while that to be calcined goes to the kettles. A certain amount of wall plaster is also made at this plant, by the addition of retarder and hair to the calcined plaster. Analyses of crude gypsum from the mines of this company follow:

Analyses of gypsum from Plasterco post-office, Va.

Constituent.	1.	2.	3.	4.
Lime	33.20	33.20	33.00	31.82
Sulphuric acid	46.04	44.74	47.14	40.24
Water	19.40	20.85	19.07	21.30
Magnesia		.05	Trace.	1.75
Baryta		.19	Trace.	1.10
Alumina and iron	.70	.46	0.55	1.95
Silica	.10	.49	.02	1.68

1. Crude rock, as mined. P. de P. Ricketts, analyst.
2. Crude rock, as mined. Henry Froehling, analyst.
3. Ground rock, for land plaster. P. de P. Ricketts, analyst.
4. Ground rock, for land plaster. Henry Froehling, analyst.

THE SALT INDUSTRY.

Although indications of salt appear at several points in the region, the salt industry is at present confined to the immediate vicinity of

Saltville. The salt licks of this locality were known, as noted above, before 1800. Early in the nineteenth century a marsh which covered the present site of the village of Saltville was drained by a channel leading to the Holston, and wells were sunk in the area uncovered. Brine was pumped from these wells for many years before the presence of rock-salt beds was established, and the entire salt product of the district is still obtained from wells, no mining of the rock salt having been attempted.

The earliest wells were about 200 feet deep, passing through earth, clay, gypsum, and shales. In 1842, when the deposits were described by Hayden, six salt wells had been put down, only two of which were then in operation. A shaft sunk in 1840 passed through the usual thickness (18 to 20 feet) of muck, clay, etc., and then through alternating beds of red and blue shales and gypsum, one of the gypsum beds being 40 feet thick, finally striking a bed of rock salt at a depth of 220 feet. This salt bed continued to the bottom of the shaft, at a depth of 273 feet, and was ascertained by boring to extend to 113 feet below the bottom of the shaft. No water was encountered in the well. This was the first discovery of a bed of rock salt in eastern United States, though Parker some years before had noticed the occurrence of salt beds in the Northwest, on the Oregon trail. The rock salt from the shaft contained, in places, some interbedded shales, these impurities being commonest near the top of the salt beds. An analysis of the rock salt gave—

	Per cent.
Sodium chloride	99.084
Calcium chloride	Trace.
Calcium sulphate	0.446
Iron, alumina, etc	.470

A well bored in 1842 to a depth of 214 feet struck a flow of strong brine at 193 feet. In 1,000 grains this brine contained—

	Grains.
Sodium chloride	240.52
Calcium chloride	.08
Calcium sulphate	5.35
Iron, alumina, etc	Trace.

At this date (1842) two establishments were producing salt, the total annual product being about 200,000 bushels. Analyses gave—

Analyses of salt from Saltville, Va.

	1.	2.
	Per cent.	*Per cent.*
Sodium chloride	98.54	98.146
Calcium chloride	.016	.034
Calcium sulphate	1.444	1.820

Further analyses of Saltville brines, rock salt, and commercial salts will be found in the tables on pages 415 and 416.

In 1885 Radcliffe discussed[a] the Saltville product as follows:

A specimen of the rock salt sent by the superintendent of the salt works was brownish-red in color, with a crystalline structure, and was obtained while deepening one of the salt wells. This rock salt is not mined, the brine alone being used for the manufacture of salt. The capacity of the works is at present 450,000 bushels per year, though at one time during the late war the yield was as high as 10,000 bushels per day. According to analysis the rock salt contained—

	Per cent.
Sodium chloride	93.05
Potassium chloride	Trace.
Calcium sulphate	2.40
Magnesium sulphate	.07
Ferric oxide	.83
Silica	2.81
Water	.30

An analysis of the marketed salt gave 98.89 per cent sodium chloride, with a small percentage of calcium sulphate, water, and a trace of magnesium sulphate, showing it to be a high-grade salt.

At present the salt industry in the Holston Valley is entirely in the hands of the Matthieson Alkali Company. Part of the product is marketed as salt, while a large proportion is utilized in the alkali plant of the company, located at Saltville.

While it is probable that brines could be obtained by boring in other parts of the Holston Valley, no possible extension of the salt field could be so favorably located in regard to transportation routes as is the present producing area near Saltville, with the exception of the property near Plasterco.

COMPARISON OF AMERICAN AND FOREIGN SALTS.

Analyses of rock salt, brines, and commercial salt from the Virginia salt region follow. For comparison, a series of analyses of similar materials from other localities, both American and foreign, has been added.

Most of the salt produced in the United States is obtained by pumping and evaporating brines from wells reaching down to beds of rock salt or to rock formations carrying much saline matter disseminated through their mass. Part of the remaining product is secured by mining and crushing rock salt, and part by evaporating ocean water or the waters of salt lakes.

In point of geologic age, the oldest salt-bearing beds now actively worked in the United States and Canada occur in the Salina group, near the top of the Upper Silurian. Brines have been obtained, it is true, from the Medina formation of the Silurian in New York, but these have never been of much economic importance. The geologic horizons from which the salt of Ontario and the various States is obtained are shown below.

[a] Mineral Resources U. S. for 1883-1884, p. 840.

Geologic horizons from which salt is obtained.

Upper Silurian	New York,[a] Michigan, Ohio,[a] Ontario (Canada).
Carboniferous	Pennsylvania, West Virginia, Virginia, Kentucky, Michigan.
Permian, Triassic	Kansas,[a] Oklahoma, Texas.
Cretaceous, Tertiary	Louisiana,[a] Texas.
Recent—sea and lake waters	Texas, Utah, Nevada, California.

Analyses of rock salts from various localities.

Locality.	Sodium chloride.	Calcium chloride.	Magnesium chloride.	Calcium sulphate.	Magnesium sulphate.	Alumina, silica, and iron.	Water.	Authority.
Saltville, Va	99.084	Tr.		0.446		0.470		C. B. Hayden.
Do.[b]	93.05			2.40	0.07	3.64	0.30	Radcliffe.
Retsof, N. Y	98.701	0.018	0.055	.484		.743	Tr.	F. E. Englehardt.
Pearl Creek, N. Y	96.885	.157	.103	.437		1.21	1.21	Do.
Greigsville, N. Y	98.28	.031	.088	.560		.835	.206	Do.
Goderich, Ontario	97.031	.007	.031	1.431			1.500	C. A. Goessmann.
Do	99.687	.032	.095	.090		.017	.079	T. S. Hunt.
Do	91.24	.57	.05	2.81		5.33		Do.
Do	99.53	.109	Tr.	.214		.007	.139	F. E. Englehardt.
Petit Anse, La	98.90	.146	0.022	.838		.014	.080	P. Collier.
Do	98.731	Tr.	.013	1.192		.034	.030	F. W. Taylor.
Do	99.097			.729	.158		.039	O. Doremus.
Cheshire, England	99.52		.02	.46				G. H. Cook.
Do	98.32	0.01	.02	.65		1.00		D. C. Davies.
Dieuze, France	97.70			2.05	.15		.10	G. H. Cook.
Do	97.45			2.35			.20	Do.
Carrickfergus, Ireland	96.28			3.50	.08		.14	Do.

Analyses of solid matter of brines from various localities.

Locality.	Sodium chloride.	Calcium chloride.	Magnesium chloride.	Calcium sulphate.	Magnesium sulphate.	Alumina, silica, and iron.	Percentage solid in brine.	Specific gravity of brine.	Authority.
Saltville, Va	97.792	0.033		2.17		Tr.	24.6		C. B. Hayden.
Do	98.39			1.22	0.39		26.4	1.198	G. H. Cook.
Pearl Creek, N. Y	97.48	.26	0.55	1.68			25.65	1.192	F. E. Englehardt.
Warsaw, N. Y	97.60	.51	.20	1.68			26.34	1.204	Do.
Leroy, N. Y	96.17	2.15	.42	1.25			24.52	1.192	Do.
Syracuse, N. Y	95.866	.90	.69	2.54		0.004	18.5	1.142	G. H. Cook.
Do	95.312	.93	.72	3.03		.008	16.1	1.122	Do.
Do	95.328	1.52	.85	2.30		.002	16.1	1.122	Do.
Goderich, Ontario	99.01	.15	.10	.72			26.15	1.205	T. S. Hunt.
Do	97.58	.08	.12	2.19			24.74	1.195	C. A. Goessmann.
East Saginaw, Mich	81.38	.73	6.91	.53		.48	22.02	1.179	Douglass.
Bay City, Mich	91.95	3.19	2.48	2.39			16.61		C. A. Goessmann.
Saginaw, Mich	82.14	12.39	5.01	.46			21.32		Do.
Bay County, Mich	82.24	12.25	5.22	.30			24.15		Do.
Kanawha, W. Va	79.45	16.48	4.07				9.2	1.073	G. H. Cook.
Pittsburg, Pa	81.27	13.93	4.80				2.8	1.019	Do.
Cheshire, England	98.07	.13	.23	1.57			26.2	1.20	Do.
Do	97.92	.15	.27	1.66			25.1	1.19	Do.
Dieuze, France	94.87			1.83	3.30		15.2	1.122	Do.

[a] Utilize both brine and rock salt. [b] A specimen evidently much below the average in purity.

Analyses of commercial salts from various localities.

Locality.	Sodium chloride.	Calcium chloride.	Magnesium chloride.	Calcium sulphate.	Magnesium sulphate.	Alumina, silica, and iron, etc.	Water.	Authority.
Saltville, Va	98.540	0.016		1.444				C. B. Hayden.
Do	98.146	.034		1.820				Do.
Do	98.45	.95	0.20				0.40	G. H. Cook.
Do	99.01	.20	.09				.70	Do.
Do	99.18	.27	.05				.50	Do.
Do	99.11	.68	.11				.10	Do.
Do	98.61	1.02	.27				.10	Do.
Do	98.89			+	Tr.		+	Radcliffe.
Piffard, N. Y	98.081	.150	.055	1.087		0.081	.547	F. E. Englehardt.
Saltvale, N. Y	97.09			1.87	0.02		.52	Habirshaw.
Warsaw, N. Y	98.072	.089	.118	.955		.013	.753	F. E. Englehardt.
Syracuse, N. Y	96.70	.05	.03	1.43			1.79	G. H. Cook.
Do	97.91	.06	.07	.67			1.29	Do.
Do	97.28	.09	.07	1.46			1.10	Do.
Goderich, Ontario	97.031	.007	.031	1.431			1.50	C. A. Goessmann.
Do	98.424		.092	1.043		.42	.65	Ellis.
Saginaw, Mich	95.84	.36	.14	.32			3.34	C. A. Goessmann.
Bay City, Mich	97.29	.33	.34	.70			1.35	Garrigues.
Zilwaukie, Mich	95.33	.70	.31	.36			3.31	Hahn.
Kanawha, W. Va	91.31	1.26	.43				7	G. H. Cook.
Do	88.39	1.48	.43				9.70	Do.

GEOLOGICAL SURVEY PUBLICATIONS ON GYPSUM, SALT, BORAX, AND SODA.

The more important publications of the United States Geological Survey on the natural lime, sodium, and potassium salts included in this group are the following:

CAMPBELL, M. R. Reconnaissance of the borax deposits of Death Valley and Mohave Desert. Bulletin No. 200. 23 pp. 1902.

CHATARD, T. M. Salt-making processes in the United States. In Seventh Ann. Rept., pp. 491–535. 1888.

DAY, W. C. Potassium salts. In Mineral Resources U. S. for 1887, pp. 628–650. 1888.

——— Sodium salts. In Mineral Resources U. S. for 1887, pp. 651–658. 1888.

HILGARD, E. W. The salines of Louisiana. In Mineral Resources U. S. for 1882, pp. 554–565. 1883.

ORTON, E. Gypsum or land plaster in Ohio. In Mineral Resources U. S. for 1887, pp. 596–601. 1888.

PACKARD, R. L. Natural sodium salts. In Mineral Resources U. S. for 1893, pp. 728–738. 1894.

PEALE, A. C. Natural mineral waters of the United States. In Fourteenth Ann. Rept., Pt. II, pp. 49–88. 1894.

YALE, C. G. Borax. In Mineral Resources U. S. for 1889–1890, pp. 494–506. 1892.

PHOSPHATES AND OTHER MINERAL FERTILIZERS.

Several papers on the Tennessee phosphate industry are here presented. Incidental references to the use of gypsum as a fertilizer will be found in a paper on the salt and gypsum deposits of Virginia, on pages 406 to 416 of the present bulletin. On pages 221 to 231 will be found a discussion of the utilization of basic steel slags for fertilizing purposes.

ORIGIN AND EXTENT OF THE TENNESSEE WHITE PHOSPHATES.

By C. W. HAYES.

VARIETIES OF WHITE PHOSPHATE.

In a former report on the Tennessee white phosphates[a] the following classification of the deposits was adopted: (1) Stony, (2) lamellar, (3) breccia.

The first variety consists of a siliceous skeleton, the cavities in which were originally filled with lime carbonate, but are now filled with lime phosphate. The latter forms from 27 to 33 per cent of the rock. This stony phosphate is found in considerable abundance in the northern part of Perry County, on Terrapin and Redbank creeks. No attempt has yet been made to utilize it, and unless some inexpensive method is devised for concentrating the lime phosphate, it is too low grade to compete with the other varieties.

The third variety, the breccia phosphate, which forms most of the surface outcrops in the Toms Creek district, appears to be confined almost exclusively to the surface. Its importance is small, and it is questionable if it exists in sufficient quantity to justify the development of machinery for separating the phosphate from the chert, even if this separation were found to be practicable.

Only the lamellar variety, therefore, has thus far been developed. Fortunately this variety, which is the highest grade and the most easily prepared for market, appears to be also the most abundant. Selected specimens of the thin plates contain 85 to 90 per cent of lime phosphate. The less dense, greenish material, which is associated with the white and pink plates, contains some ferrous iron and runs slightly under 80 per cent of lime phosphate. There appears to be no difficulty,

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. III, 1901, pp. 473-485.

however, in getting from such deposits as are being worked on Wilsdorfs Branch a uniform product which will run between 79 and 81 per cent of lime phosphate.

ORIGIN OF THE DEPOSITS.

As stated in a former report, the conclusion arrived at from examination of the surface outcrops was that the lamellar variety had been formed by deposition from solution in cavities in the limestone. Observations recently made on more extended exposures amply confirm this conclusion. They show, moreover, what could not be determined from the surface outcrops, that the cavities in which deposition took place were very extensive, forming, in fact, large caverns in the limestone. It appears that the phosphate was deposited in a somewhat uniform and continuous layer on the floors of these caverns, in general following their undulations, but more was deposited in the depressions than on the elevations. Phosphate was also deposited in less regular cavities in a limestone above the stratum in which the main cavern formed. When this limestone was dissolved these masses settled down with the residual clay in which they are now embedded. During this readjustment, brought about by the solution of the limestone, the phosphate was repeatedly fractured and recemented, giving it a brecciated structure. The phosphate was doubtless deposited in these caverns from quiet water, but they also contained at times rapid streams which carried sand and gravel and formed alluvial deposits. The latter differ distinctly from those formed by surface streams under ordinary conditions. Since the stream was more or less confined above by the roof of the cavern, as well as at the sides, the water was sometimes under hydrostatic pressure. Under such conditions the laws which govern ordinary stream transportation and deposition do not apply, and the deposits possess certain characteristics which clearly indicate the conditions under which they were formed.

EXTENT OF THE DEPOSITS.

Since the lamellar variety of the white phosphate was deposited in limestone caverns, it will be found only where the conditions were favorable for the formation of caverns. It need not be expected above the top of the Silurian, since the Carboniferous limestone in this region contains so large a proportion of chert and other impurities that it probably never gives rise to the formation of caverns. It should further be noted that certain horizons in the Silurian limestone are much more soluble, and hence better adapted to cavern formation, than others. This is the characteristic of certain beds of Upper Silurian limestone which have a granular crystalline structure and are composed largely of crinoid stems. Wherever these beds are exposed by stream cutting they are apt to be cavernous. At numerous points in this region the streams sink and flow for considerable distances in underground channels, and this is most often the case where the erosion of the valleys has reached the surface of this easily soluble limestone. The white phosphate therefore, although its connection with any particular bed is in a measure accidental and not essential, as is the case with the brown phosphate, may be expected to occur in greatest quantity at the horizon of these particular beds. Hence the latter, identified by their peculiar fossils and physical characteristics, will afford a guide of some value in further prospecting.

Since this phosphate was deposited in caverns, it can not be expected to have very great lateral extent. As stated in the previous report, it is essentially a pocket deposit, although the possibilities for extensive deposits are much greater than were recognized at the time that report was made. The examination of one deposit, no matter how thoroughly it is exposed to view, will not enable the prospector to make definite estimates as to the extent of any other deposit. Doubtless similar natural exposures may lead to inferences of some value, but they can not be depended upon to take the place of actual prospecting. Each deposit must be examined itself, and the amount of rock which it contains, as well as its character and the depth of overburden, must be determined by systematic exploitation, similar to that which has been employed by the Perry Company at Wilsdorfs Branch. The necessity for this thorough examination of each individual deposit can not be dwelt upon too strongly.

Probably the greater part of the white phosphate in this district will be obtained by open workings. The character of the overburden—unconsolidated clay in which movement takes place with great ease—is such that underground working will be attended with the greatest difficulty. Substantial and expensive timbering would be required wherever the phosphate was removed, and doubtless even then a large proportion of the rock would be wasted. The specific gravity of this rock is so much greater than that of the brown phosphate that a very much greater overburden can be removed with profit for the same thickness of bed. Where the phosphate bed has a thickness averaging 3 feet it is probable that 16 or 18 feet of overburden can be removed with profit while the rock commands present prices. The phosphate which is disseminated through the overlying clay can be saved easily with the proper plant, which should include screens and washers. Owing to the much greater density of this rock, the matter of drying is less important than with the brown phosphate. It would, however, probably pay to dry the rock before shipment, and this might be done by open-air burning, or more economically with an ordinary rotary drier.

POSSIBLE EXTENSIONS OF THE FIELD.

Considerable interest attaches to the distribution of the white phosphate and the possible extension of the productive territory. If the conclusion outlined above is correct—namely, that the phosphate deposits were accumulated in caverns in the limestone—consideration of the geologic conditions prevailing elsewhere in the district should be of material assistance in locating other deposits.

The topography of the region between the Tennessee and Buffalo rivers has been described in a previous report, but its main features may be again briefly described in order to render statements regarding the distribution of the deposits intelligible. For a considerable distance the Buffalo and Tennessee rivers flow north nearly parallel with each other, and their tributaries head upon the intervening land and join the trunk streams very nearly at right angles, flowing east to the Buffalo and west to the Tennessee. The tributaries of the Buffalo are very short as compared with those of the Tennessee, so that the divide between the two drainage basins is much nearer the former stream than the latter. Streams of considerable size enter the Tennessee at intervals of about 5 or 6 miles, and shorter ones frequently intervene between these main tributaries.

Beginning in the vicinity of Perryville, the creeks of the first class which enter the Tennessee are Spring, Lick, Toms, Roan, and Crooked, while the streams of the second class are Parish Branch, between Spring and Lick creeks, and Deer Creek, between Lick and Toms creeks. These creeks are characterized by rather narrow, level valleys and are separated by ridges rising 300 or 400 feet higher than the valley bottoms. These ridges are simply portions of a deeply dissected upland plateau, the altitude of which in this region is between 900 and 1,000 feet. They are capped by the Lower Carboniferous chert, and are entirely covered with forests. While these ridges reach a tolerably uniform elevation, the distance from their summits down to the limestone is variable. Thus, in the ridge between Lick and Spring creeks the chert is comparatively thin, the limestone reaching more than two-thirds of the way from the valley bottom to the top of the ridge. The rocks of the region are, in a general way, horizontal, though not strictly so, and when considered in broad area they show considerable undulations. It should be remarked that the Devonian appears to be entirely wanting in this region, the Lower Carboniferous chert or cherty limestone resting directly upon some member of the Silurian, usually the sparry crinoidal limestone above described. The beds descend toward the north, and in Roan and Crooked creeks the valleys are not cut down to the surface of the limestone. On Toms Creek there is a dip to the west which carries the surface of the limestone below the creek valley about 4 miles from its mouth. It then rises so that the limestone is exposed between this point and the Tennessee River, but again dips westward, and the surface of the limestone is probably near the river surface at the mouth of Toms Creek. On Roan Creek the limestone is nowhere exposed except in the bed of the Tennessee River near its mouth. It will be readily understood that the conditions favorable for the deposition and preservation of deposits of white phosphate are most favorable in those regions where the surface of the limestone reaches a short distance above the level of the valley bottoms. Where the surface of the limestone is too high above the valley bottoms the deposits, if they were ever present, have been largely removed by erosion, whereas the conditions for the formation of caverns are not present where the limestone surface is below the level of permanent ground water in the valleys.

On the south side of Spring Creek about three-fourths of a mile from the Tennessee River is a small deposit of white phosphate, on the hillside, from 75 to 100 feet above the level of the creek. The slope is steep and covered with a thin layer of chert, through which the limestone ledges project at many points. The deposit has been thoroughly prospected by means of a long trench on the hillside and also a shaft. The chert is confined chiefly to a few inches of surface soil. Under this is yellow clay, with fragments of limestone and some chert, down to the surface of the solid limestone ledges. The latter is extremely irregular, and the small cavities contain numerous bowlders of white phosphate embedded in the yellow or blue clay. The amount of phosphate exposed in the cut is very small, and there is no indication of a large body at this point.

About 2 miles east of the above locality, on a tributary of Spring Creek, there are on the hillside a couple of small areas carrying some bowlders of phosphate. The slopes are covered with chert and yellow clay, in which the phosphate is embedded. No prospecting has been done at this point, but the limited extent of the territory covered by the float indicates that the deposits are small in extent. Numerous outcrops of limestone show that the solid rock is near the surface, which precludes the possibility of finding extensive deposits of phosphate here.

The next deposits to the north are on the hillside facing the Tennessee River near the mouth of Parish Branch, and about a mile from the river on the south side of this branch. Both these localities have been thoroughly prospected. The phosphate is somewhat more abundant than at the locality first described, but it is evidently limited by the shallowness of the clay which covers the limestone. The phosphate appears to be of excellent quality, being made up entirely of the lamellar variety, white or pink in color, alternating with zones slightly more massive and somewhat porous, which have a gray or greenish color. The phosphate occurs, so far as can be seen, only in bowlders disseminated through the clay, but most abundant near the surface of the limestone. It does not form a continuous layer as at Toms Creek, and the amount of clay to be removed would be considerable compared with the amount of phosphate obtained. These deposits may contain a few hundred tons, but from present indications the amount would scarcely exceed that.

The white phosphate has been found at three points on Lick Creek. The first is about 2 miles from the Tennessee River, on the Sparks place. It is near the top of a spur on the south side of the creek. The surface of the limestone is covered with a thin layer of cherty clay, and within an area about 50 by 100 feet numerous fragments of phosphate occur on the surface and are shown in a few shallow pits. The smallness of the area within which the float rock is found indicates that no considerable deposit occurs here, although there may be a pocket of some depth. About 5½ miles from the river, also on Lick Creek, the phosphate shows in the roadside as a ledge in place about 2 feet in thickness. Its lateral extent can not be determined, but it is probably not great. Little if any float rock appears on the surface, and the presence of the ledge would not be suspected except for the accidental exposure in the road cutting. About a mile farther up the creek on the south side of the valley, on Tom Young's place, several large bowlders of phosphate occur on the cultivated hillside. No prospecting has been done here, but the scarcity of float would indicate that the deposit is small.

The distribution of the phosphate deposits on Toms Creek has already been described, and thorough prospecting has failed to reveal any considerable amount between the main deposits near the mouth of Wilsdorfs Branch and the Tennessee River.

On Roan Creek, which is next north of Toms Creek, white phosphate has been found at one point about 5½ miles from the Tennessee River. A prospect pit in the creek bottom has brought to light a small amount of the breccia variety. The phosphate forms a matrix in which partially rounded chert pebbles are embedded. The latter are in every way similar to the gravel forming the bed of the creek. As already stated, this creek does not cut down to the limestone, except at its mouth, and therefore the conditions favorable for the formation of the lamellar variety are nowhere present in its valley. The same conditions prevail in the next creeks to the north, Crooked Creek and Blue Creek. Numerous leases have been taken on the farms in these valleys, but they afford no indication whatever of deposits of phosphate. Occasional bowlders of chert breccia cemented by limonite are found, and these are locally regarded as indications of phosphate. They, of course, afford no indication whatever of the presence of such deposits.

Little can be added to descriptions of the Toms Creek deposits east of Wilsdorfs Branch contained in the former report. They have not been opened to any extent, and while conditions at a few points are favorable for the existence of extensive deposits, their extent can be determined only by further systematic prospecting.

Some prospecting has been done in the vicinity of Beardstown at points noted in the 1896 report. The lamellar phosphate here occurs more or less intermingled with clay, and the test pits have not yet revealed a continuous bed such as appears at Toms Creek. It is by no means impossible, however, that such a bed may not occur at greater depth than the pits have yet reached. This locality affords better promise than any other in the district except Wilsdorf, and is worthy of more systematic exploration than it has yet received.

THE WHITE PHOSPHATES OF DECATUR COUNTY, TENN.

By E. C. Eckel.

In several papers, one of which will be found on pages 418 to 423 of the present bulletin, Dr. C. W. Hayes has discussed the origin, geologic relations, and development of the white phosphates of Perry County, Tenn., and has pointed out the areas in which careful prospecting might reveal extensions of the producing field. The present paper is a description of an outlying field of very promising character so discovered.

Most of the prospecting work prosecuted after the discovery of the Perry County white phosphate deposits was carried on in the vicinity of the original discoveries and on the east side of the Tennessee River. Within the last few years, however, considerable exploratory work has been carried on in Decatur County and adjoining areas on the west side of the river. At first, prospecting in this district was attended with little success; but during 1901 phosphate was discovered in quantity, and the new field is rapidly becoming of importance.

The Decatur County phosphate field was visited in August, 1901, by the writer, acting under instructions from Dr. Hayes. The present paper is partly based upon the results of that examination, which was made very soon after the first discovery of phosphate in the region. The progress of the industry in that field during 1901 and 1902 has been rapid, and notes on that progress have been inserted in order to bring the present account up to date as nearly as possible.

The earliest discoveries of workable white phosphate west of the Tennessee River were those made in 1901 by Mr. L. H. Burke, of Parsons, Tenn. After the discovery careful exploratory work was carried on at other points in Decatur County, and control was secured of all the land showing workable phosphate. The holdings of Mr. Burke and his partner, Mr. Hughes, were transferred to the Beech River Phosphate Company, and active work on the development of the deposits was commenced by that company early in 1902. During 1902 about 2,000 long tons of phosphate rock were shipped from this district to various fertilizer factories; and it seems probable that the output of 1903 will be much larger, as machinery is now being installed which will permit more ready handling of the rock.

The phosphates of Decatur County, so far as at present known, can be grouped in three well-separated areas, within each of which the phosphate occurs in isolated deposits. A small area occurs on Cub Creek several miles north of Parsons; the second and largest area includes deposits lying along the tributaries of Beech River between Parsons and Decaturville, while the third area is located along Whites

Creek about 10 miles south of Decaturville. Of these, the second area only was visited, the others not having been developed so extensively. So far as can be estimated at present, the three areas together contain some 300 to 400 acres of land on which the phosphate exists in workable thickness and quality.

In the Beech River area the phosphate is found on the low divides lying between the various tributaries of Beech River. Of the streams entering from the north, only Bear Creek shows phosphate. Along the tributaries coming from the south the phosphate deposits are more numerous, workable quantities being found on the divides between these streams as far east as Lost Creek. As yet no phosphate has been found between Lost Creek and the Tennessee River.

Occasionally the phosphate shows at the surface, but commonly it is concealed by other materials. A typical pit in this area would show a section, from the ground surface down, about as follows:

Typical section in the phosphate field of Decatur County, Tenn.

	Feet.
Chert fragments, mingled with soil or clay	2–5
Phosphate fragments, scattered through clay	1–3
Massive phosphate	3–8
Unaltered limestone (Silurian).	

The overburden, as shown in the pits visited, rarely exceeded 5 or 6 feet. It should be remembered, however, that most of these pits are located on the lower levels of the divides, and that the thickness of the overburden may be expected to increase as the workings get farther into the hill; for Dr. Hayes has shown that deposits of white phosphate, though in no sense stratified, occupy practically horizontal positions.

At the time of the writer's visit, in 1901, the greatest thickness of phosphate shown in any of the prospecting pits was 18 feet, and the writer then estimated the average thickness in the pits at 5 feet. Active exploitation of the deposits has developed the fact that these statements were too conservative rather than too flattering to the new district. Much greater thicknesses are now shown in the workings near Beech River, and it is said that one mine shows a thickness of over 30 feet of workable phosphate.

The rock from this area, as mined, will average 75 to 77 per cent bone phosphate. A series of analyses by Mr. L. P. Brown, of Nashville, Tenn., shows that it varies from 70 to 85 per cent bone phosphate, while its content of iron oxide and alumina together varies from less than 1 to about 3 per cent.

Aside from the areas in southern Decatur County, above described, it is probable that workable white phosphate deposits will be found farther to the north. One such area is now being carefully examined, and may prove to be worth exploitation. The black bedded phosphates (Devonian) have also been reported from various points in northern Decatur County, but at present no trustworthy data regarding the value or distribution of these deposits are available.

PUBLICATIONS ON PHOSPHATES AND OTHER FERTILIZERS.

The following papers relative to natural materials used as fertilizers have been published by the United States Geological Survey, or by members of its staff:

DARTON, N. H. Notes on the geology of the Florida phosphates. In Am. Jour. Sci., 3d series, Vol. XLI, pp. 102–105. 1891.

ECKEL, E. C. Recently discovered extension of Tennessee white phosphate field. In Mineral Resources U. S. for 1900, pp. 812–813. 1901.

ELDRIDGE, G. H. A preliminary sketch of the phosphates of Florida. In Trans. Am. Inst. Min. Eng., Vol. XXI, pp. 196–231. 1893.

HAYES, C. W. The Tennessee phosphates. In Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 610–630. 1895.

——— The Tennessee phosphates. In Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 1–38. 1896.

——— The white phosphates of Tennessee. Trans. Am. Inst. Min. Eng., Vol. XXV, pp. 19–28. 1896.

——— A brief reconnaissance of the Tennessee phosphate field. In Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VI, pp. 633–638. 1899.

——— The geological relations of the Tennessee brown phosphates. In Science, Vol. XII, p. 1005. 1900.

——— Tennessee white phosphate. In Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 473–485. 1901.

IHLSENG, M. C. A phosphate prospect in Pennsylvania. In Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 955–957. 1896.

MEMMINGER, C. G. Commercial development of the Tennessee phosphates. In Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 631–635. 1895.

MOSES, O. A. The phosphate deposits of South Carolina. In Mineral Resources U. S. for 1882, pp. 504–521. 1883.

ORTON, E. Gypsum or land plaster in Ohio. In Mineral Resources U. S. for 1887, pp. 596–601. 1888.

PENROSE, R. A. F. Nature and origin of deposits of phosphate of lime. Bulletin U. S. Geol. Survey No. 46. 143 pp. 1888.

STUBBS, W. C. Phosphates of Alabama. In Mineral Resources U. S. for 1883–84, pp. 794–803. 1885.

WILBER, F. A. Greensand marls in the United States. In Mineral Resources U. S. for 1882, pp. 522–526. 1883.

MINERAL PAINTS.

The following paper on the Georgia ocher deposits represents part of the results of field work by the Survey in that region during 1902. On page 228 will be found a brief note on the utilization of slags in the manufacture of pigments. Many localities still worked for mineral paints were described, with analyses, by Benjamin in Mineral Resources of the United States for 1886, pages 702–714, and incidental references of value occasionally occur in other volumes of that series.

OCCURRENCE AND DEVELOPMENT OF OCHER DEPOSITS IN THE CARTERSVILLE DISTRICT, GEORGIA.

By C. W. Hayes and E. C. Eckel.

OCCURRENCE.

Intimately associated with the brown hematite deposits of the Cartersville district, described on pages 238–241 of the present bulletin, are extensive deposits of yellow ocher which have essentially the same composition, but differ in their physical characteristics. The ocher is confined to the Cambrian quartzite, and occurs along a more or less continuous band extending from the south side of the Etowah River at the wooden bridge northward at least to Rowland Springs, and probably beyond. Since it occurs in the form of a fine powder it makes little show at the surface, and its presence is made evident only by natural or artificial cuttings, which have removed the overlying mantle of fragmental and residual materials. The best exposures of the ocher occur at the south end of the wooden bridge across the Etowah River southeast of Cartersville. Here the river, in cutting across the quartzite ridge, has made a good natural exposure of the beds in place. The ocher has also been extensively mined at this point, so that abundant opportunity is afforded for studying its mode of occurrence. The quartzite with which it is associated has been so extensively shattered by compression that its original bedding is very difficult to determine. At this point the ocher usually forms a series of extremely irregular branching veins, which intersect this shattered quartzite without any apparent system. These veins frequently expand into bodies of considerable size, and when the ocher is removed rooms 6 to 10 feet in diameter are sometimes left, connected by narrow, winding passages. The mining of the ocher has left the point of the ridge completely honeycombed with these irregular passages and rooms.

The contact between the ocher and the inclosing quartzite is never sharp and distinct, but always shows a more or less gradual transition from the hard, vitreous quartzite to the soft ore which may be easily crushed between the fingers. The quartzite first becomes stained a light yellow and loses its compact, close-grained texture. This phase passes into a second, in which the rock is perceptibly porous, having a rough fracture and a harsh "feel," and containing enough ocher to soil the fingers. In the next phase the ocher preponderates, but is held together by a more or less continuous skeleton of silica, although it can be readily removed with a pick. The final stage in the transition is the soft yellow ocher, filling the veins, which crumbles on drying and contains only a small proportion of silica in the form of sand grains.

The intermediate zone between the pure ocher and the quartzite is usually a few inches in thickness, although it may be several feet between the extremes, and, on the other hand, sometimes only a fraction of an inch. When the transition rock is examined under a microscope the character of the transition can be seen even more clearly. The more compact portions, which are only slightly stained with iron, are seen to be composed of a transparent groundmass, threaded with minute cavities which penetrate the rock in all directions and contain a fine dendritic growth of iron oxide. The latter occurs only rarely in isolated grains, but generally in clusters of minute grains or fibers attached to one another and branching irregularly from a central stem. They have no trace of crystal form. Passing toward the ore body, these minute passages become larger and increase in frequency, until only a finely branching siliceous skeleton remains, the greater part of the rock having been replaced by the iron oxide. Under polarized light the transparent groundmass is broken up into an aggregate of small quartz grains penetrated in all directions by the iron oxide. The latter does not lie between the individual grains, but passes through them as though the groundmass were quite homogeneous. The process of replacement is never complete, for all the ocher contains more or less sand. When this is washed clean from the iron oxide it is found to differ from ordinary sand grains in having extremely irregular outlines. This sand, as might be anticipated from the microscopic structure of the slightly altered quartzite, is evidently composed, not of the original grains of the rock, but of detached portions of the irregular siliceous skeleton which in the intermediate stages of replacement holds the iron oxide in its cavities. Aside from the silica the ocher as mined contains only hydrated ferric oxide, a small amount of alumina, and a trace of manganese oxide, the latter giving it a slightly greenish tint.

Some portions of the Cambrian quartzite contain interbedded siliceous shales, and the silica in these has also been replaced to some extent by iron oxide, producing an ocher which is inferior to that derived from the quartzite, since it contains considerable clay—practically all the argillaceous matter originally contained in the shales. Embedded in this ore are numerous small cubes of pyrites, or rather limonite pseudomorphs after pyrite. These were probably an original constituent of the shales, before the replacement occurred.

The above-described structure of the ocher and the inclosing quartzite, particularly as observed under the microscope, throws considerable light upon its mode of origin. The forms of the residual sand grains in the ocher and of the siliceous skeleton about its border were evidently produced by solution. It seems probable, therefore, that the iron oxide is a direct replacement of silica. The faulting of the region, by fracturing the rocks, afforded favorable conditions for the percolation of surface waters to great depths; and since the faulting was doubtless accompanied by the development of considerable heat, the region was probably characterized by numerous thermal springs. The work of Van Hise and others has shown that, under favorable conditions, especially under great pressure and at high temperatures, silica becomes one of the readily soluble rock constituents. It appears that, under certain conditions, a carbonic acid solution of iron carbonate, meeting an oxidizing solution, precipitates its iron as hydrated ferric oxide and at the same time dissolves silica.

The conditions for this reaction seem to have been present in the Cartersville region. Water, containing in solution iron carbonate or other ferrous salts derived from the decay of surface rocks, must have penetrated to considerable depth, particularly through the shattered quartzite. But in addition to this solution of iron percolating downward from the surface, the open fissures probably afforded abundant opportunity for the free circulation of water containing oxygen. The two solutions coming in contact, the iron carbonate was oxidized and precipitated as limonite, in the place of silica dissolved at the same time. The solution of the silica, which is the part of the process difficult to understand, may have been assisted by the presence of alkalies in the oxidizing solution. It was probably greatly assisted by the heat which must have resulted from the faulting. It is also possible that carbonic acid, in the so-called nascent state, at the point where it is freed from one compound, may be a much more efficient solvent for silica than in its ordinary condition.

Numerous open passages and cavities penetrating the quartzite and the bodies of ocher are met in mining. The smaller cavities are generally lined with a crust of small quartz crystals, while the larger ones frequently contain beautiful crystals of barite, which were probably deposited after the conditions favorable for the solution of silica and the deposition of ocher had passed. Groups of acicular crystals of this mineral, several inches in length, are not uncommon. It also occurs in white granular veins. The barite is called "flowers of ocher" by the miners. It remains in the residual soil which covers the quartzite outcrops and affords the best means of tracing the ocher deposits. It is found at numerous points on the low quartzite ridge north and south of the Etowah River, and prospecting at these points has never failed to reveal more or less extensive deposits of ocher. A small amount of barite is annually shipped from the Cartersville district, the material being obtained in the course of ocher mining.

DEVELOPMENT.

The ocher industry in the vicinity of Cartersville has developed rapidly within the last few years. At present four mines, with their accompanying mills, are in active operation, while two additional properties have been sufficiently developed to be worthy of note. Numerous undeveloped prospects are to be found within a few miles of Cartersville, and it is probable that the industry will increase in importance in the future.

The mines and mill of the Georgia Peruvian Ocher Company are located about 2 miles southeast of Cartersville, on the south bank of the Etowah River, at the wooden bridge. The deposits and workings here have been described in considerable detail on a preceding page of the present paper. Recently the workings have run into large masses of ocher, and in consequence work is now mostly carried on in open cuts, instead of the small tunnels which were formerly used. The mill is located at the river bank, near the mine. The methods of milling the product do not differ greatly at the various ocher plants in the Cartersville district, and a general description of the practice followed will be given later in this paper.

The Cherokee Ocher and Barytes Company is working at a point about 1 mile northeast of Cartersville. The workings here are all underground and quite extensive. They have been opened up along a slope driven down on the dip of the beds, which here dip eastwardly at an angle of 30° or so. It is to be noted that in these mines the ocher appears to have replaced particular beds of the quartzite, so that it now occupies a fairly definite stratigraphic position. In this respect the deposit differs greatly from that of the preceding company, where replacement appears to have taken place largely along joint planes in the quartzite, causing great irregularity in the shape and position of the resulting ocher deposits.

At the plant of the American Ocher Company, located 1 mile northeast of the railroad bridge over the Etowah, preliminary mining work had been done at the time of visit, and a mill was in process of construction. Trenches and open cuts exposed ocher, but the underground work was not far enough advanced to show the relations of the ocher to the quartzite.

The mines and mill of the Blue Ridge Ocher Company are located about 1½ miles east of Cartersville. Considerable underground work has been done, the deposit being opened up by slopes running down the dip, which is to the eastward. Though the relations between the position and shape of the ocher deposit and the bedding planes of the quartzite are not quite so clear in this mine as in that of the Cherokee Company, it is evident that the ocher body is fairly regular. The manager states that a body of ocher 118 by 174 feet in area and averaging 6 feet in thickness has been effectively exposed by crosscuts. The brightest colored ocher is said to occur immediately above the quartzite of the foot wall, a relation which exists also in the mine of the Cherokee Company.

An ocher deposit of fair size is exposed in a railroad cut about 1 mile south of the Etowah River crossing. The Satterfield openings are located on the north bank of the Etowah, about 100 yards east of the railroad bridge, and the Laramore property is about 3 miles east of Cartersville, on the north bank of the river. At neither of these points has sufficient work been done to give a clear idea of the extent or relations of the ocher deposits, though ocher is shown in natural outcrops or in small cuts at each of them.

The composition of Cartersville ocher, as compared with that of similar products from other localities, is shown in the following table of analyses:

Composition of natural ochers.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Fe_2O_3	55.84	70.00	63.30	35.00	36.67	42.45	52.92	33.00	56.59
SiO_2	32.20 (SiO_2 + Al_2O_3)	13.00	20.00	47.00	50.00 (SiO_2 + Al_2O_3)	30.58	2.88	39.00	30.17
Al_2O_3		3.60	5.00	6.00				15.00	3.79
CaO									2.65
MgO									1.43
Alk								0.5	
CO_2									1.73
H_2O	12.00	13.00	11.70	10.80	10.60	11.85	14.62	11.5	1.62

1. Cartersville, Ga. Dark brown. Merrill, Rept. U. S. Nat. Mus. for 1899, p. 240.
2. East Whately, Mass. Deepest yellow. C. U. Shepard, analyst, Bull. U. S. Geol. Survey No. 126, p. 101.
3. East Whately, Mass. Deepest yellow. C. U. Shepard, analyst, Bull. U. S. Geol. Survey No. 126, p. 101.
4. East Whately, Mass. Yellowish brown. C. U. Shepard, analyst, Bull. U. S. Geol. Survey No. 126, p. 101.
5. Hancock, Berks County, Pa. Yellow brown. Merrill, Rept. U. S. Nat. Mus. for 1899, p. 240.
6. Northampton County, Pa. Deep red brown. Merrill, Rept. U. S. Nat. Mus. for 1899, p. 240.
7. Brandon, Vt. Dark brown. Merrill, Rept. U. S. Nat. Mus. for 1899, p. 240.
8. Marksville, Va. Mineral Resources U. S. for 1885, p. 528.
9. Persian Gulf. "Indian red." Mineral Resources U. S. for 1883-84, p. 926.

Milling.—As above noted, the ocher milling practice at the various plants in the Cartersville district is fairly uniform. As mined the ocher contains a considerable quantity of coarse sands, with occasional fragments of quartzite. The presence of part of these impurities can be avoided by careful selection during mining, but owing to the manner in which the deposits have originated, the ocher will always contain some sand and quartzite, representing those portions of the original material which have not been entirely replaced. It is the object of the treatment described below to separate from the ocher as much as possible of these impurities.

The ocher, brought in cars from the mines, is either dumped directly into a log washer or dumped on a platform and shoveled into the washer. The log washer consists of a log 12 to 20 feet in length and 8 to 14 inches in diameter. Iron teeth or paddles are set along the log in an irregular spiral. The log revolves in a trough (into which water flows) by power applied to gearing at one end of an axis passing lengthwise through the log. The paddles, during the revolutions of the log, break up the material (crude ocher) fed in and gradually force the solid residue (sand, etc.) to the upper end of the trough, while at the same time the water carries off the lighter portion (containing the ocher and the finer particles of sand and clay) at the lower end of the washer. The ocherous water is led through a series of settling troughs 300 to 800 feet in length, set at a gentle slope. The heavier particles are deposited in these troughs, while the water, still carrying the fine ocher, passes on into large settling tanks. Here it is allowed to stand until the ocher has settled to the bottom. The overlying water, fairly clear, is then drained off through pipes set in the sides of the tanks. The ocher in the tanks is allowed to dry, under the action of the sun, until it is solid enough to be handled. It is then shoveled out and taken to the drying house. The final drying takes place either on racks in the open air or over coils of steam pipe. The latter process is of course quicker, but results in the loss of part of the ocher, as that portion nearest the pipes is dehydrated too much and takes a reddish tint. After drying, the material is finely ground. The machine used for this purpose is a Clark pulverizer or other mill of the same type (disk pulverizer).

TALC.

Various folios issued by the United States Geological Survey have contained data relative to North Carolina talc deposits. This material has been combined, and forms, with additional data collected during the last field season, the paper presented below.

TALC DEPOSITS OF NORTH CAROLINA.

By Arthur Keith.

One of the chief sources of talc in the United States is the series of deposits in North Carolina. These are found almost exclusively in the mountain region at the western end of the State, but one class of rocks in which talc is found appears to a limited extent in the Piedmont Plateau as well.

Talc is a hydrous silicate of magnesia, and is notable for its infusibility, its softness, and its smooth, greasy feel. On account of these characteristics its various uses have been developed. Its infusibility fits it for gas tips and vessels which have to stand extreme heat. The massive varieties are manufactured into pencils and articles for marking. Little of the North Carolina talc is suitable for cutting into pencils, practically all of that character coming from the narrow belt in Cherokee and Macon counties. When scratched or rubbed against any ordinary surface the talc gives a white streak. Its softness also renders it easily cut, sawed, or ground into powder. Its unctuous nature enables its powder to diminish friction.

There are two general sources of the North Carolina talc. It occurs as a series of lenticular masses and sheets in the blue and white Cambrian marbles along the Nantahala, Valley, and Nottely rivers. These rocks, termed the Cherokee marble, have a length of about 40 miles in North Carolina, and are continued in Georgia for a much greater distance. The development of talc is much less in Georgia, however, than in North Carolina. The second class of talc deposits is connected with the bodies of soapstone which are found at many more or less separated places in the Archean rocks of North Carolina.

The soapstones and allied rocks are part of a great belt of such rocks which passes through northern Georgia, South Carolina, North Carolina, Virginia, and Maryland into Pennsylvania, running practically the entire extent of the Appalachians. Although the formation is thus very widespread, few of its areas are over a mile in length. Many of the outcrops are to be measured by a few feet, and not many of them cover more than an acre.

In the first or "marble" group of talc deposits is found the best talc in the State. Talc appears in more than twenty-five places along the marble belt of North Carolina, but is less common in Georgia. The situation of these will be indicated on the maps of the Nantahala and Murphy folios. It occurs in the shape of lenticular bodies inclosed in the marble and varying in size from mere scales up to masses 50 feet thick or 200 feet long. Owing to its soft nature the talc does not withstand weathering, but readily crumbles down. It does not outcrop, therefore, and its position is marked on the surface only by a few weathered fragments. Thus it is impossible to determine the full extent of the talc bodies except where they have been exposed by mining. For this same reason it is probable that many bodies of talc have escaped observation thus far. Some of the bodies are so extensive that they resemble sheets of sedimentary material. This is especially the case where the talc sheets grade into the adjoining sandstone beds. They are termed "veins" by the miners, but have none of the characteristics of true veins.

It is not probable that the talc was deposited in its present form as a sediment, although the inclosing marbles are of that character. The rocks of the entire region have been tremendously folded and compressed, and most of the original materials and minerals have been recrystallized. No sedimentary deposits of talc are known in the Appalachians, so that it is probable that the constituents of the talc existed in the adjacent sedimentary rocks in some other form. Some of the beds of the marble formation now contain a considerable percentage of magnesia in the form of the carbonate. It is probable that the source of the magnesium carbonates and that of the hydrous silicates are the same, both being derived from the materials of an original sedimentary dolomite. The development of the talc in the scales which are disseminated through the mass of the marble is thus easily accounted for. The concentration of the talc into lenses and sheets is, however, difficult to understand. Some of the lenses are barely twice as long and broad as they are thick, while others are very much attenuated and form thin sheets, as already stated. The lenses appear to be somewhat drawn out, and pass into the marble with very thin edges.

The color of the talc varies considerably in the different lenses and sheets. By far the greater part of it is dull white. Of this color are all of the weathered or semiweathered portions, which are near the surface. In the talc which is secured by mining from the solid rock light colors prevail, varying from bluish and greenish white to a dull blue and a pale green. The freshest mineral is translucent. This character has been lost by all of the weathered talc, which is perfectly opaque. Much of the weathered material is also stained with iron oxide from the ferruginous minerals in the schists which border the marble formation. This rust coats and stains the surface of the fragments and penetrates into their interior by cracks and seams. It is a serious detriment to the quality of the talc, since it is mixed throughout the latter when it is ground.

As can be readily understood from the dimensions of the talc lenses, the quantity of the talc varies greatly. It is only by actually working out each body or by thoroughly testing by diamond drill that any idea of the amount can be obtained. A lens whose edge only can be seen is as likely to be large as small. It is equally impossible to predict where a mass of talc will or will not be found. Many of the miners say that the talc is always overlain by a white sandstone called the "cap rock." This is often the case, but is not the rule, for the talc is frequently formed where there is no associated sandstone. The talc lenses are not confined to one horizon in the marble, but may appear between several distinct layers. Variations in the quality of the talc are considerable, also, even in the same body of marble. For instance, at Hewitt's mine on Nantahala River both the massive and the fibrous varieties are found, as well as the blue, green, and white colors. One quality and color usually predominate in a single lens or sheet.

The texture and grain of the talc are very variable, even in the same group of lenses, as was just stated in reference to the Hewitt mine. The talc scattered through the mass of the marble is usually in the shape of foliated scales. The same is true to a greater or less degree of the thin edges of the various lenses. Some of the thicker lenses are composed practically entirely of massive talc. This has no cleavage or tendency to part in one direction rather than another, and is sawed into pencils and sheets. Most of the talc has a tendency to break into long, thin fragments, flakes, and fibers.

Inasmuch as the methods of manufacture of the talc depend upon its softness, any impurities which affect that quality are a detriment. Other impurities, such as stains by iron rust and soil, were spoken of above. These can be removed, however, in part. The principal impediments to the working up of the talc are the associated minerals, mostly silicates. These are inclosed in the mass of the talc in crystals arranged at a great variety of angles. The silicates consist chiefly of hornblende, tremolite, actinolite, and chlorite, all containing a certain large percentage of magnesia. There are also found occasional grains of pyrite and magnetite. In localities where the sandstone "cap rock" is found there is sometimes a mixture of the sand grains and the talc, as if the talc was a sedimentary deposit. The crystals of the silicates vary in size from mere needles up to prisms with diameters of half an inch and a length of 2 or 3 inches. These may be developed singly or arranged in radiating bunches and groups. The greatest development of these silicates is seen 5 miles northeast of Murphy, where the largest talc body of the region is rendered worthless by them for the present. They are intergrown with the talc in such numbers that it is not practicable to separate and work up the talc. These same minerals are to be seen in a number of localities crystallized in the marble where there is no talc.

The methods employed in extracting the talc lenses from the marble are very simple. For the most part the talc is obtained from pits and shallow shafts in the soil and decomposed rock. The pockets of talc thus encountered are usually a good deal weathered, and accordingly of less value. In the large mass of talc exposed 5 miles northeast of Murphy an open cut 50 feet square has been made, and the amount of talc in sight is large. As above stated, however, the silicate impurities there render the talc less desirable and easy to work. The chief developments in talc mining are confined to the extreme end of the Cherokee marble belt, on Nantahala River. Tunnels and shafts have been sunk in several adjoining properties, extending about a quarter of a mile along the river, and a body of talc has been proved for a vertical extent of about 150 feet. The dip of the strata and the included talc sheets is about 45° SE., which carries them under the bed of the river. The talc has been found in a shaft sunk considerably below the level of the river and is now being mined. In the past most of the talc has been taken out from the smaller and more irregular lenses encountered here and there in the marble at points up to 100 feet above the river. From various tunnels of the Hewitt mine at this point a considerable amount of marble has been taken out in following up the talc. The slope of the hillside follows very nearly down the dip of the marble, and has been stripped over a large area in the search for talc. All the talc deposits of the Cherokee marble are readily accessible, for a branch of the Southern Railway runs within a few rods of the marble belt throughout its extent in North Carolina.

The second, or "soapstone," group of talc deposits is of far greater extent than the preceding group. The soapstone and talc are derived from the metamorphism of a very basic intrusive rock and are almost always found in connection with the areas of hornblende-gneiss and schist. Metamorphism of these basic rocks at different places has also resulted in the production of serpentine, dunite, and a number of less important rocks. Although the areas of the formation seldom exceed an acre, it is customary to find several of the metamorphic varieties associated in each area. The dunite type prevails in the southwestern portion of the mountains in North Carolina and the soapstone type in the northeastern. In the French Broad Valley, about in the middle of the belt, soapstone is by far the most common, over 80 separate areas being known below Asheville. In this district alone are there any considerable bodies of workable talc. They are concentrated in a belt 4 or 5 miles wide on each side of the French Broad River between Marshall and Alexander, and will be shown in the forthcoming Asheville geologic folio. In the forthcoming Mount Mitchell folio, and in the Cranberry folio, now in press, many other areas of soapstone are represented.

The talc or hydrous silicate of magnesia was formed by alteration of a basic rock which contained originally an abundance of magnesian silicates. In most cases, however, there were formed in addition to the talc a number of other silicates containing magnesia, such as tremolite, actinolite, hornblende, and chlorite. These are practically the same minerals which occur as impurities in the talc of the Cherokee marble formation. As a rule, the talc is equaled or exceeded in amount by the other silicates, and the rock formed by them is a soapstone. This is especially the case in Watauga and Ashe counties, where the other silicates so predominate that the rock is often of no value even for the uses of soapstone.

Why the talc predominates in one region and the other silicates in another is a matter of doubt. In many places a portion of the mass is mainly talc or a very pure soapstone, while other portions may be filled with the silicate minerals. Where there are differences of this kind in a single soapstone body the purer soapstone and talc are usually at the borders of the mass, being influenced in some manner by the contact of the adjoining rocks. Besides the talc of this form, pure talc is also found in veins a few inches in width passing here and there through the mass of the rock. This form of the mineral is usually fibrous or foliated and free from the objectionable silicates. Talc veins of this character seem to be of later formation than the large bodies of talc and the soapstones. These veins are also found in the serpentine and dunite masses, together with veins of chlorite and asbestos.

The talc so far mined has been taken from the veins and from the purer portions at the borders of the soapstone mass. Although the amount of talc disseminated through the soapstone is infinitely greater, it is not practicable to separate it from the chlorite and other minerals which are intermingled with it. In following the vein talc there is a fair amount of certainty as to the product, both in quality and in quantity. In the bordering bodies of talc the quantity is much greater and can be figured upon fairly well. The quality is quite uncertain, however, and the value of the talc is liable to be much lessened by the presence of the other silicates. It is impossible to say in advance when the quality of the talc will be thus depreciated.

The talc is almost entirely white, sometimes translucent, but usually opaque. It is probable that if work were pushed into the solid rock the translucent material would predominate. Thus far mining has been confined to pits in the clay and decomposed rock. Stains of earth and iron oxide are common in this material, as they were in the weathered talc of the Cherokee marble. The talc now produced varies from massive to fibrous, the latter being the most common It is fitted only for grinding into powder. Although the amount of talc of this class is considerable, very little is now produced, and the industry is nearly at a standstill. Practically all the talc mined in the State comes from the Cherokee marble.

MISCELLANEOUS NONMETALLIFEROUS MINERAL PRODUCTS.

Several nonmetalliferous products have been discussed in the present bulletin in conjunction with closely associated and economically more important metalliferous ores. Under the head of lead and zinc, for example, will be found a discussion of the fluorspar deposits of Illinois and Kentucky (p. 205), while a newly discovered pyrite deposit in Georgia is described in connection with the gold deposits of the same region (p. 62).

PUBLICATIONS ON MICA, GRAPHITE, ABRASIVE MATERIALS, ETC.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various nonmetalliferous mineral products not treated separately in the present bulletin:

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EMMONS, S. F. Fluorspar deposits of southern Illinois. In Trans. Am. Inst. Min. Eng., vol. 21, pp. 51–53. 1893.

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HIDDEN, W. E. The discovery of emeralds and hiddenite in North Carolina. In Mineral Resources U. S. for 1882, pp. 500–503. 1883.

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RABORG, W. A. Buhrstones. In Mineral Resources U. S. for 1886, pp. 581–582. 1887.

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TURNER, G. M. Novaculite. In Mineral Resources U. S. for 1885, pp. 433–436. 1886.

——— Novaculites and other whetstones. In Mineral Resources U. S. for 1886, pp. 589–594. 1887.

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