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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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W. C. MENDENHALL, CHIEF GEOLOGIST

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[The letters in parentheses preceding the titles are those used to designate the papers for advance publication]

ILLUSTRATIONS

CREDITS AND CORRECTIONS, PROFESSIONAL PAPER 154

The Director of the United States Geological Survey regrets that the paragraphs on pages 5 and 10 of this report concerning Mr. Lawrence Martin's studies in the Lake Superior region appear to reflect unjustifiably upon the published work of that author and the amount of field work done in its preparation. Had the matter come to attention sooner, a revised and more appropriate statement of the differences of interpretation of Messrs. Martin and Leverett would have been inserted.

Credit should also be given to Mr. Martin and to the department of geology of the University of Wisconsin for the use of the photograph of a copyrighted model of the Lake Superior region (pl. 3), which was prepared under the direction of Mr. Martin for and is owned by the University of Wisconsin.

The reference to Figure 7 on page 58 should read Figure 8.

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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1928

MORAINES AND SHORE LINES OF THE LAKE SUPERIOR BASIN

By Frank Leverett

INTRODUCTION

SCOPE OF THE REPORT

The district discussed in this report embraces the entire northern peninsula of Michigan and the parts of northern Wisconsin and northeastern Minnesota that were covered by a readvance of the Superior lobe of the Labrador ice sheet late in the Wisconsin stage of glaciation. Part of the northern peninsula of Michigan is outside the limits of the Lake Superior drainage basin, but the Superior lobe passed over it in this readvance to reach the basins of Lake Michigan and Lake Huron. There is, however, a small area in Iron County and southeastern Gogebic County, Mich., which was not overridden by the readvancing Superior lobe. This area is included in the present report in order to bring out the contrast between its features and those produced by the Superior lobe at the later time. A similar comparison is also made between the glacial features of the Superior lobe in northern Wisconsin and northeastern Minnesota and those immediately outside the limits of the readvance.

TIME GIVEN TO THE INVESTIGATION

The studies on which this report is based began in the field season of 1905, during which three or four counties in the east end of the northern peninsula of Michigan were examined. No further work was done in this district until 1909, when studies were made along the immediate border of Lake Superior in Michigan and to some extent in Wisconsin and Minnesota. This work was continued in 1910 and 1911, so that nearly the entire district had been examined by the end of the 1911 field season. In 1912 about three weeks was spent in running levels to shore lines in the northern peninsula, and in each of three subsequent years—1913, 1914, and 1916—this district received three or four weeks' attention in connection with other studies in Minnesota. In 1919 about five weeks was spent in Menominee County, Mich., and a number of places farther east, including Drummond Island. The entire time taken in field work in the several years amounts to about 16½ months by the writer and about 6 months by his assistants.

WORK BY ASSISTANTS

The assistants were furnished by the Michigan Geological Survey during part of the work in that State. Although they did very little independent work on the surface geology, they were very helpful in running out side lines and filling in intervals between traverses made by the writer, as well as by their companionship in breaking courses through the woods in unsettled or very thinly inhabited parts of the district.

G. E. Tower, a student of the University of Michigan, and W. C. Gordon, of the Michigan Geological Survey, assisted in 1905; L. H. Wood, of the Western Normal School of Michigan, in 1908; I. D. Scott, of the geological department of the University of Michigan, in 1910; L. G. Hornby, university student, in 1912; and R. W. Peterson, of the Michigan Agricultural College, in 1919. In the Minnesota work assistance was furnished by the State Geological Survey, connected with the University of Minnesota. This included the services of A. H. Elftman for a few days in 1913 and a considerable part of the services of F. W. Sardeson for a period of years. The expenses of the work by Doctor Sardeson prior to 1912 were met by the United States Geological Survey. The Wisconsin Geological Survey contributed the services of F. T. Thwaites and an assistant in running levels to high shore lines at Bayfield and on Oak Island. Some of the writer's work in Wisconsin was done in company with Samuel Weidman, of the Wisconsin Geological Survey, who was making investigations preparatory to a general report of his own on northern Wisconsin for the State survey.

NATURE OF COUNTRY AND CHARACTER OF INVESTIGATION

The present report on the glacial and lake features of the Lake Superior Basin is made as a report of progress rather than of a completed study. Owing to the imperfect development of roads or lines of travel, the sparseness of settlement, and the uncleared and brushy condition of much of the land bordering this basin, it was found to be impracticable to work in the detail that is done in more fully cleared and well-settled districts. As a consequence there has been very little consecutive tracing of the courses of shore lines and of other features that need close work for complete mapping. The entire set of beaches has been crossed along a number of lines leading from the shore of Lake Superior up to the limits of lake action, but these traverses have only served to show that the development of beaches was not at all uniform, there being a larger number of definite beaches on certain lines of traverse than were found on neighboring lines. It has thus become apparent that a complete correlation of beaches can be made only by detailed work that will entail much more time and expense than it has seemed best to allot to the study of the region at present. The extent of lake action has been determined with close approximation, however, and a large amount of information concerning the tilting of shore lines has been collected. The direction of the melting away of the border of the ice sheet has been somewhat fully worked out, and the relation of the lake stages to the ice has been determined to some extent. There are, however, a few matters of uncertainty as to the correlation of some of the moraines with shore lines that it has been found difficult to clear up, and for these a tentative correlation is the best that can now be given.

RESTRICTION TO LATE PART OF GLACIAL EPOCH

This region has experienced not only repetition of glaciation from one direction but also a marked shifting of ice movement in the last glacial stage, so that transportation of glacial débris and striation of rock ledges are far from uniform in direction. Thus at times the ice passed southward across the west end of the Lake Superior Basin with a surprising disregard of the topography, whereas at other times the ice movement was markedly controlled by the topography, and the axial direction was through the basin from its northeast to its southwest end. The present report deals almost entirely with the latest ice movement that affected the Lake Superior Basin. The disappearance of the ice from this basin occurred very late in the Wisconsin stage of glaciation. Indeed, this basin seems to have been about the latest part of the northeastern quarter of the United States to lose its ice covering.

This report supplements Monograph 53 by carrying the description from the north end of the Huron and Michigan Basins to the west end of the area of the great Laurentian lakes. Taken in connection with that monograph, it sets forth how the ice front made its final retreat and how ponded waters were formed in front of it; how earth movements as well as ice barriers have been influential in controlling the extent and the outlets of the waters; and how the present Great Lakes have come to have their drainage connections and discharge to the Gulf of St. Lawrence. As yet there is lacking an adequate report on the Green Bay Basin and certain other parts of the west side of Lake Michigan, though the features on the west side of the south end of the basin have been covered by the writer in Monograph 38 and those of southeastern Wisconsin by W. C. Alden in Professional Paper 106. There is also lacking an adequate study and treatment of the Ontario Basin, the Georgian Bay Basin, and the northern part of the Superior Basin—much of which falls to the Canadian geologists.

EARLY EXPLORATIONS AND INVESTIGATIONS

The Lake Superior shores were visited by missionaries, explorers, and traders as early as the second half of the seventeenth century, or fully 250 years ago. A map of Lake Superior coast line published in Paris in 1672 shows that most of the shore had been explored by persons skilled in observation and mapping. This map is reproduced in the Foster and Whitney report on the Lake Superior land district published in 1850. An interesting compilation of journals of these early explorations, by Louise Phelps Kellogg, entitled "Early narratives of the Northwest, 1634–1699," was published by the Scribners in 1917.

Over a century ago, in 1820, Henry R. Schoolcraft conducted a scientific expedition to the upper Great Lakes, giving attention to their shore features as well as the mineral formations. He noticed evidence of lake action at high levels in the form of both shore lines and lake deposits. These features were also noted by the British traveler Dr. John Bigsby at an even earlier date, his observations having begun in 1817 and his papers being published in 1821. A paper by H. W. Bayfield outlining the geology of the Lake Superior basins appeared in 1829. A report by Douglass Houghton on the copper of the Lake Superior Basin appeared in 1834, and his offical reports as State geologist of the First Geological Survey of Michigan for 1840, 1841, and 1842 deal to some extent with the northern peninsula. After the discontinuance of this geological survey arrangements were made by Houghton with the United States General Land Office to combine a geological survey with the linear land survey in the northern peninsula. This work, which began in 1845, was terminated near the end of the first field season by the drowning of Houghton in Lake Superior in October, 1845. His notes and maps, however, were brought out the following year by Bela Hubbard, and with them the notes of William A. Burt, an engineer in the land survey. The township plots made in the survey carry numerous notes on the geology and topography. The cliffs marking high shore lines are accurately shown in many places and for considerable distances. The Land Office report for 1847 contains geologic observations by John Locke on the northern peninsula of Michigan.

Brief reports on the Lake Superior mineral land district were issued in 1845 and 1846 in congressional documents, which the writer has not seen. One of 22 pages, with maps, by John Stockton included reports by J. B. Campbell, G. N. Sanders, and A. B. Gray. Another of about 25 pages was prepared by William Bartlett and David Tod.

The transportation of a boulder of copper from the south shore of Lake Superior by drift agencies and the occurrence of drift furrows, grooves, scratches, and polished surfaces were brought to notice in 1847 by Forrest Shepherd in two articles in the American Journal of Science.

In 1847 Congress passed an act providing for geologic exploration of the Lake Superior land district, and C. T. Jackson was appointed to lead the survey His explorations were carried on for two field seasons and a report of about 800 pages was issued.[1] This report refers briefly (p. 389) to the occurrence of several terraces, each of which marks an ancient lake level; also to lake action at high level on the Pictured Rocks, between the present towns of Grand Marais and Munising. The bouldery tracts on the site of the present city of Sault Ste. Marie were also correctly interpreted as the product of a higher lake level.

On the resignation of Jackson the survey was continued and completed under the direction of J. W. Foster and J. D. Whitney. Their reports, commonly known as the Foster and Whitney reports, embrace a volume of 224 pages on the copper lands, submitted as Part I in April, 1850, and a report of 406 pages on general geology and the iron region, submitted as Part II in November, 1851. Foster and Whitney were aided in the field work by S. W. Hill and E. Desor and by James Hall, who served as paleontologist. Their report contains papers by I. A. Lapham and by Charles Whittlesey, chiefly on the Wisconsin portion of the district. The studies set forth in Part II extended around the entire lake border of the northern peninsula as far as the head of Green Bay and embraced the islands from Drummond Island to Mackinac Island. Desor presented in this report and also in papers for the Boston Society of Natural History, the American Journal of Science, and foreign journals discriminating and interesting discussions of the surface geology. He inclined, however, to the view that the surface boulders and the surface sand at all altitudes are due to the action of lakes rather than of glaciers, but was correct in holding that the lakes succeeded the glaciers in occupying this country. He discussed in some detail old shore lines on Mackinac Island. Whittlesey contributed a chapter to the Foster and Whitney report on the fluctuations in the level of the present lakes and on magnetic variations.

In 1847, by congressional action, a survey of the Chippewa land district of Wisconsin was authorized, and D. D. Owen was appointed as the head of the survey. His report of 134 pages, submitted in April, 1848, appears as Senate Executive Document 57 of the Thirtieth Congress. It embraced a report by his assistant, J. G. Norwood, and covered a considerable part of northern Wisconsin, including notes of journeys through the district on different routes. These notes are essentially a journal, with but little generalization or interpretation, owing to the insufficiency of the data. Pains were taken with barometric observations, in order to obtain reliable data as to the altitude of Lake Superior. The report is embellished with artistic sketches by Owen, and the map is of interest in showing the state of knowledge of lakes, drainage, and rock outcrops. Studies were continued by Owen and Norwood after making this preliminary report. Norwood's work, embracing the field seasons of 1847, 1848, 1849, and 1850, was the basis for a report of about 200 pages, included in Owen's "Geological survey of Wisconsin, Iowa, and Minnesota," published in 1852, It comprised the Minnesota as well as the Wisconsin shore of Lake Superior and extended across to Mississippi, St. Croix, and Wisconsin Rivers. The conditions of streams as to rapids and rock outcrops, the lakes, and the general topographic features are well brought out. It was also noted that there are swampy channels across the divide between the Great Lakes and Mississippi drainage basins at several places. In this final report only a few pages were contributed by Owen on the district bordering Lake Superior.

A chapter by Charles Whittlesey on the Wisconsin part of the country bordering Lake Superior appears in Owen's report just cited. It discusses the features resulting from glaciation and from lake occupancy and considers the clays to be fresh-water deposits. In 1851 Whittlesey brought out two papers, one of which is incorporated in Foster and Whitney's report, and deals with low beaches on the borders of the lakes now referred to the Nipissing Great Lakes, and the other is a general paper on the superficial deposits of the "northwestern part of the United States" (that is, Ohio, Michigan, Illinois, and Minnesota), published in the Proceedings of the American Association for the Advancement of Science. Whittlesey also published brief papers in the Cleveland Annals of Science in 1853 and 1854 on the drift and "drift etchings" of this region.

At about the time surveys were in progress under Foster and Whitney and under Owen a study of the features of the Lake Superior region was made by Louis Agassiz, the results of which appear in the volume of 428 pages entitled "Lake Superior; its physical character, vegetation, and animals compared with those of other and similar regions, with a narrative of the route by J. Elliott Cabot," issued in 1850. This was preceded by a short paper published in the Proceedings of the American Association for the Advancement of Science for 1849 on the "Terraces and ancient river bars, drift, boulders, and polished surfaces of Lake Superior," in which the terraces were referred

[1] Messages and Docs. 1849-50, pt. 3; 31st Cong., 1st sess., S. Ex. Doc. 1, vol. 3, 1849.

to lake action. A chapter of the volume mentioned, "Erratic phenomena about Lake Superior," was published in the American Journal of Science in 1850. The opinion is expressed in this volume that earth movements rather than the cutting away of a land barrier have brought about changes in the lake level. The influence of the ice sheet as a barrier was not mentioned, though Agassiz, like Desor, considered glacial action to have operated during at least part of the period of drift deposition.

From about 1855 to 1870 there appears to have been little study of the surface features of the Lake Superior Basin in progress in any of the three States bordering the lake, and writings on this subject were restricted to an occasional brief paper. A paper by Charles Whittlesey on "Fresh-water glacial drift of the Northwestern States" (Ohio to Minnesota) was issued in the series of Smithsonian Contributions to Knowledge in 1866. In 1870 G. R. Stuntz, a land surveyor, published a note in the Proceedings of the American Association for the Advancement of Science on the rise of water in the southwest end of the Superior Basin and the encroachment of Lake Superior on areas that once sustained forest growth, as shown by the presence of stumps. In 1871 N. H. Winchell contributed a short paper to the American Journal of Science suggesting that Lake Superior at a former high stage had discharged southward through the Au Train-Whitefish Valley to Little Bay de Noc, at the north end of Green Bay.

There was in this period a State Geological Survey of Wisconsin, under the direction of J. G. Percival in 1855 and 1856 and of James Hall and J. D. Whitney for a few years later, but its investigations pertained largely to the fossiliferous rock formations, including the geology of the lead region. A State Geological Survey of Michigan, under the direction of Alexander Winchell, was instituted in 1859 and issued a report in 1860. This report pertains almost entirely to the southern peninsula, and studies by Winchell in the northern peninsula were restricted largely to the vicinity of Drummond Island and along St. Marys River up to the Sault.

The State Geological Survey of Michigan was revived in 1869 and, under the direction of Alexander Winchell, studies were pursued for four years in the northern peninsula on the iron-bearing formations by T. B. Brooks, on the copper-bearing formations by R. W. Pumpelly, and on the Paleozoic formations by Carl Rominger. The results of these investigations are embraced in volumes 1 and 2 of the Geological Survey of Michigan, which contain only incidental notes on the surface geology, chiefly in the Rominger report. A continuation of the investigation of the iron formations of the northern peninsula was made by Rominger as State geologist in 1876 to 1880, and his report forms volume 4 of the Geological Survey of Michigan. This volume also contains but little material on the glacial deposits, but it covers the topography in some detail.

A State Geological Survey of Wisconsin was organized in 1873, with I. A. Lapham as State geologist and R. D. Irving, T. C. Chamberlin, and Moses Strong as assistants. The northern part of the State was assigned to Irving, who, with E. T. Sweet, covered most of the area bordering Lake Superior. The variations in the topography and structure or texture of the glacial deposits are set forth in a general way in volume 3 of the Wisconsin Geological Survey, and also the evidence of lake action up to heights of 300 to 500 feet above Lake Superior. The reports were published under the administration of T. C. Chamberlin as State geologist, and the glacial interpretations were thus brought to a standard corresponding to that developed by Chamberlin in his studies of glacial formations in eastern Wisconsin.

The State Geological and Natural History Survey of Minnesota was organized in 1872 under the direction of N. H. Winchell, State geologist, and the work was carried through vigorously to its completion in 1900. The northeastern part of the State was studied with considerable care by N. H. Winchell and U. S. Grant. The rock formations received the major part of their attention and that of their assistants, A. H. Elftman, J. E. Spurr, and H. V. Winchell, and of Alexander Winchell, who spent some months in the region. The principal moraines, the high shore lines, and the bearing of glacial striae were studied in the field and briefly discussed in the reports. Warren Upham made a more special study and prepared a comprehensive outline of the glacial and lake features of northeastern Minnesota for the annual report for 1893, and Grant and Elftman prepared papers for the American Geologist dealing with special features of the drift in that part of the State. A. C. Lawson ran several lines of levels back from the Lake Superior shore to determine the height of the old lake levels. The results appear in the Twentieth Annual Report of the Minnesota Survey for 1891. It seems that Lawson did not reach the highest limits of lake action with these levels, except in the vicinity of Duluth, and did not trace the beaches across the intervals between the lines of levels sufficiently to establish their correlations. His results, therefore, throw but little light upon the amount of uplift any particular beach has suffered. In 1901 N. H. Winchell prepared a special paper on the glacial lakes of Minnesota, which was published in the Bulletin of the Geological Society of America and describes the relation of lakes to the retreating ice border. Most of the material embraced in this paper had been presented in his official reports some years earlier.

The moraines and ice lobes are graphically delineated in Chamberlin's volume 1 of the Wisconsin Geological Survey for the region bordering Lake

Superior and also in his paper on the terminal moraine of the second glacial epoch published in the Third Annual Report of the United States Geological Survey, for 1881–82. The relation of the Superior basin to the lobation of the ice is particularly set forth. Though Chamberlin's conclusions were correct in the main, it now appears that the Superior lobe had its greatest extension westward into Minnesota prior to the ice invasion from Manitoba which brought in the gray drift; also that the movement through Keweenaw Bay did not have sufficient strength to extend to the Chippewa Valley, the Chippewa lobe being fed by ice carried from the part of the basin west of the Keweenaw Peninsula.

Several papers dealing with shore lines of this region have been brought out by F. B. Taylor. The earliest was one on the highest shore of Mackinac Island, published in the American Journal of Science in 1892, and others in the next five years came out in that journal and the American Geologist. It was through Taylor's studies that the Nipissing Great Lakes and North Bay outlet became clearly differentiated from Lake Algonquin, and much of the knowledge of the Algonquin beach in the Huron and Superior Basins has been furnished by him, largely through studies carried on at his own expense.

Although much work has been done by J. W. Spencer on the shore lines of the Huron, Erie, and Ontario Basins, he seems to have done but little within the region embraced in this report, and this region is mentioned by him only in papers giving a comprehensive discussion of the Great Lakes region. Similarly studies of this region by Warren Upham have been confined to the Minnesota border of the Lake Superior Basin, but in several comprehensive papers he has considered the whole basin and the basins of the other Great Lakes.

The surface geology of this region was written up by Lawrence Martin for Van Hise and Leith's report (Monograph 52 of the United States Geological Survey) after a very rapid reconnaissance covering but a few weeks' time. It is not surprising that under these circumstances some of the interpretations are either poorly sustained by field observation or based too largely on outgrown ideas culled from old reports. Instances of such errors and defects are given in connection with the discussion of features in the body of the present report. A paper on the physical geography of Wisconsin, by Martin, issued as Bulletin 36 of the Wisconsin Geological Survey, embodies much of the same material.

Among the latest contributions to the surface geology of the region are several bulletins issued by the Wisconsin Geological and Natural History Survey on soil surveys in charge of A. R. Whitson. The bulletins touching the area embraced in the present report are Bulletin 31, on the Bayfield area; Bulletin 32, on the northern part of northwestern Wisconsin; Bulletin 43, on Vilas County and portions of adjoining counties; and Bulletin 47, on northeastern Wisconsin. On the last-named area there is also a report by the Bureau of Soils of the United States Department of Agriculture, forming part of the report on field operations in 1913. The Bureau of Soils has also issued a report on the area around Superior, Wis., and one on the area around Carlton, Minn. The scale of the maps in these reports, being usually about 3 miles to the inch and in some maps still larger, has proved adequate to bring out most of the detail of soil variations. As the soil variations bear a close relation to the geologic deposits, the distribution of moraines, till plains, and outwash gravel plains can be determined from the soil maps to a large degree.

The agricultural conditions and surface features of the entire northern peninsula of Michigan are described in a report by the present writer published in 1911 by the Michigan Geological and Biological Survey. A strip along the southern border of the northern peninsula was studied by I. C. Russell in 1904 and 1905, and two reports on surface geology prepared by him have been published by the State Survey. A report on the agricultural conditions of northeastern Minnesota prepared by F. W. Sardeson and the present writer has been recently published as a bulletin by the Minnesota Geological Survey. It is the second of a series of three reports (bulletins 12, 13, and 14) covering the surface geology of the entire State of Minnesota. The Michigan and Minnesota bulletins deal more largely with soil classes than with geologic history, though an outline of geologic history is presented, and moraines, till plains, drumlins, eskers, and outwash plains are represented on the accompanying maps, which show also the character of the lake beds and the position of some of the shore lines. A complete tracing of shore lines was not attempted in the field because of the wooded condition and the extreme difficulty of tracing such features.

In his report on Isle Royal, published in volume 6 of the Michigan Geological Survey, A. C. Lane discussed the shore lines and cited evidence that the entire island has been covered by the lake waters since the ice sheet melted.

In reports to the Ontario Bureau of Mines, for the period between 1899 and 1907, A. P. Coleman has discussed high shore lines on the north side of Lake Superior and around Lake Nipigon, of which the highest are above the limit of levels of shores on that coast seen by A. C. Lawson. Robert Bell briefly outlined the origin of the Great Lakes and the History of the Lake Superior Basin in a paper published in 1899 in the Transactions of the Canadian Institute.

The earth movements in the Great Lake region were studied by G. K. Gilbert and the results were presented in part 2 of the Eighteenth Annual Report of the United States Geological Survey, for 1896–97, and also in the National Geographic Magazine in 1897. George L. Collie has presented a paper in the Bulletin of the Geological Society of America citing evidence of the rising of water in recent time on the Wisconsin shore of Lake Superior.

Leveling to shore lines bordering the north end of Green Bay in Delta County, Mich., was done by W. H. Hobbs, and the results were published in Publication 5 of the Michigan Geological and Biological Survey. Similar leveling was done by F. B. Taylor and J. W. Goldthwait on Mackinac Island and neighboring parts of the northern peninsula and the results are presented in Monograph 53 of the United States Geological Survey.

TOPOGRAPHY AND DRAINAGE

TOPOGRAPHIC CONTROL OF THE SUPERIOR ICE LOBE

THE LAKE SUPERIOR BASIN

The Lake Superior Basin is the dominating feature of this region, for it induced a lobation of the continental ice sheet and also held the waters of glacial lakes that antedated the present Lake Superior. The mean water level of Lake Superior is about 602 feet above sea level, but the lowest part of the bed of the lake is nearly 400 feet below sea level, the maximum measured water depth being 978 feet. The contours of the basin below present lake waters are indicated on a map (pl. 3) taken from Monograph 52, and another map (fig. 1) shows the features outside of Lake Superior. It appears that the principal deeps of Lake Superior lie near the north side, opposite Isle Royal and between the Apostle Islands and the north shore. There is also an extensive branching deep portion east of Keweenaw Peninsula, where one arm runs toward Michipicoten Island and the other toward the south shore near Grand Marais, and another deep portion east of the Apostle Islands, extending northeastward between Isle Royal and the Keweenaw Peninsula. These deep parts, with the exception of that lying southeast of the Keweenaw Peninsula, all trend westward or southwestward, in the direction taken by the Labrador ice sheet in its passage through the Lake Superior Basin. It is very probable that in the eastern part of the basin the ice moved southward as well as westward, and that the Lake Michigan Basin was filled by ice flowing through this deep eastern part of the Lake Superior Basin. The Keweenaw Peninsula and the Huron Mountains are separated only by a shallow depression and thus form a great obstacle of either southward or westward movement. It is because of these prominences that the edge of the drift at the limit of the Driftless Area (see pl. 1) lies so far northeast in north-central Wisconsin. The relief map (pl. 3) also serves to make evident a fact that had been determined independently by field studies—that

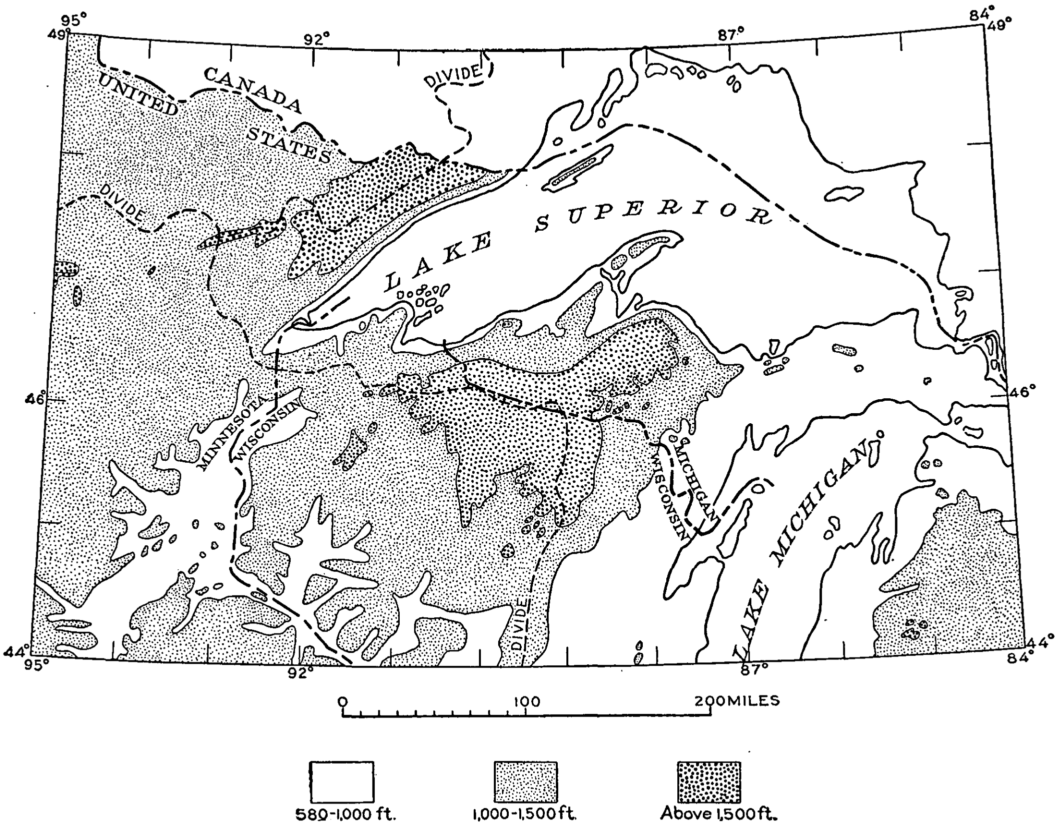


FIGURE 1.—Generalized topographic map of the Lake Superior region. Revised from Figure 4 of Monograph 52

the Chippewa drainage basin is likely to have been covered by ice moving into it from the deep part of the Lake Superior Basin between Keweenaw Peninsula and the Apostle Islands instead of through the shallow basin in Keweenaw Bay, as was suggested by Chamberlin.

The west end of the Lake Superior Basin has features well suited to the development of a double ice lobe, with a reentrant at the Bayfield Peninsula and Apostle Islands, and it did induce such lobation in the late part of the Wisconsin glacial stage, which is under consideration in this report. The latest striae on the north shore in the vicinity of Duluth bear west or north of west in such a manner as to show an ice movement from the basin up over the high bordering rim. A study of the rock constituents of the drift, however, shows that there was at some earlier time a southward or southeastward movement past the west end of the basin into northwestern Wisconsin, for the upper Huronian slate is very plentiful in the drift there, and rocks from the Mesabi iron range are also present. The writer's investigations have served to make it clear that this movement occurred prior to the westward movement through the basin. This is shown by the distribution of the moraines and of the outwash from the Superior ice lobe, as well as by the direction of the striae. It is also shown by the relation of the Superior lobe to the ponded waters or glacial lakes formed between it and the divide between the Superior and Mississippi drainage basins.

As the highlands next to Lake Superior in Minnesota were 1,500 to 2,000 feet above sea level, the Superior ice lobe could extend only a few miles over them. Its limits were reached on the south side of Cloquet River, so that outwash from it extended down that river valley. At the time of the greatest expansion of this ice lobe the south front of the Patrician ice, which had previously extended from the west end of the Lake Superior Basin as far south as St. Paul, had already been melted back so far that it formed a junction with the Superior ice lobe in Lake County, as shown on page 20.

The prominence of the uplands on the south side of the Lake Superior Basin, on the Douglas copper range and the Bayfield Peninsula (altitude 1,200 feet), the Penokee iron range (1,600 to 1,800 feet), the Porcupine Mountains (1,400 to 2,000 feet), the Keweenaw copper range and Keweenaw Peninsula (1,200 to 1,400 feet), and the Huron Mountains and highlands to the south (1,500 to 1,800 feet), served to prevent the Superior lobe from extending far beyond the rim of the basin in that direction. Its limits in northern Wisconsin are only about 30 miles south of the edge of the lake. There was a marked reentrant in the ice border on the Bayfield Peninsula and a great checking of movement in the passage over prominences farther east, so that in the lee of the Huron Mountains the ice reached only to the vicinity of Crystal Falls, Mich. But still farther east the land on the south side of the basin is low, much of it less than 800 feet above sea level, and the ice extended with but little hindrance across the northern peninsula of Michigan into the Lake Michigan Basin. The lake beaches in this eastern part of the Lake Superior Basin show an uplift of about 400 feet since the ice disappeared; so at the time of the ice movement from the Lake Superior to the Lake Michigan Basin the checking effect of the northern peninsula was probably much less than it would be under present conditions of altitude.

TOPOGRAPHIC PECULIARITIES AROUND THE BASIN

Although the relief of this region is great enough to have exerted a marked control over the ice movement, the highest tracts on the border of the Lake Superior Basin show only a moderate depth of dissection or valley cutting. This dissection is not of a narrow, youthful sort, but the slopes are gentle and the valleys wide open. The valleys were excavated in early geologic time and then filled by Cambrian and later sediments. This filling was then largely removed by the action of streams prior to the glacial epoch, and what has been termed a fossil topography was uncovered. Broad lowlands such as border the Bayfield and Keweenaw Peninsulas and the lowland at the head of the lake were not so markedly reexcavated, and thus they retain the Cambrian sediments. These sediments are trenched by small valleys, which became filled with glacial deposits and are now traceable mainly by borings, for the present streams follow them to only a slight degree. On the south shore of Lake Superior these filled valleys have rock beds much below the level of the lake. Near the head, at Superior, Wis., the drift extends 550 feet below the lake level.

In the eastern part of the northern peninsula of Michigan the Cambrian and later rock formations form what are termed belted lowlands, in which resistant formations present steep escarpments at their outer edges and softer formations occur in the intervening troughs and fade out at their edges. From St. Marys River westward to the Manistique drainage basin the escarpments face northward. Thence they curve around to the southwest and run into eastern Wisconsin. Where the trend is west the ice was obliged to rise over these escarpments. But in the southwestward-trending part the latest axial movement of the ice seems to have been in line with the troughs and escarpments. The trough occupied by Green Bay thus had an ice lobe distinct from that in the Lake Michigan Basin. The highest escarpments rose 200 to 400 feet above the troughs. They are now largely buried under the glacial deposits and their preglacial relief is made known only by borings. The Keweenaw Peninsula and Isle Royal present a series of sharp ridges of resistant rocks separated by narrow troughs with softer strata. Those on Isle Royal are nearly in the line of the ice movement, though Lane reports a slight difference in course. The latest ice movement in the eastern part of the Keweenaw Peninsula was in the same general direction as the troughs and ridges and there was but slight deposition in the trough or on the ridge. But in the remainder of the peninsula the westward ice movement crossed over ridges and troughs and filled the troughs with the glacial material.

DRAINAGE

LAKE SUPERIOR TRIBUTARIES

The tributaries of Lake Superior in Minnesota, Wisconsin, and Michigan are nearly all small streams. The largest is St. Louis River, with a drainage area of about 3,500 square miles, and the second in size the Ontonagon, with a drainage area of 1,400 square miles. Only one other, Bad River, has even 1,000 square miles of drainage area, and most of them have less than 250 square miles. The divide between Lake Superior and the Hudson Bay drainage system in northeastern Minnesota lies only a few miles back from the shore of the lake, and the divide between Lake Superior and the Mississippi drainage system is also close by the lake in northeastern Minnesota and northern Wisconsin. The divide between the Lake Superior and Lake Michigan drainage basins is nearer to Lake Superior than to Lake Michigan in the northern peninsula of Michigan. A considerable part of the drainage basin of St. Louis River lies outside the limits of the Lake Superior ice lobe, but with this exception the streams that drain to Lake Superior in these three States lie within the limits of this ice lobe.

In much of the Lake Superior Basin the present streams are controlled but slightly by preglacial valleys. Those valleys were so completely filled by drift back of the ranges, as well as next to the lake, that they not only have failed to control the courses of the postglacial streams but are known only by means of borings. In crossing rock ranges the streams form numerous rapids and cascades. In Minnesota and parts of Michigan where rock ranges are close to the lake shore cascades occur on many streams near the mouths, and thus are especially favorable for the development of water power, for at such a site nearly the entire flow of the drainage basin can be utilized. Surveys have been made of several of the minor tributaries in Minnesota and of St. Louis River, and some of the results are given below. The altitude of the land close to the lake is greater in Minnesota than in Wisconsin and in much of Michigan, and thus some of the small Minnesota streams have a de-

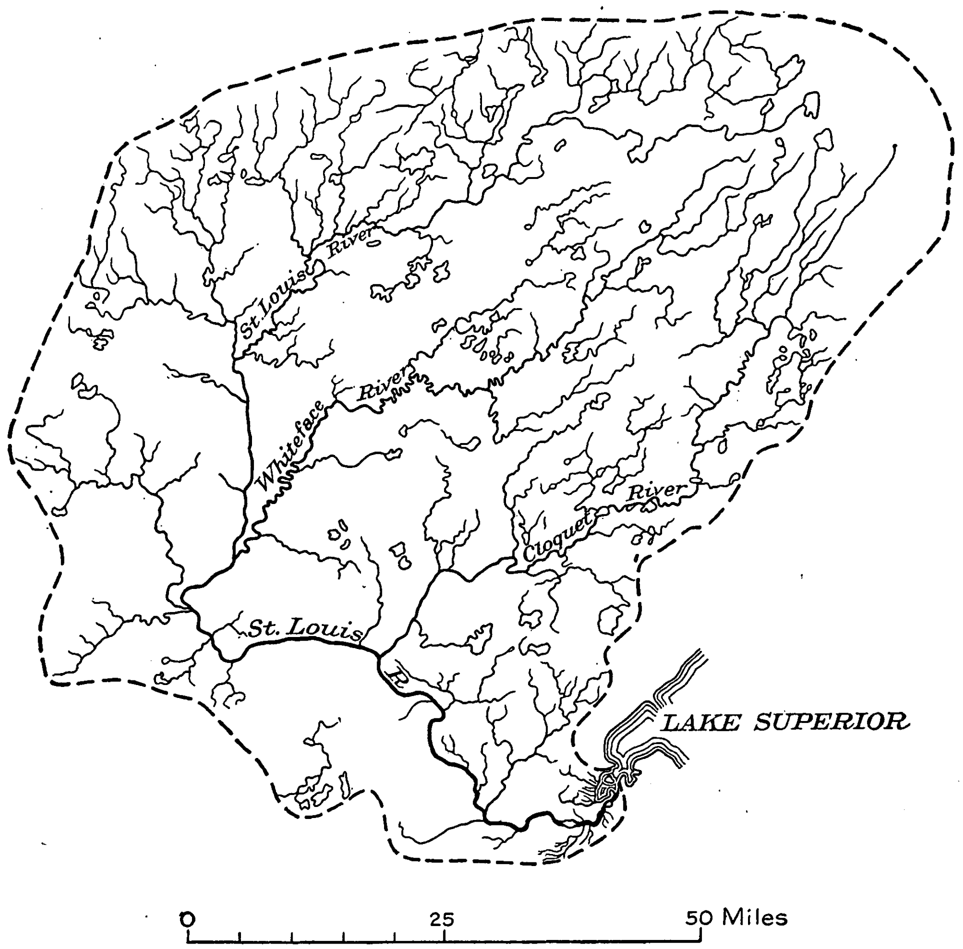


FIGURE 2.—Map of St. Louis River drainage basin, Minnesota and Wisconsin

scent of 1,000 feet or more in their short courses to the lake. On interstream areas in northeastern Minnesota there is usually a rise of 400 feet, and in places nearly 1,000 feet, within a mile of the lake.

On the headwaters of many of the streams that flow to Lake Superior in the three States there are a large number of lakes, which serve as storage reservoirs to supply a flow through dry seasons of the year and thus add to the water-power value of the streams.

St. Louis River heads in western Lake County, Minn., and has a general southwestward course for about 60 miles (by direct line), southward 25 miles to Mirbat, thence eastward, southeastward, and finally northeastward into Lake Superior. (See fig. 2.) Only the part of its course below Mirbat lies in the area covered by the Superior ice lobe. A considerable part of the basin above Mirbat was covered by ice that came in from the northwest and deposited a sheet of clayey calcareous till. But the headwaters are outside the limits of this drift, as well as of the drift of the Superior lobe, and they were covered by ice coming in from the north, which left a very stony drift deposit. The limits of the drainage basin on the north are in general at the Mesabi iron range, but it receives one tributary, Embarrass River, which brings in drainage from territory north of the range. Of the 3,500 square miles in the drainage basin only 60 square miles lies in Wisconsin. The greater part of the basin is a plain which is between 1,200 and 1,500 feet above sea level, or 600 to 900 feet above Lake Superior, but the altitude of the extreme headwaters on the ranges is nearly 1,800 feet. St. Louis River reaches Cloquet at an altitude of 1,172 feet and within a mile makes a descent of 67 feet, which is divided between two dams at the city. The stream falls about 500 feet between Cloquet and Fond du Lac, a distance of about 14 miles. The Great Northern Power Co. has diverted a considerable part of the flow into a canal near Thomson, 5 miles below Cloquet (see fig. 3), and has developed a head of 378 feet where the canal is returned to the river. There is still a fall of 90 feet unutilized below the tailrace of the power plant. The stream reaches lake level at Fond du Lac, several miles above its mouth, for a northward differential uplift has caused the lake to rise on its south shore and flood tributary valleys. Although the stream makes a descent of about 470 feet in 9 miles below Thomson, it does not have rock cascades such as are characteristic of the lower ends of the minor streams. It cuts very little into the rock but has eroded deep channels in the glacial deposits, which are banked here against the south face of the rock range

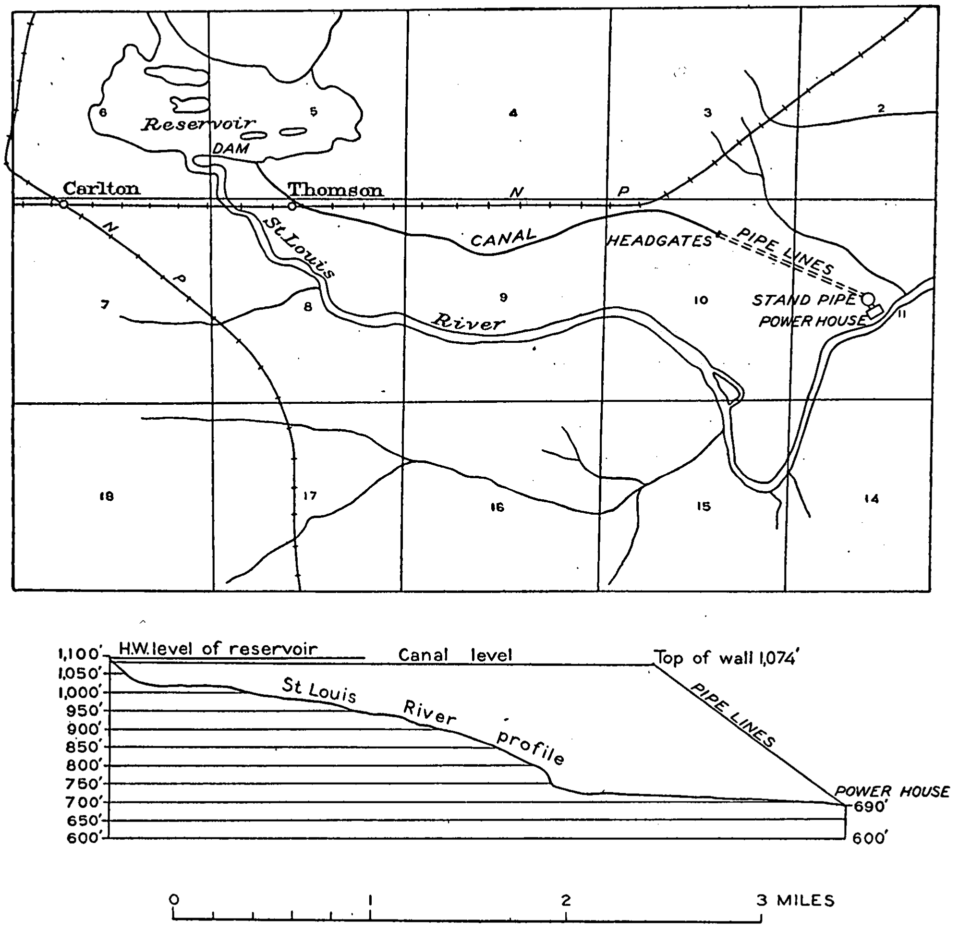


FIGURE 3.—Map and profile of canal of Great Northern Power Co., St. Louis River

that forms the north border of the Lake Superior Basin. Its course does not run through a preglacial valley, either here or across the rock range, for the range seems to have no break in this vicinity, continuing at an altitude of 1,100 feet or more from the west end of Lake Superior some distance beyond Thomson, the place where St. Louis River leaves it.

Martin,[2] in maps as well as in discussion, makes it appear that a small stream having the present course of St Louis River below Thomson worked headward across the rock range above Thomson and captured a large drainage system that had been flowing to the Mississippi. The present writer's investigations, however, and indeed those by Winchell many years ago have shown that the St. Louis River basin carried a lake outside the limits of the Superior lobe, which was held up by that ice lobe until it had shrunk to a position between Cloquet and Thomson, near Scanlon, when it was drained southwestward into Kettle River. With the further shrinking of the Superior ice lobe the drainage led down the present course of the river about to Thomson, where it entered a lake (Lake Duluth) that stood about 500 feet above the level of Lake Superior. As the lake level dropped the river lengthened its lower course, and it has come to its present condition without any such piracy as was pictured by Martin. The idea that such piracy may have occurred in preglacial time is also unsupported by any evidence thus far obtained, for, as indicated above, no break in the rock range such as a preglacial drainage line should have made has been brought to light.

A survey of St. Louis River for a distance of 149.4 miles from Scanlon to the Duluth & Iron Range Railroad crossing near Skibo was made by the State drainage commission in 1910 to determine chiefly the power possibilities of the river. The results are given in Plates 76 to 82 of an atlas accompanying the commission's report of water-resources investigations for 1909–1912. Recommendations as to the placing of dams or the location of the best power sites are presented on pages 500–502 of that report. Surveys made by the State drainage commission also cover parts of certain tributaries of St. Louis River, Embarrass River having been surveyed for 21 miles from its mouth, and Cloquet River as far up as Brimson, where it is crossed by the Duluth & Iron Range Railroad. (See pls. 15–18 of the atlas.) The feasible power sites on these tributaries are also discussed on pages 502 and 516–518. These surveys show a very moderate rate of fall in the sections covered, compared with the fall between Thomson and Fond du Lac (52 feet to the mile), in the lower course of St. Louis River. The fall on St. Louis River in the 146 miles downstream from the Duluth & Iron Range Railroad crossing to Cloquet is only about 400 feet, or less than 3 feet to the mile. Cloquet River falls about 260 feet in the 70 miles from the Duluth & Iron Range Railroad crossing to its mouth. Another large tributary, Whiteface River, falls 384 feet in 80 miles from the Duluth & Iron Range Railroad crossing to its mouth.

[2] Martin, Lawrence, U. S. Geol. Survey Mon. 52, figs. 9, 10, 1911; Wisconsin Geol. Survey Bull. 36, fig. 176, 1916.

The minor tributaries of Lake Superior entering from Minnesota have a rapid fall from source to mouth, except for very short sections through lakes or swamps. The data on the fall in the lower courses of several of these streams presented below are taken from the report of the State drainage commission for 1909–1912. There is a striking contrast between the gradient of Pigeon River, a stream that forms the international boundary for much of its course, and the minor streams entering Lake Superior between the Canadian line and the head of the lake at Duluth. Pigeon River has a drainage basin of 628 square miles, or more than double that of any of the other minor streams. This difference may account for a part of the difference in gradient, but not a large part. Unlike the other streams, it has a comparatively gentle slope from the general plateau level in its lower course, and a distance of 30 miles is embraced in a fall no greater than is made in one-third that distance on some of the other streams. The chief cause for the lower gradient seems to be found in the location of Pigeon River along somewhat weaker strata than those encountered by the other streams. Pigeon River has scoured practically to lake level up to a distance of 1½ miles from its mouth, but the other streams descend over rock beds to points within a few rods of the lake.

Drainage areas and descent of minor tributaries of Lake Superior

River	Drainage area	Altitude at source	Character of drainage basin
	Square miles	*Feet*	
Pigeon	628	1, 650	Flows through lakes; has three notable falls.
Brule	282	1, 850	Sources of main stream and of tributaries are in lakes.
Devil Track	75	1, 920	Heads in small lake and flows through larger one (Devil Track) with area of 3 square miles.
Cascade	84	1, 950	Receives overflow from Devil Track Lake at high lake stages; other reservoirs in smaller lakes in upper course.
Poplar	144	(?)	Many lakes within its drainage area give good reservoir effect.
Temperance	198	1, 850	Divides the discharge from Brule Lake with Brule River, nearly equally, and flows through a chain of small lakes.
Cross	32	(?)	Descends nearly 800 feet in lower 6 miles.
Manitou	71	(?)	Has few lakes large enough for good reservoirs.
Baptism	135	1, 850	Do.
Beaver Bay	120	1, 700	Has few lakes or reservoir sites. Large tributary enters near mouth. Has numerous other tributaries.
Gooseberry	85	1, 700	Has numerous tributaries, but not good reservoir sites.
Lester	55	(?)	Has cascades in lower course and swamps in upper.

At two of the heaviest falls on Pigeon River log chutes have been constructed.

Data from survey of Lake Superior tributaries in Minnesota

Gooseberry River, Lake County

Distance from mouth	Location	Altitude above Lake Superior
Miles		*Feet*
0.75	Foot of rapids	7
.95	Head of rapids	120
1.8	Foot of rapids	168
1.85	Head of rapids	215
2.7	Forks in sec. 21	241

Beaver Bay River, Lake County

0.02	Foot of falls	3
.3	Head of falls	114
1.0	Head of rapids	303
2.5	Highway bridge	313
3.9	Foot of rapids	335
4.1	Head of rapids	400
5.0		424
6.0		485
6.6	Highway bridge, sec. 17, T. 55, R. 8 W.	486

Baptism River, Lake County

0.1	Foot of rapids	1
.85	Foot of falls	68
1.0	Crest of falls	125
1.3	Foot of rapids	128
1.8	Head of rapids	241
3.0		373
4.0		442
5.8	Highway bridge	505
6.6		575
8.0		704
8.9	Highway bridge	733

Manitou River, Lake County

0.05	Foot of falls	0
.1	Crest of falls	54
1.0		204
2.0		285
3.0		371
4.0		482
5.0		703

Temperance River, Cook County

0.05	Foot of rapids	0
.5	Head of rapids	162
1.0		203
2.0		284
3.0		345
4.0		425
5.0		450
6.0		463

Cross River, Cook County

0.3	Foot of rapids	17
.35	Head of rapids	113
1.2	Foot of rapids	236
1.5	Head of rapids	391
2.7		592
4.0		678
5.0		738
6.0		781
7.2	Foot of log dam	848
7.2	Crest of dam	858
7.5	Upper end of pond	858
8.2	End of survey	867

Data from survey of Lake Superior tributaries in Minnesota—Con.

Poplar River, Cook County

Distance from mouth	Location	Altitude above Lake Superior
Miles		*Feet*
0.3	Highway bridge	71
1.0		197
2.0		353
2.5	Foot of rapids	423
2.8	Foot of logging dam	608
2.8	Crest of dam	619
4.0		620
5.1	Highway bridge	634
5.6	Foot of logging dam	648
5.6	Crest of dam	650
6.2	End of survey	652

Cascade River, Cook County

0.15	Foot of falls	8
.35	Crest of falls	132
1.0		226
2.0		398
3.0		556
4.0		688
5.0		735
6.0		817
6.8	End of survey	840

Brule River, Cook County

0.5	Highway bridge	18
1.0		74
2.0		228
3.0		320
4.0		415
5.0		554
6.0		681
7.0		763
7.2	End of survey	768

Pigeon River, on international boundary

0.0	Head of Pigeon Bay	0
1.5	Foot of rapids	3
1.7	Foot of Big Falls	17
1.7	Crest of Big Falls on low dam	111
2.0	Upper end of pond	111
2.4	Head of rapids	152
3.45	Foot of rapids	163
3.5	Head of rapids	190
5.0		198
6.05	Foot of rapids	223
6.1	Head of rapids	241
8.15	East boundary of Indian reservation	271
9.2		288
10.5		322
11.5	Arrow River	331
14.95	Foot of rapids	379
17.45	Foot of falls	519
17.45	Crest of falls on low dam	652
19.1	Upper end of pond	652
19.8	Foot of Partridge Falls	664
19.8	Crest of falls	714
21.95	West boundary of Indian reservation	714
24.45	Missaich River	725
27.85	Portage Brook	746
28.8	Stump River	748
29.7	Foot of dam	762
29.7	Crest of dam	782
30.05	Foot of dam	791
30.05	Crest of dam	808
30.4	Foot of dam at South Fowl Lake	828
30.4	Crest of dam	834

The streams entering Lake Superior from Wisconsin are shown in Figure 4. They are very irregularly distributed, being numerous and nearly parallel in part of the area and relatively scarce and more winding in other parts. This difference is due largely to differences in the character of the deposits, there being many streams in clay areas and relatively few in the loose-textured drift. On the Bayfield Peninsula the drift is very loose textured and wide areas of it have no surface streams. The character of the erosion in the clay areas is well shown in the topographic map of the Superior quadrangle. This map also shows a short section of the Douglas copper range and south of it an area of loose-textured drift with relatively few streams. This map also shows by contours the highest waterfall in Wisconsin (pl. 4), that made by Black River in descending from the copper range at Manitou Falls, in sec. 21, T. 47 N., R. 14 W., where the river drops about 160 feet, from a point above the 960-foot contour nearly down to the 800-foot contour. Before leaving section 21 the river gets below the 700-foot contour, thus making a descent of more than 260 feet in passing through a single section. The river has a 31-foot fall above Manitou Falls, where it cuts the copper range in the SE. ¼ sec. 28.

The westernmost stream entering the lake in Wisconsin is Nemadji River, of which Black River is a southern tributary. It has a drainage basin of about 400 square miles, of which 60 per cent is in Minnesota and 40 per cent in Wisconsin. Nemadji River drains the part of the Lake Superior Basin lying southwest of the head of the lake. The river and its northern tributaries and the lower courses of its southern tributaries are in a clay plain in which no rock ledges are encountered. The southern tributaries head on or south of the Douglas copper range and descend from the range to the clay plain over low cascades and rock rapids. Nemadji River is only about 20 feet above Lake Superior at the mouth of Black River, 10 miles from the lake by direct line and probably 30 miles by the meanders of the stream. Its gradient here has been greatly reduced as a result of the northward differential uplift which has affected this region and which has caused estuarine conditions on the lower course of St. Louis River. The bottom lands are marshy for several miles up the Nemadji Valley, and the river has built along its immediate banks natural levees that stand above the remainder of the valley bottom.

The Nemadji River Basin held a small glacial lake in its headwaters in Carlton County, Minn., called Lake Nemadji, which discharged westward to Moose Horn River at Moose Lake village, and thence southward by way of Kettle and St. Croix Rivers to Mississippi River, as described on pages 55 and 56. The portion of its drainage system included in this glacial-lake bed is younger than that on the highest areas bordering it, which was in operation during the existence of the lake.

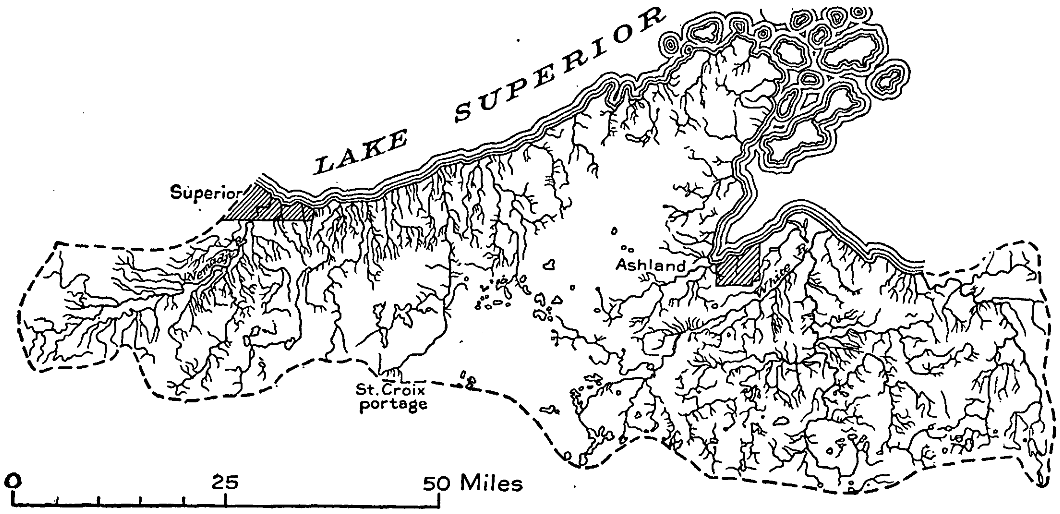


FIGURE 4.—Map showing streams entering Lake Superior in northern Wisconsin

Between the Nemadji drainage basin and the Bayfield Peninsula there are several small streams classed as rivers, though none of them have drainage areas of 200 square miles. Some of them cross the copper range and have cascades on its slope, but several head near the base of the range and flow almost wholly on the clay plain bordering Lake Superior. Bois Brule River is the largest of these streams, the area of its drainage basin being estimated at 162 square miles. Its headwater portion is of exceptional interest, for it carries the outlet of the glacial Lake Duluth, which covered at its greatest expansion the whole west end of the Lake Superior Basin from points as far east as the Huron Mountains. This headwater portion of Bois Brule River flows in a broad swampy channel that opens at its south end into St. Croix Lake, which discharges through St. Croix River to the Mississippi. Immediately south of the copper range there was in the drainage basin of this stream a small lake, here named glacial Lak

RELIEF MAP OF THE LAKE SUPERIOR REGION

THE HIGHEST WATERFALL IN WISCONSIN

Manitou Falls, on Black River

Brule, which antedated Lake Duluth and through which Lake Duluth discharged after the ice lobe had shrunk away from the copper range far enough to let its water pass into this small glacial lake.

East of the Bayfield peninsula is the Bad River drainage system, in which White River is a large tributary. The entire drainage system embraces about 1,000 square miles, of which fully 350 square miles is drained by White River. A large part of the drainage basin is in a clay plain, which borders Chequamegon Bay of Lake Superior and which was covered by the waters of Lake Duluth. The headwater streams head among or south of high rock ranges, the most prominent of which is the Penokee iron range, but there are others nearer the lake. Several cascades occur where the streams cross these ranges and also in their courses between the ranges. But after the several tributaries unite to form Bad River the stream flows in a clay plain without encountering rock ledges. White River is in the clay plain except in its headwaters.

There was a small glacial lake, Lake Ashland, which antedated Lake Duluth in occupying part of the drainage basin of Bad and White Rivers and which discharged across the Bayfield Peninsula into glacial Lake Brule through a channel passing just south of the site of Iron River village. With the recession of the ice border from the Bayfield Peninsula, Lake Duluth gained access to the Bad River drainage basin. Its altitude was but little lower than Lake Ashland, perhaps 20 feet lower.

Montreal River, which forms part of the boundary between Wisconsin and Michigan, has a drainage area of 280 square miles, of which nearly 200 square miles is in Wisconsin and only 85 square miles in Michigan. The main stream is about 50 miles long and heads on a table-land south of the Penokee iron range at an altitude of about 1,600 feet. It makes scarcely one-fourth of the 1,000 feet fall to Lake Superior in three-fourths of its course, the great descent being in the remaining lower fourth, where there are several waterfalls, including one of 35 feet only a quarter of a mile from its mouth. Gogshungun River, a branch of the Montreal, has a length of about 30 miles and a descent of 500 feet. It breaks through the Penokee iron range in sec. 27, T. 46 N., R. 2 E., and has falls in that part of its course, but the headwaters are sluggish.

There are two streams of considerable size in the western part of the northern peninsula of Michigan—Black River, with a drainage area of 250 square miles and Presque Isle River, with 390 square miles. Each heads in the north edge of Wisconsin and traverses the entire width of the peninsula. A considerable part of the drainage area of each stream is south of the Penokee-Gogebic iron range, and in that part the streams are rather sluggish. In crossing the range and the copper range, farther down, the streams have rapids and cascades that promise to be of much value in water-power development, as they occur so near the mouth of the river. The area drained by these streams lies west of the Porcupine Mountains and of Lake Gogebic.

The Porcupine Mountains are drained largely through Carp River, which flows into the lake at their western base. Its sources are at the base of knobs in this group of steep hills and ridges, at an altitude 600 to 700 feet above the lake. The highest knob stands about 1,400 feet above lake level, and others reach an altitude of 1,000 feet or more above the lake. This group of hills stands very close to the shore of Lake Superior. From the Porcupine Mountains westward into Wisconsin the copper range lies so close to the shore of Lake Superior that the clay plain is reduced to a strip only 1 or 2 miles wide. This strip is crossed by a multitude of short streams running directly to the lake. From the Porcupine Mountains eastward past the Ontonagon Valley to the Keweenaw Peninsula a clay plain several miles in width lies between the lake and the copper range, and, like the plain west of the Porcupine Mountains, is crossed by numerous small streams running directly down the slope to the lake. These streams have cut sharp deep trenches in the plain, which make the east-west roads difficult to construct. The existing roads, therefore, nearly all follow north-south lines or lines parallel to the streams instead of crossing them. A single main road runs from east to west close to the lake shore, where the trenching by the streams is shallow.

Ontonagon River has a drainage system embracing about 1,400 square miles and is the largest of the Lake Superior tributaries entering in Michigan. The extreme headwaters drain about 50 square miles in Wisconsin. Several streams 30 to 50 miles or more in length are brought together in a single river at the outer or south border of the copper range, about 2 miles south of Rockland, Mich., and 15 miles in direct line from the shore of Lake Superior at Ontonagon. Gogebic Lake lies in the course of the westernmost tributary and has a length of fully 15 miles. Its trend is toward Lake Superior, but its outlet runs for more than 20 miles eastward, parallel with the lake shore, along the south base of the copper range and receives the main south branch of the river midway of this course. It is probable that Gogebic Lake lies in a preglacial valley whose continuation extends northward from the lake to Lake Superior, beneath a moraine that here fills a gap in the copper range and through a plain north of the moraine, now drained by Iron River. The main south branch may have passed through the copper range at a break about 5 miles farther west than the one now utilized by Ontonagon River and have traversed the part of the clay plain now drained by Portage River, northward from the copper range. The middle branch of Ontonagon River finds a direct continuation along the present lower course, and the east branch seems likely to have had a preglacial drainage similar to that of the present stream and to have joined the middle branch just south of the copper range. As there are only a few places where this drainage system encounters rock ledges, rapids and falls are less numerous and conspicuous here than on some of the smaller drainage systems farther west. At the gap in the copper range south of Rockland the drainage is so concentrated as to give a large flow, and the valley there is sufficiently narrow to be easily dammed to a considerable height. The banks or bluffs consist of clay, which is so compact that it would allow hardly any leakage.

There are a number of small rivers both east and west of the Ontonagon which head in the copper range and flow across a clay plain to Lake Superior. The longest are about 25 miles in length, but most of them are only 10 to 15 miles. Few of them cut deeply enough to reach rock. Montreal River drains the interior of the eastern part of the Keweenaw Peninsula and flows through a trough between rock ranges to a point near its mouth, where it turns southward and falls rapidly over rock ledges just before entering the lake. Eagle River and other small streams drain the slopes of this peninsula and have falls where they cross rock ridges.

Sturgeon River has a drainage basin of about 725 square miles on the southeastern slope of the Keweenaw Peninsula and on the highlands south of Keweenaw Bay. It does not discharge directly into Lake Superior but into Portage Lake, from which there is an outlet discharging into Keweenaw Bay. More than 200 square miles of the Keweenaw Peninsula aside from the Sturgeon River drainage basin is tributary to Portage Lake. The lake and its outlet are at the level of Lake Superior, as are also Torch Lake and an inlet to Portage Lake which leads southeastward across the peninsula past Hancock and Houghton. A ship canal now connects the head of this inlet with Lake Superior by a cut about 30 feet deep across a gravel bar of Nipissing age.

The lower course of Sturgeon River for a distance of about 15 miles has almost no fall, for differential uplift has converted this part into a marshy estuary, through which the stream now flows in a meandering channel. The stream flows in a relatively low clay plain for about 15 miles before it enters this marsh. The headwater part of the river is on a tract of hills standing 1,600 to 1,800 feet above sea level; thus the descent is fully 1,000 feet from source to mouth. At least 80 per cent of this fall is made in the upper half of the course. The headwater tributaries encounter a few rock ledges and have rapids and low cascades, and some of the western tributaries to the lower part of the river come in over rock ledges, but the main stream is nearly free from rapids for the greater part of its course.

The area from the head of Keweenaw Bay eastward to the Huron Mountains is drained through several small streams, of which Silver, Slate, and Huron Rivers are the largest. They rise about 1,000 feet above the lake and consequently have a rapid descent with numerous cascades. They are much like the small streams on the Minnesota shore of Lake Superior, but their lower courses lead through a lowland several miles wide, which was covered by the waters of glacial Lake Duluth.

From the Huron Mountains eastward to Whitefish Bay, at the southeast end of Lake Superior, there are about 20 small streams called rivers, as well as numerous creeks, which make a rapid descent to the lake, with numerous cascades. At several places a head of 100 feet or more could be easily developed for water power. The largest of these streams drains less than 200 square miles and most of them less than 100 square miles each. They are thus of little value for water power except where a great head can be developed. Those having cascades lie west of Grand Marais, for the streams east of that village flow through a region containing heavy deposits of drift. There are cascades in nearly every stream entering the lake west of Grand Marais. Anna River, however, which enters at Munising, at the head of a bay, seems to follow a preglacial drainage line, for its course leads through thick deposits of drift. Some of its eastern tributaries cascade over rock ledges to reach the main stream. The lower course of Au Train River is controlled by a succession of Nipissing Lake beaches, which cause the stream to swing back and forth between ridges and flow several miles to reach a distance of only 1 mile by direct course. This river has a series of falls just north of the Munising railroad bridge, with a descent of about 100 feet, above which there is a drainage area of about 80 square miles. These falls, as well as many others in the Lake Superior region, have not yet cut back into the rock bluff so as to have a rock gorge below them and are therefore in an extremely youthful stage. Dead River, which enters Lake Superior in the northern part of the city of Marquette, has a 96-foot fall a few miles above the mouth, in sec. 9, T. 48 N., R. 26 W., and a descent of about 600 feet below this fall over numerous small cascades. It is thus far from being a "dead" stream. Its drainage basin is about 150 square miles and there has been considerable development of its water power.

Whitefish Bay receives the discharge from Taquamenaw River, which drains about 800 square miles in the eastern part of the peninsula. There are two waterfalls a few miles from its mouth, the upper with about 40 feet and the lower with about 20 feet fall. At the foot of the lower fall the stream reaches the level of Lake Superior, though 15 miles from its mouth. The slack water thus produced is due to the northward differential uplift that has caused a rise of the water along the south shore of the lake. The main stream and also an eastern branch lead through swamps from points near their sources down to the upper fall. In a distance of 70 miles above the fall the main stream has an average gradient of only 6 inches to the mile. This low gradient and swampy condition is due, to some extent, to differential uplift, for the stream is flowing northeastward into the uplifted area, and the ledges of the upper fall have risen more as a result of this uplift than the headwater part of the stream. The swamps are largely underlain by clay or clayey till of closer texture than that on the bordering dry land, but sand is present under a considerable part of the swamp land.

ST. MARYS DRAINAGE BASIN

The main function of St. Marys River is to serve as the outlet for Lake Superior. Its tributaries, both in Michigan and on the Canadian side, are small and add very little to its volume. The falls or rapids at the head of this river give a descent of about 18 feet and furnish water power of great value, which is already largely utilized. In comparatively recent time, perhaps since the beginning of the Christian era, the ledges at the rapids on St. Marys River have risen above the level of the water of the Lake Huron Basin, through northward differential uplift. Before this occurred a strait connected Lake Superior with Lake Huron along the course of this stream. Whether this uplift is still in progress has not been determined. If it is, the fall at Sault Ste. Marie will increase to correspond to the uplift of this outlet.

The preglacial line of connection between the Lake Superior and Lake Huron Basins was not along the course of St. Marys River but a few miles farther west. It led south from Whitefish Bay past Rudyard to Pine River and thence to Lake Huron. Wells along this line have reached depths about 200 feet lower than the surface of Lake Superior without striking rock The rock floor of the valley is thus known to be less than 400 feet above sea level, and it may be considerably lower. The tilting of the Algonquin beach shows that an uplift of 400 feet has occurred at Sault Ste. Marie since the beginning of that glacial-lake stage. The rock bed of this preglacial channel was at that time below sea level. It probably stood considerably above sea level in preglacial time, and it may now have recovered only part of its preglacial altitude.

The principal tributary of St. Marys River in Michigan is Munuscong River, which has a drainage basin of 225 square miles, chiefly in a low clay plain lying north of what is known as the Niagara escarpment. It is a widely branching system, but nearly all the streams in it are rather sluggish. Other tributaries are Charlotte River, to the north of the Munuscong, and Gogomain River to the south. The Charlotte drains a fertile farming district; the Gogomain is largely in cedar swamp.

LAKE HURON DRAINAGE BASIN

Two streams, Pine River and Carp River, lead into Lake Huron from the northern peninsula of Michigan. Both of these discharge into St. Martin Bay, at the extreme head of the lake. The drainage basin of Pine River covers about 280 square miles and is chiefly a lowland tract north of the Niagara escarpment. The river flows south through a gap in the escarpment, which, as already indicated, appears to have been in the preglacial line of discharge from the Lake Superior to the Lake Huron Basin. Pine River, so far as known to the writer, has but one rock outcrop along its bed, about 5 miles south of Rudyard. The stream is not regular in flow, for much of the basin is clay, which sheds water rapidly, and thus it has but little discharge in dry seasons.

Carp River drains an area of about 200 square miles immediately south and west of the Pine River drainage basin, much of which is underlain by limestone thinly coated with glacial deposits. Several rock rapids occur along the main stream and some of its tributaries. There are, however, extensive swamps among the limestone ridges through which these streams flow.

LAKE MICHIGAN DRAINAGE BASIN

From Manistique eastward the drainage into Lake Michigan from the northern peninsula goes through small streams, none of which has a drainage area of 100 square miles. The streams head near the Niagara escarpment and flow down the dip slope of the limestone, which stands 200 to 300 feet or more above the lake, but several of them run through strips of swampy land before reaching the lake. Some of the swamps are high among the limestone ridges, but the lower land near the lake is occupied by sand ridges and is relatively dry. A considerable number of the swamps have a subsoil of clay or of till thickly set with limestone pebbles.

Manistique River, which enters Lake Michigan at the city of Manistique, is one of the largest streams in the northern peninsula, its drainage area being about 1,400 square miles. Some of the largest lakes in the northern peninsula are tributary to this river, Manistique Lake having an area of about 16 square miles, Whitefish Lake 7 square miles, and Indian Lake 13 square miles. It has a widely branching system, of which several streams head in a high moraine on the upland south of Lake Superior, their sources being but 5 to 10 miles from the edge of that lake. These streams lead down in converging courses through a great sandy swamp and marsh that covers much of Schoolcraft County and connects at the east with the Taquamenaw Swamp, which is drained to Lake Superior. There are narrow strips along parts of the streams which are fairly well drained, but the interstream areas are practically undrained and are covered with water throughout much of the year. The sandy condition of this swamp area makes drainage less needful than if it were a better soil. There appears to be sufficient southward slope in it to give good conditions for extensive drainage. The fall can not be less than 2 feet to the mile and in places may reach 5 feet. A valuable water power has been developed at the mouth of this river, where the water is held by dams to a height of about 20 feet above Lake Michigan. There are also dams in the outlet of Indian Lake. A large area west of Indian Lake has underground drainage which feeds springs that discharge into the lake in great volume.

GREEN BAY DRAINAGE SYSTEM

Big Bay de Noc, at the extreme northeast end of Green Bay, receives several small streams—Garden and Valentine Creeks from the east and Fishdam, Little Fishdam, Sturgeon, and Ogontz Rivers from the north. Sturgeon River drains about 200 square miles, or more territory than all the others combined, and has a length, disregarding the river meanders, of about 50 miles. It rises in Sixteenmile Lake, on the outer border of a moraine that runs along the south shore of Lake Superior, at an altitude of about 300 feet above that lake. It encounters rock ledges and has rapids in the southern part of T. 42 N., R. 19 W., and at other points nearer its mouth, but its headwater portion is in a sandy region with thick drift. Fishdam, Little Fishdam, and Ogontz Rivers, and Valentine Creek drain large swamps and encounter few rock ledges. Garden Creek drains a good farming district on the Garden Peninsula, with clay-loam soil.

Little Bay de Noc, at the north end of Green Bay, receives Whitefish, Rapid, and Tacoosh Rivers at its head and Days and Escanaba Rivers on the west. The largest of these streams are Whitefish and Escanaba Rivers, the others being very small. Whitefish River, which drains about 350 square miles, has its source on the "Calciferous" escarpment near Lawson, at an altitude of nearly 1,100 feet. It has a rapid fall from source to mouth, much of the way over a rock bed in which rapids are numerous, though no cascades of note occur.

Rapid River heads in a swamp near Helena station, at an altitude of about 1,100 feet, and drains a narrow strip along the southwest edge of the Whitefish drainage basin, the drainage area being about 140 square miles. It has rapids at short intervals, as its name suggests, from a point near its source to its mouth, and there is a cascade of about 20 feet near the county-road bridge, in sec. 19, T. 42 N., R. 21 W.

Tacoosh River heads near Maple Ridge station, at an altitude of about 950 feet, and for 15 miles or more runs southeastward parallel with the Chicago & Northwestern Railway. It then turns eastward and enters Little Bay de Noc just west of Rapid River. Its drainage area is less than 2 miles in average width and is estimated to embrace less than 50 square miles.

Days River also has its source near Maple Ridge, at an altitude of less than 1,000 feet, and drains a narrow strip along the west side of the Chicago & Northwestern Railway to Brampton station, where it crosses the railroad and runs eastward into Little Bay de Noc, about 2 miles south of Rapid River. The drainage area is between 50 and 60 square miles.

Escanaba River drains nearly 1,000 square miles in Marquette, Dickinson, and Delta Counties, its headwaters being in the pre-Cambrian hills of western Marquette County at an altitude of about 1,600 feet. The estimated length of the stream, disregarding minor meanders, is about 100 miles, and its descent from source to mouth is fully 1,000 feet, thus giving an average fall by direct line of about 10 feet to the mile. The river has numerous rapids and small cascades in its course and a large cascade near the Princeton mine, where there is an available head of 100 feet.

Ford River drains a narrow strip on the southwest side of the Escanaba drainage basin. Its headwaters are near Floodwood and Channing, in northern Dickinson County, and its mouth just below Escanaba. As the altitude at the source is 1,400 to 1,450 feet, the stream has a descent of more than 800 feet. There are numerous rapids in its bed but no large cascades. Limestone bluffs set in near Northland and are present at numerous points below.

The remaining streams of Michigan tributary to Green Bay include Cedar River, a small stream in Menominee County, that enters Green Bay midway between Escanaba and Menominee, and Menominee River, which through much of its course forms the boundary between Michigan and Wisconsin and enters the bay at the city of Menominee. Menominee River has numerous cascades which furnish valuable water power. A report upon its water power appears in volume 17 of the Tenth Census of the United States. Its drainage basin is estimated to be 4,100 square miles, of which 1,450 square miles is in Michigan and the remainder in Wisconsin. The river is formed by the junction of Brule and Paint Rivers near Crystal Falls, Mich.

The entire drainage basin of Brule River in Michigan and Wisconsin is outside the limits of the Superior lobe of the Labrador ice field. So also are the streams from the south which are tributary to Paint River above Crystal Falls. The drift of this part of Michigan is referred to an ice movement that was much more extensive and definitely earlier than that of the Superior lobe. The direction of striae and the trend of drumlinoid hills show that the movement was west of south over this outlying area, whereas the striae and the moraines of the Superior lobe show that the ice in this later movement was converging toward this area from the west and north and east. Paint River follows a curving course immediately outside the drift of the Superior lobe, its headwaters flowing northeastward, its middle course eastward, and its lower course southward. The sources of the river are at an altitude of more than 1,600 feet, and so are the sources of several northern tributaries that head within the area covered by the Superior ice lobe. The altitude at the junction of Paint and Brule Rivers is below 1,200 feet. The largest cascades are on the main Paint River near Crystal Falls. Above Crystal Falls this river and its several tributaries are in an area with thick drift and few and small outcrops of rock, but below Crystal Falls rock ledges are prominent and widely exposed, and they continue to be numerous down the Menominee and cause several notable cascades.

Menominee River was shifted several times to correspond to changes in the position of the ice border and came to its present course only when the Green Bay ice lobe had shrunk to a position east of its lower portion. When this lower course was covered by the ice lobe the river turned southward along or near the ice border and followed it to the end of the lobe or to some drainage way that led southward. These temporary courses ran through the sandy outwash plains which lie between moraines in Marinette County and eastern Florence County, Wis. These plains occur at lower and lower levels down the valley, and it is evident that the stream shifted from higher to lower plains as such plains came within its reach by the ice recession.

Michigamme River, which enters the Menominee just below the junction of Brule and Paint Rivers, drains a large area that falls within the limits of the Superior lobe. Its headwaters gather into Lake Michigamme, one of the largest lakes in the northern peninsula. Its course extends through a region in which rock outcrops are numerous and the drift deposits more scanty than in bordering districts both to the east and to the west.

Sturgeon River is another large tributary of the Menominee which drains a considerable part of Dickinson County and along which rock ranges are prominent. It has a remarkably winding course caused by its following swales or depressions that lie between the ridges of rock or of glacial material, which have deflected it some miles to the right or left of a direct course. Because of this use of swales, it has but few rock rapids or cascades.

The Menominee receives two streams in Menominee County, Little Cedar River and Little River, each of which flows through a chain of swamps between drumlin ridges, which are numerous in that county. Almost the entire course of Little River is in swamps, and the highest part of this chain of swamps is little if any above the highest level of glacial Lake Algonquin. They may therefore have been prevented from developing a drainage line until the Lake Algonquin waters were drawn away. There was also a flooding of the lower course of Menominee River throughout the Lake Algonquin stage.

LAKES

The great glacial lakes that occupied the Superior, Michigan, and Huron Basins and stood at levels considerably higher than the surface of the three upper Great Lakes are discussed at some length below, and their relations to the present Great Lakes are set forth. In the present section reference is made to the many small lakes that are still filling basins and depressions in the drift deposits or among the rock hills. Almost all these small lakes are represented on the glacial map (pl. 1), only those that are too small to appear on a map of this scale being omitted. It is obvious that although these lakes are widely scattered over the region embraced in this report, they are particularly numerous in certain places and relatively rare elsewhere, also that there are very few of them on the smooth clay plains which were covered by the great glacial lakes. They are very numerous among the rock hills and ridges and on the prominent moraines of northeastern Minnesota. They also abound along the moraines that form the divide between the Lake Superior drainage system and that of Mississippi River in northern Wisconsin and the south edge of the west end of the northern peninsula of Michigan. There are probably more than a thousand of these small lakes within the area here discussed. Of these only two have an area so great as 20 square miles—Gogebic Lake in Gogebic and Ontonagon Counties, and the combined Portage and Torch Lakes, practically a single lake, in Keweenaw Peninsula. There are about 40 with an area of 2 square miles or more, and at least 100 exceeding 1 square mile. The aggregate area of the small lakes exceeding 2 square miles does not amount to 200 square miles, and the area of all these lakes in the region appears to be between 500 and 600 square miles.

Many of the lakes are bordered by swamps in which thick deposits of peat have accumulated. The base of the peat is very generally below the level of the lake surface, and its growth evidently has reduced the areas of the lakes to a large degree. Many lakes have been entirely converted into peaty swamps by this growth of organic matter. There has been more extinction of lakes by this process than by the draining away of the water through the cutting down of their outlets. Many of the lakes have no outlet except through swamps that connect them, and careful leveling has been found necessary to determine the direction of flow across some of the swamps. The drainage of not a few swamps and of some open lakes takes widely divergent courses. Thus Brule Lake, in Cook County, Minn., divided its waters between Brule River and Temperance River. On some lakes dams or even high-water stages cause a discharge by a course different from that of the low-water flow. It is because of the presence of these connecting swamps that the Indians and explorers and also geologic studdents have been able to make their way by canoes through the greater part of northern Minnesota and adjacent parts of Canada. Such traverses are also possible at several places in passing from waters tributary to Lake Superior to those tributary to the Mississippi or to Hudson Bay. Some of the swamps are in the beds of the outlets of glacial lakes or in the line of discharge of water from the melting ice sheet.

These small lakes have considerable variation in depth, but as yet soundings in them are incomplete. Some of them are said to reach a depth of 100 feet or more, but the usual depth is much less, and it is doubtful if many of them are more than 50 feet deep.

The lakes have great value in water-power development by holding back the discharge after freshets or rainy seasons and giving a steady flow through dry seasons. Many of them are fed by springs, another important factor in producing good flow in the dry seasons. One of the most remarkable springs that has come to the writer's attention discharges into Indian Lake a few miles west of Manistique, Mich. It wells up near the west edge of the lake in sec. 25, T. 42 N., R. 17 W. It is several yards across, and its depth is said to be fully 60 feet. The stream flowing from it is large enough to be navigated from the lake to the spring by small gasoline launches. An area of several square miles to the west of this spring is free from surface streams, and water goes into underground courses through sink holes in the limestone. This spring, therefore, probably affords an outlet for an underground drainage system embracing a considerable part of this limestone tract.

GLACIAL FEATURES

OUTLINE OF THE GLACIAL FORMATIONS

The Pleistocene glacial formations in America, as in Europe, include a complex series of deposits, there being on both continents four distinct sheets of boulder clay of widely different age, separated by soils and nonglacial deposits formed during stages of deglaciation. Aside from the four distinctly recognized drifts there is in Iowa and part of bordering States a glacial deposit of debatable rank and age which has been termed Iowan drift. It has been interpreted as having been deposited between the third or Illinoian drift and the latest or Wisconsin drift. But some geologists, including the present writer, are now inclined to refer part of it to the Wisconsin drift and part of it to the Illinoian. Others are disposed to place it between these drifts with a rank as high as is given to them.

The States bordering the upper Mississippi Valley have an especially full exhibit of the deposits and are thus classic ground for their study. The exhibit is not so full and clear in the relatively rugged area adjoining Lake Superior, though in places deposits of early glacial stages as well as those of the latest or Wisconsin stage are preserved.

The several drift sheets of the region bordering the Great Lakes and the Atlantic seaboard are named from States in which they are well displayed or in which a drift was clearly differentiated at an early date. The oldest drift on the Atlantic seaboard thus differentiated was named Jerseyan, from New Jersey, where it was clearly recognized in the 1890's. The oldest drift of the North Central States has been given the distinctive name Nebraskan, though it is very poorly displayed in Nebraska. In order from older to younger the drift sheets of the Great Lakes and Mississippi Valley region are as follows:

1. Nebraskan drift.
2. Kansan drift.
3. Illinoian drift.
4. Iowan drift (a deposit of debatable rank and age).
5. Wisconsin drift, separable into early, middle, and late Wisconsin.

The first and second drift sheets are best displayed on the west side of the Mississippi Valley, but one of them, probably the Kansan, has been recognized as far north as the north side of the Lake Superior Basin, in the Kaministikwia drainage basin back of Fort William, Ontario. These drift sheets have been covered by the Illinoian drift to a large degree in Illinois, Wisconsin, Michigan, Indiana, and Ohio. The distribution of the drift sheets in the north-central part of the United States, with the exception of the Nebraskan drift, which is almost wholly covered by Kansan drift and loess, is shown in Figure 5, together with the main subdivisions of the Wisconsin drift.

The latest or Wisconsin drift is the uppermost deposit over fully 90 per cent of the glaciated area of North America and is thus more widely open to inspection than the earlier drifts. A study of the distribution of its moraines and of the material embodied in it has served to show that the outline or shape of the ice field and the direction of ice movement were subject to wide variation. In the early part of this glacial stage (substages 1 and 2, fig. 5) the ice appears to have moved southwestward from Labrador across the Great Lakes into central Illinois. At that time it may not have extended into the region north and west of the Driftless Area in Wisconsin, Minnesota, Iowa, and the Dakotas. But later the ice sheet appears to have gradually extended westward, so that in the midst of this stage of glaciation (substage 3, fig. 5) its highest part, or center of radiation, was in the district of Patricia, in Ontario, north of the Great Lakes. The ice then moved southward across the eastern part of the Lake Superior Basin and through the basin of Lake Michigan into Indiana and Illinois. At the same time it moved slightly west of south across the west end of the Lake Superior Basin into western Wisconsin and eastern Minnesota. It deposited the sheet of young red drift of that region, called in this report the Patrician drift.[3] The prominent morainic system on the border of the Green Bay and Chippewa lobes in Wisconsin and of a large lobe to the west, in western Wisconsin and eastern Minnesota, was formed at this time. (See pl. 1.)

After the Patrician drift was deposited there appears to have been less snowfall in the region north of the Great Lakes and a corresponding shrinking of the ice in the Lake region; but the snowfall appears to have become greater in central Canada, in what is known as the Keewatin center of glaciation, and ice moved from that center southward across Manitoba and through western Minnesota and eastern North and South Dakota into Iowa. The main movement was through the Red River Valley into the Minnesota River Valley

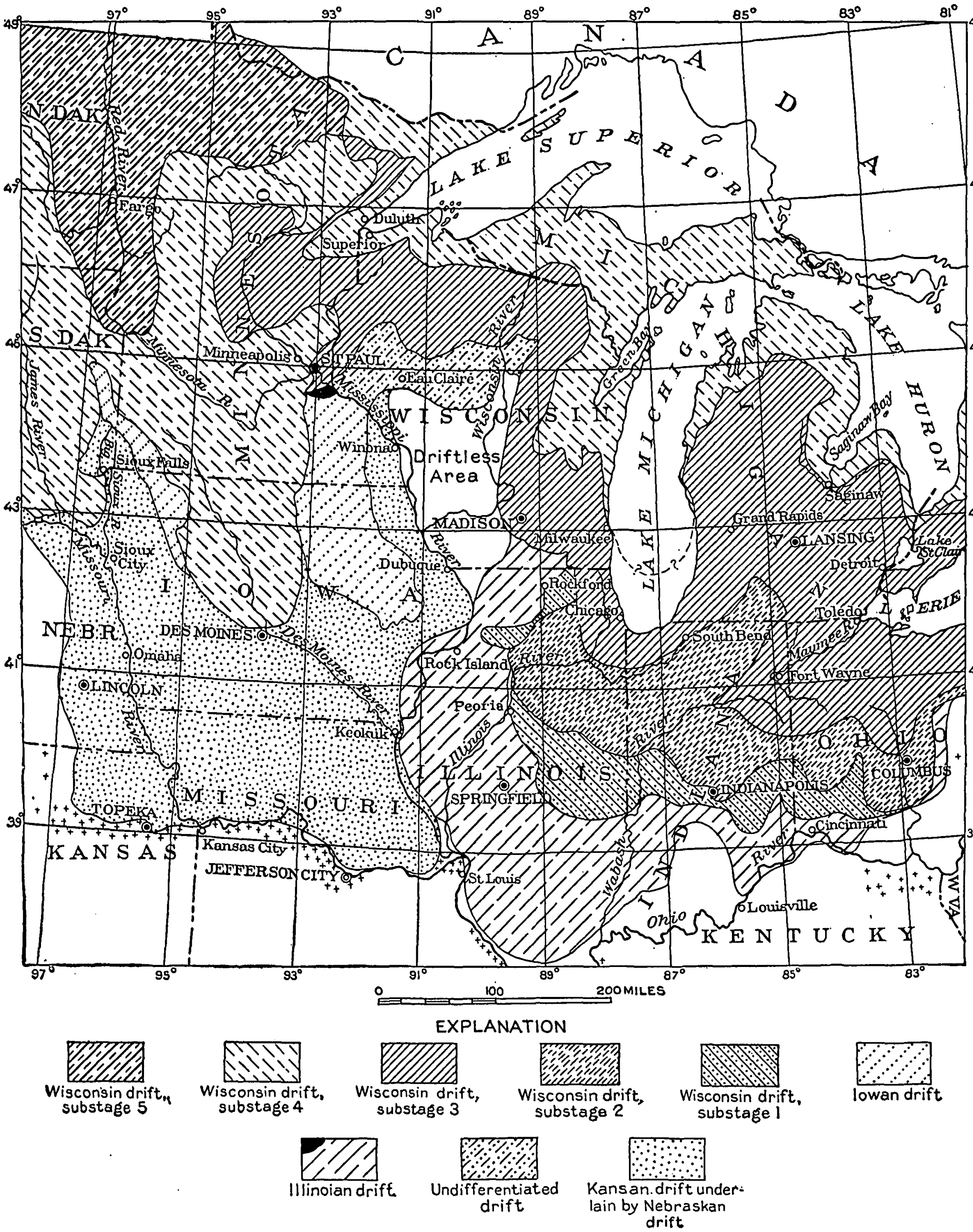


FIGURE 5.—Map of drifts in the northern United States, showing subdivisions of the Wisconsin drift. Crosses indicate outlying erratic boulders and patches of till. A small area of Illinoian drift south of St. Paul is indicated in solid black

[3] A late readvance of ice from the Patrician center of radiation south of Hudson Bay was brought to notice by J. B. Tyrrell in 1913 at the International Geological Congress at Toronto, Canada, and a brief abstract is published in the proceedings of that congress. There is clear evidence that a much earlier radiation from the Patrician district reached its culmination prior to the culmination of the Keewatin center of radiation in the middle part of the Wisconsin stage of glaciation.

and thence into the Des Moines River Valley, down which it passed to the site of the city of Des Moines. There were two minor lobes in eastern Minnesota, branching off from the main lobe. One of them crossed the Mesabi range and filled the middle part of the St. Louis River drainage basin, and the other extended from the Mississippi Valley above St. Paul northeastward to the St. Croix Valley, which it covered between Grantsburg and Osceola, Wis.

It was at about this time (substage 4, fig. 5) that the lobe in the Lake Superior Basin, which forms the theme of the present report, reached its fullest extension. The ice at this time moved much farther southwest through the deep basin of Lake Superior than it did over the relatively high land lying northwest of the Lake, in northern Minnesota. The ice there appears to have had a movement west of south and to have reached a little beyond Vermilion Lake and Lake of the Woods. This ice coalesced with that in the Lake Superior Basin from eastern Lake County, Minn., northeastward into Canada. It probably also coalesced with that moving south from central Canada in the district west of Lake of the Woods. Later (substage 5, fig. 5) the ice from central Canada extended past this line of coalescence in Manitoba and northern Minnesota.

The ice movement from central Canada brought in a clayey, calcareous blue-gray drift similar to that of the Kansan and pre-Kansan drifts of Minnesota but much fresher in appearance. It is known as the Young Gray drift. It is strikingly different from the very stony Patrician drift, which it overlaps. In the St. Louis River drainage basin, however, this calcareous drift contains so much iron gathered from the formations of the Mesabi range that it presents a red color, but it is easily distinguished from the underlying Patrician drift, being much less stony and having a more clayey matrix.

LIMITS OF THE SUPERIOR ICE LOBE

The extent of the Superior lobe of late Wisconsin time was first worked out in 1913 in Minnesota by F. W. Sardeson and in Wisconsin and Michigan by the present writer. The general glacial map (pl. 1) shows the extent of this lobe in the three States.

A variety of features have been taken into account in determining the limits of this ice lobe. The most conspicuous of these features are the moraines that loop around the west end of the basin and shed their outwash into the outlying districts. These moraines ride over moraines of Patrician red drift at various angles and in such a way as to make it clear that they were formed by a different ice lobe and at a later time. This discordance with the earlier moraines is found in northern Wisconsin and in the western part of the northern peninsula of Michigan as well as in Minnesota.

A second feature is that of difference in drift constitution. The drift of the Superior lobe along the northwest side of the Lake Superior Basin includes many rocks that were gathered near the Lake Superior shore and carried westward beyond their belt of outcrop, which falls within the limits of the Superior ice lobe. The Patrician ice, moving southward, would have carried them into and across the basin and could not have transported them so far westward. This Patrician ice movement carried rocks from formations such as the upper Huronian slates, iron ores, and associated rocks, which crop out farther west, in a southward course past the west end of the Lake Superior Basin and dropped them in the district later invaded by the Superior ice lobe.

A third feature is that of glacial striae. Those formed by the Superior lobe at this latest advance radiate from the basin toward its rim, their bearing on the north side of the basin being westward or considerably north of west, and on the south side of this part of the basin generally southwestward. The striae of the Patrician ice movement trend nearly south throughout northeastern Minnesota, or about at a right angle to those of the Superior lobe. This discordance in trend is shown on Plate 1. It is found as far east as Iron County, Mich., where the earlier movement was about south-southwestward, and that of the Superior lobe was east-southeastward in the northwestern part of the county, southward in the northern part, and southwestward or even westward in the eastern part. There is also in the Iron County district a difference in the rock constituents of the earlier and later drift. The later movement carried rocks from the Gogebic iron ranges to the east of their outcrop, but the earlier movement did not.

FEATURES OF THE BORDER OF THE SUPERIOR ICE LOBE

The Superior lobe seems to have held almost its maximum extent in northern Wisconsin and on much of the border northwest of Lake Superior while it was melting back considerably at the west end of the lobe. There are several small moraines at this west end which are the equivalents of a single massive morainic belt farther east.

On the northwest shore of Lake Superior, in Lake and St. Louis Counties, Minn., as far west as Duluth, the Superior ice lobe extended only 12 to 15 miles beyond the limits of the lake, the district farther back having been covered by ice that came in from the highlands of Canada on the north. The morainic system that runs westward across central Lake County and thence west-northwestward in St. Louis County past the south side of Vermilion Lake marks a contemporary position of the ice that came in from the north. This ice coalesced with that which came into the Lake Superior Basin from the northeast. The junction was in eastern Lake County, where an interlobate spur of great prominence was developed, its altitude being about 2,000 feet above sea level, or, 1,400 feet above Lake Superior. Northeast of this interlobate spur eskers are a conspicuous feature, and they seem to have been formed at the junction of the ice lobes.

At the west end of the Lake Superior Basin the Superior ice lobe extended about 60 miles beyond the present limits of the lake, its terminus as worked out by Sardeson being in southeastern Aitkin County, Minn., near the sources of Rice and Snake Rivers, about 10 miles east of Mille Lacs Lake. The south edge of the lobe crossed northern Pine County, 4 to 8 miles from its north line. The north edge crossed the northwestern part of Carlton County and came to St. Louis River in southwestern St. Louis County. It crossed the St. Louis River Valley just below the mouth of Cloquet River and kept south of that stream its entire length in St. Louis and Lake Counties.

In Douglas County, Wis., the Superior ice lobe extended 20 to 25 miles south of the shore of Lake Superior but fell short several miles of reaching St. Croix River and encroached but slightly on the headwaters of its northern tributaries. In Bayfield County an interlobate moraine was developed on the Bayfield Peninsula, there being a lobe of ice on the east that projected southward from Ashland or Chequamegon Bay and a lobe on the west that filled the west end of the Lake Superior Basin. The ice extended 25 to 30 miles south from Chequamegon Bay, or far enough to embrace Long Lake and Namakagon Lake, in southern Bayfield County. It passed a few miles beyond the Penokee iron range in Ashland and Iron Counties. The border follows or its moraine constitutes the divide between the Lake Superior drainage basin and that of large tributaries of the Mississippi, such as St. Croix and Chippewa Rivers, in much of its course across Douglas, Bayfield, and Ashland Counties, but it lies in places a few miles south of that divide in Iron and Vilas Counties. The border runs nearly due east from southeastern Bayfield County across Ashland, Iron, and Vilas Counties, Wis., and southeastern Gogebic County, Mich. As the Lake Superior shore there bears north of east, the distance from the lake to the border of the Superior ice lobe increases eastward and is 45 to 50 miles where the border passes from Wisconsin into Michigan.

In Michigan the border of the Superior lobe continued eastward past the north side of Lac Vieux Desert about to the line between Gogebic and Iron Counties. Thence it took a northeastward course for 10 to 12 miles and then turned eastward and followed the north side of Paint River in an eastward and southward course to the mouth of the stream, a few miles south of Crystal Falls. It then passed into Wisconsin and maintained a course nearly due south for 35 miles across Florence County to central Marinette County, forming the west edge of the Green Bay lobe of that time. From Marinette County southward the writer, in company for part of the way with Samuel Weidman, made a reconnaissance trip through Oconto, Shawano, Waupaca, Waushara, and Winnebago Counties, during which the tentative interpretation was reached that this readvance of the ice in the Lake Superior Basin is to be correlated with a readvance in the Green Bay and Lake Michigan Basins, which, as shown by Alden, developed red-clay moraines and worked upon a sheet of red clay that overlies the earlier deposits in that region. This advance that developed the red-clay moraines in Wisconsin, as shown by the writer in Monograph 53, seems to be correlatable with the advance in the Huron Basin to the Port Huron morainic system. It thus appears to be part of a widespread readvance in the Great Lakes region.

RANGE IN ALTITUDE ALONG THE BORDER

In eastern Lake County, Minn., where the Superior lobe coalesced with ice coming in from the north, the altitude is about 2,000 feet above sea level. There are a few hills and ridges still higher to the northeast, in Cook County, the highest being about 2,300 feet. The altitude along the border of the Superior lobe declines gradually toward the southwest, being about 1,700 feet at the line between Lake and St. Louis Counties and 1,200 to 1,300 feet at the west end of the lobe in Aitkin County and southwestern St. Louis County. It falls below 1,100 feet for a few miles in northwestern Pine County but rises eastward to about 1,300 feet at the Wisconsin-Minnesota line. It is below 1,100 feet at the outlet of glacial Lake Duluth but rises gradually eastward, reaching 1,400 feet on the east side of Long Lake and 1,500 feet east of Namakagon Lake, 1,600 feet in eastern Ashland County, and 1,700 to 1,800 feet in eastern Iron County and northern Vilas County, Wis., and southern Gogebic County, Mich. It is generally above 1,500 feet and in places reaches 1,700 feet in Iron County, Mich., but drops below 1,400 feet at the Michigan-Wisconsin line. For a few miles into Wisconsin it is up to 1,500 feet or more, but then it begins a gradual descent southward and is below 900 feet at the south end of the Green Bay lobe, south of Lake Winnebago. It falls within the limits and below the level of Lake Michigan (580 feet) at the south end of the lobe in the Lake Michigan Basin. The highest point covered by the Superior lobe in the northern peninsula of Michigan is about 2,000 feet above sea level and is near the Lake Superior shore in the Porcupine Mountains of western Ontonagon County. This lobe thus covered the highest points in Minnesota and Michigan and very high points in Wisconsin.

OUTER BORDER FEATURES

The features on the outer border of the Superior ice lobe furnish evidence as to the limits of this lobe. A series of outwash plains and heads of glacial drainage lines show clearly the position of the edge of the ice.

The outwash plains are conspicuous along Cloquet River throughout much of its length and in places reach a width of 3 or 4 miles. Locally no outwash was deposited because of high altitude in the outer border district, but there were numerous places in this district where the water found escape from the ice and spread out gravel.

For a few miles west from the mouth of Cloquet River conditions were unfavorable for outwash, but around the end of the lobe there is a sandy plain covering about 20 square miles from which drainage now leads both to the northwest, down Rice River, and to the south, down Snake River. The sand contains few pebbles, and the outwash seems to have been rather sluggish, probably because of the gentleness of the slope.

On the south border of the lobe near its west end there is a sandy area drained to Kettle River. This area, however, seems to have been covered to some extent by the ice and to have had boulders incorporated in the sand, and there was also some disturbance of the deposits which seems referable to glacial action on them.

From Kettle River eastward into Wisconsin there was remarkably little outwash, perhaps because a free discharge was not offered across the rather broken tract outside the ice. But in the reentrant angle on the Bayfield Peninsula between the Ashland lobe and the lobe in the west end of the Lake Superior Basin an extensive plain of sandy gravel was formed which covers more than 100 square miles in Douglas County and fully 50 square miles in Bayfield County. The interlobate moraine to the north of this plain is made up largely of waterworn material of rather coarse texture. Most of the surface of this outwash plain is more than 1,100 feet above sea level, or nearly 100 feet higher than the Brule-St. Croix outlet of glacial Lake Duluth, which runs along its northwest edge. The plain stands above 1,200 feet in the head of the recess between the lobes in western Bayfield County.

The Namakagon Valley appears to have been a line of strong glacial drainage from the Superior lobe from a point near Cable. Above Cable the stream flows in a narrow valley, and the Superior ice lobe probably covered part of its course between Namakagon Lake and Cable. Below Cable a sandy gravelly plain 1 to 2 miles wide follows down the river.

In western Ashland County a sandy plain stands just outside the outer moraine of the Superior lobe at the head of one of the headwaters of Chippewa River. It has a general width of more than a mile in its course across T. 43 N., R. 4 W., from the edge of the moraine to the Chippewa Lakes but is somewhat narrower below (south of) the lakes. From the Chippewa Valley eastward for several miles considerable swampy land occurs along the border of the outer moraine of the Superior lobe, and there was probably some ponding of water there. Still farther east are the extensive Manitowish marshes, occupying a strip 1 to 3 miles wide and 12 to 15 miles long on the outer border of the moraines of the Superior lobe. Farther east there are small sandy and gravelly outwash plains in Vilas County.

At the head of Wisconsin River, around Lac Vieux Desert, there is an extensive sandy gravel plain formed by outwash from the Superior lobe. It lies partly in Gogebic County, Mich., and partly in Vilas County, Wis. The altitude of its northern edge at State line station on the Chicago & Northwestern Railway is 1,712 feet. The outwash plain or glacial gravel fill along Wisconsin River is 1,670 feet above sea level at Conover, about 8 miles south of the State line, and 1,635 feet at Eagle River, 10 miles farther south.

In Iron County, Mich., there was glacial drainage all along Paint River from the ice border along the north side of the valley to its mouth. The outwash did not continue down Menominee River, because the ice was at that time covering the Menominee Valley nearly up to the mouth of Paint River. It passed southward across Florence County, Wis., through a district just outside the Green Bay lobe of that time. It received accessions from that ice lobe from point to point in Florence and Marinette Counties, Wis.

MORAINES OF THE SUPERIOR ICE LOBE IN MINNESOTA[4]

The moraines of the Superior lobe are markedly discordant with the moraines formed by the ice coming in from the north, that of the Patrician ice sheet. The Superior moraines either cross over the Patrician moraines because of difference in trend, or they face in the opposite direction where the courses are more nearly similar. The moraines of the Superior lobe are less bulky than some of the outlying and also underlying moraines formed by ice from the north. They belong to a rather thin till sheet. The knolls and ridges consist to some extent of crumpled and disturbed Patrician drift, over which there is in places only a thin veneer of the brighter-colored drift of the Supeior lobe.

On the north side of the Superior ice lobe, north of Lake Superior in Lake and St. Louis Counties, Minn., a great system of moraines, referred to in earlier reports of the Minnesota Geological Survey as the Highland morainic system, lies immediately within the border of this drift sheet. (See fig. 6.) This morainic system is formed by the converging and coalescence at the side of the lobe of moraines, which are distinct and separate toward the west end of the lobe. The moraines are likewise combined on the south side of the lobe in northern Wisconsin but are split up toward the west and there appear as distinct moraines.

On the south side of the lobe in Pine and Carlton Counties, Minn., there are two morainic systems, the

[4] Prepared largely from notes and manuscript by F. W. Sardeson.

Kerrick and the Nickerson, which are the equivalent of six more or less distinct moraines on the north side in Aitkin and Carlton Counties and southern St. Louis County—namely, the Wright, Cromwell, Draco, Cloquet, Thomson, and Fond du Lac moraines. The Wright and Cromwell moraines are regarded as the equivalent of the Kerrick morainic system, and the other moraines as the equivalent of the Nickerson morainic system; the entire series of moraines enumerated above are equivalent to the Highland morainic system.

KERRICK MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

THE MORAINES

The subdivision of the Highland morainic system of the north side of the Superior lobe into distinct constituent morainic ridges begins near the crossing of the St. Louis River Valley just below Brookston. To the northeast there is no distinct separation, but to the west there are two moraines of nearly equal strength, the Wright moraine and the Cromwell moraine, here named by the writer for villages on them in northwestern Carlton County, Minn. The Wright moraine bears away from St. Louis River near Paupori and passes by Prairie Lake to Wright station on the Northern Pacific Railway and thence runs along the south side of the railroad into Aitkin County, where it turns southward and runs about 4 miles west of Lawler and dies out in a sandy outwash plain near the sources of Rice and Snake Rivers, about 10 miles east of the northeast edge of Mille Lacs Lake. The Cromwell moraine runs southwestward from Brookston past Cromwell to Lawler and there turns abruptly south and marks the end of the Superior lobe of that time. Its position is

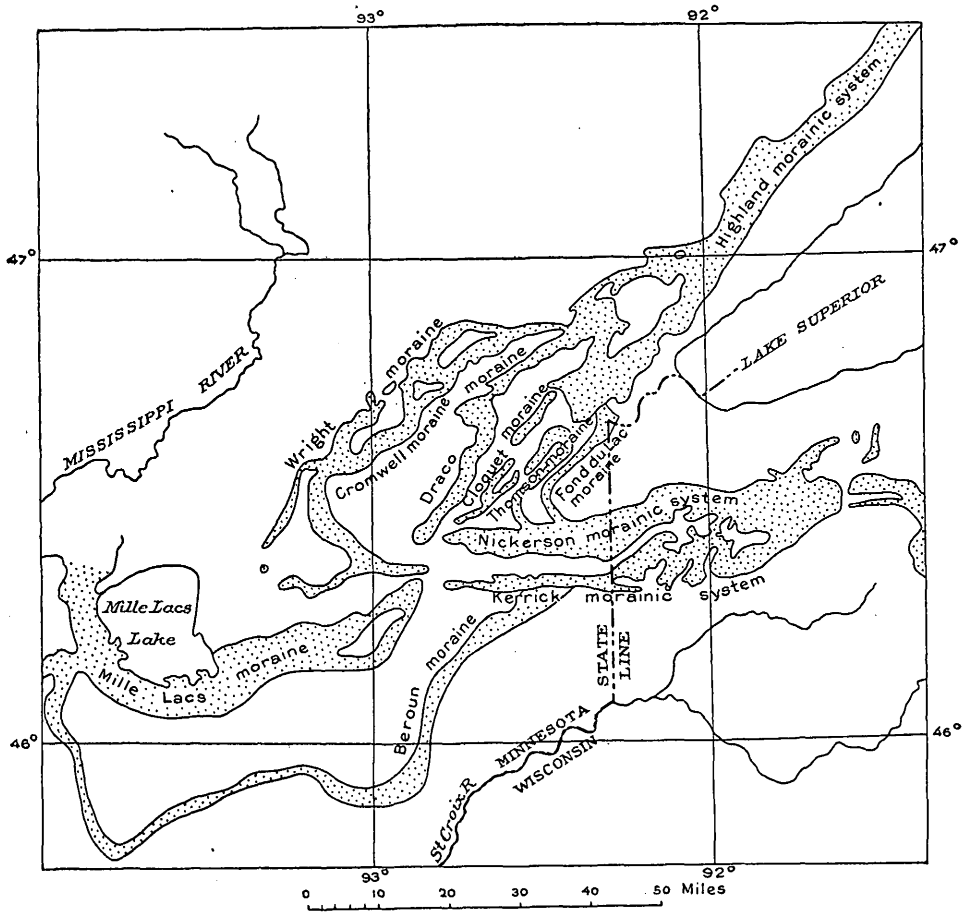


FIGURE 6.—Map showing moraines of Lake Superior lobe in northeastern Minnesota and the Mille Lacs and Beroun moraines of the Patrician ice sheet

The time relations of the moraines of the Superior lobe as well as those of the Patrician ice sheet in this area are shown below.

Superior lobe (Highland morainic system).	Fond du Lac moraine (deposited in water).	Nickerson morainic system.
	Thomson moraine.	
	Cloquet moraine.	
	Draco moraine.	
	Cromwell moraine.	Kerrick morainic system.
	Wright moraine (oldest).	
Patrician ice sheet.	Mille Lacs moraine.	
	Beroun moraine.	

several miles east of the Wright moraine at the end of the lobe. On the south side of the lobe the two moraines are separated only for a few miles in Aitkin County. In Pine County they are united into a single morainic system, which passes through or near Denham, Kerrick, and Belden and is here named the Kerrick morainic system. Near the Wisconsin line the Kerrick morainic system becomes coalesced with a later one, which is here designated the Nickerson morainic system, from the village of Nickerson.

The Kerrick morainic system has a general width of about 3 miles from Belden to Kerrick but is only about 2 miles wide in the vicinity of Denham. It widens a little to the west of Denham. The Wright and Cromwell moraines are each about 2 miles wide.

The Kerrick morainic system consists at Kerrick of closely distributed small knolls 10 to 20 feet high. Near Belden its knolls are 5 to 15 feet high and separated by much swampy land, probably half the surface being bog. For 5 miles west from the State line the proportion of bog is still higher, so that the morainic knolls are scattered widely. Midway between Belden and Kerrick the morainic expression becomes strong again, the morainic system crosses obliquely over the Beroun moraine, of the Patrician ice sheet, here named by the writer for Beroun, Minn., and for 3 miles there is the combined strength of the two systems. There is much less swamp west of the crossing of the Beroun moraine, although near Kerrick the moraine is interrupted by a swamp half a mile to a mile wide. A few miles west of Kerrick the moraine is weak in expression and consists of slightly disturbed outwash gravel and sand in a strip along Moose and Kettle Rivers. To the west of this outwash plain the moraine becomes strong again. It overrides the Mille Lacs moraine, of the Patrician drift (here named by the writer from its position on the borders of Mille Lacs Lake), and some outwash was spread over the lower places in that moraine in northwestern Pine County. In secs. 15, 22, and 27 and also in secs. 25 and 36, T. 45 N., R. 20 W., it rides obliquely over prominent ridges of the older moraine and caps them with its own small knolls. In the vicinity of Denham the Kerrick morainic system lies partly on a rock ridge and partly in a valley south of the ridge.

After separation into two distinct parts or members, the Wright and Cromwell moraines, the knolls become more scattered than in much of the united belt and in places are so diffuse as to be difficult to map. They run through a region of bogs and consist of groups of knolls or of short ridges for stretches of 1 to 3 miles, which are separated by wide swamps. As these bogs have a peaty filling of 5 to 20 feet, low knolls may be completely overgrown and concealed under them.

In a few places the Kerrick morainic system consists of heavy clay till, but for the greater part it is loose textured or sandy, with numerous pebbles of Keweenawan diabase and red rock, greenstone, red sandstone, quartz, and chert and rarely a limestone pebble. Sandstone is most common on the south and west sides of the lobe but is also found on the north side as far north as the crossing of St. Louis River near Brookston.

At Kerrick the till is a light clay of bright red color with many pebbles of sandstone and basic volcanic rocks. Heavy clay is found west and north of Denham but the drift is loose textured between Kettle River and Denham, in parts of the morainic system south of Arthyde, and from Solana to Snake River. This loose-textured till is, however, in places only a few feet thick and lies on heavier till of the Patrician drift. The clay is heavier in many places in Carlton County.

An isolated gravel hill or kame of the Wright moraine, standing nearly 100 feet above the surrounding land, rises from an outwash plain on Snake River in the NW. $\frac{1}{4}$ sec. 5, T. 44 N., R. 24 W. It covers about 40 acres. It is at the apex of the Superior lobe. Boulders and till occur at the surface, but the hill appears to consist of gravel below.

OUTWASH DEPOSITS

Glacial drainage from the part of this lobe in Minnesota occurred at several points but was of slight extent and relatively weak. On the south side outwash is present on Willow River. At the apex of the lobe it extends down Snake River and on the north side it occurs at Cromwell and Brookston and along Cloquet River. Nearly all the outwash at Willow River appears to pertain to the Mille Lacs moraine of the Patrician ice sheet. The Kerrick morainic system passes across this outwash, but a part of the deposit seems to belong with the Kerrick system. The narrow strip of terraced gravel along the south fork of Willow River could not have been formed earlier. The outwash on Snake River lies in strips and patches, as if deposited slowly during the entire time in which the Wright moraine was forming. It takes the place of the moraine for 6 miles in length and is spread over a belt 2 to 4 miles wide at the end of the lobe. There is a little gravelly outwash along Split Rock Creek connected with the Cromwell moraine. It forms a terrace where the stream enters the moraine from the southwest in sec. 5, T. 45 N., R. 22 W. Outwash occurs in connection with both of the moraines near Cromwell, but the largest deposit lies near the inner one. The outwash occupies an area of about 5 square miles west of the village, along the Northern Pacific Railway. That north of the railroad is outside the moraine, but that on the south is partly within the moraine. The outwash at Brookston is opposite the mouth of Cloquet River and seems to be the west end of a strip that comes down that river from Burnett. It is of especial interest at Brookston, for it was there carried up St. Louis River from the mouth of Cloquet

River instead of down the valley, the part of the valley below the mouth of Cloquet River being covered by the ice of the Superior lobe. About half a mile south of Brookston are exposures showing outwash involved in the morainic material by a forward thrust of the ice. There appears also to have been some invading of the outwash by forward ice movement in other places between Brookston and Burnett.

TILL PLAIN OR GROUND MORAINE

The till plain between the Wright and Cromwell moraines is narrow in southern St. Louis County and northwestern Carlton County, Minn., its width being about the same as that of either moraine. In Aitkin County north of Solana, however, it widens to 7 miles. The drainage in this plain is rather imperfect and is effected by several small streams that start in the plain or in neighboring moraines. The altitude is relatively high, as may be inferred from the fact that the plain is the starting point of drainage lines.

The plain that lies between the Cromwell moraine of the Kerrick morainic system and the succeeding Draco moraine of the Nickerson morainic system is somewhat wider than that between the Cromwell and Wright moraines. Though only 3 to 5 miles wide on the south side of the lobe, it widens to about 20 miles near the end of the lobe, in western Carlton County. It is narrow also on the north side of the lobe in St. Louis County. It is partly occupied by outwash in its narrow parts north of St. Louis River and on the borders of Willow River. This plain drains partly to St. Louis River, of the St. Lawrence drainage system, and partly to Kettle River, of the Mississippi drainage system, but the divide here between the two systems is mostly flat and ill drained. The plain is composed largely of clayey till, which is so thick that rock exposures are rare. There are slate outcrops, however, in secs. 14, 15, 22, and 23, T. 46 N., R. 21 W., and sec. 9, T. 45 N., R. 20 W. A diabase ridge that is cut through by the Minneapolis, St. Paul & Sault Ste. Marie Railway (Soo Line) 2 miles south of Harris runs across T. 45 N., R. 16 W., from sec. 12 to sec. 31.

NICKERSON MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

THE MORAINES

On the north side of the Superior lobe the Nickerson morainic system becomes distinct from the Kerrick morainic system near Grand Lake, Minn. Its outer member, here designated by the writer the Draco moraine, branches off in that locality, and the others branch off a few miles farther east. The Draco moraine passes in a southwesterly direction to St. Louis River at Draco. Across the river in Carlton County it runs to Big Lake, thence southward by Sawyer station to Park Lake near Mahtowa, thence southwestward to Kettle River west of Moose Lake.

The middle member, or Cloquet moraine, comes to St. Louis River at Cloquet from the north-northeast and thence takes a southwesterly course at Atkinson, Barnum, and Moose Lake, where it meets the Draco moraine and turns east with it to form the undifferentiated Nickerson morainic system.

The inner member, or Thomson moraine, is interrupted by a wide gap at St. Louis River immediately north of Thomson and is closely associated with the Cloquet moraine northeast of this river. From Carlton and Thomson it runs southwestward to Nemadji, turns to the south and east, and within a short distance coalesces with the other parts of this morainic system. For a few miles from Carlton it is a double ridge with a narrow gravelly strip between its members.

On the south side of the lobe from a point near Nickerson eastward there is a single massive morainic belt that forms the equivalent of the three moraines just described. It leaves the State of Minnesota at the corner of Pine and Carlton Counties and, in combination with the Kerrick morainic system, continues eastward into Wisconsin. From the State line westward to Nickerson, for 10 miles, its border lies about 2 miles south of the Pine-Carlton county line, but it nearly follows the county line from Moose Horn River to Kettle River. The apex of the lobe was a mile west of Kettle River at Split Rock Creek.

The united morainic belt along the Pine-Carlton county line is about 4 miles in width. Where the members are separate the Draco, Cloquet, and Thomson moraines are each 1 to 2 miles wide, but near the apex of the lobe the Draco moraine spreads out to nearly 5 miles. The Cloquet moraine spreads out near Barnum to a width of 3 miles, and the Thomson moraine is of similar breadth just south of Carlton if the gravelly plain between its two members is included.

The Nickerson morainic system presents throughout a knolly and ridged surface of moderate strength. Where a moraine of this system overrides or crosses the Mille Lacs moraine of the Patrician drift, as the Draco moraine does near Moose Horn Lake, its knolls are less prominent than the ridges of the older moraine. From Moose Lake eastward to the State line the morainic system lies on a high divide and is thus prominent as well as compactly morainic. In the turn at the apex of the lobe west of Moose Lake the knolls and ridges are more scattered than to the east. Northwest of Moose Lake the moraine is broken by swamps and also by drainage channels but still is well defined. It has especially rugged features near Big Lake and Perch Lake.

The middle or Cloquet moraine is cut through by the outlet of glacial Lake Nemadji east of Moose Lake village, at the place where it makes the turn at the apex of the lobe. This outlet is, however, only about one-sixth of a mile in average width. From Moose

Lake nearly to Atkinson the Cloquet moraine lies high on the ridges of the Mille Lacs moraine. Between Atkinson and Cloquet it is broken by swamps, drainage courses, and outwash. North of Cloquet it includes some very prominent knolls and a short gravel ridge of esker type.

The Thomson moraine is closely associated with its outwash plain for several miles west from Nickerson and is rather inconspicuous there and around the end of the lobe, for it was laid down for a few miles in the water of Lake Nemadji. A short distance beyond the point where it rises to the north from Lake Nemadji, about 5 miles northeast of Nemadji station of the Soo Line, it runs over the Mille Lacs moraine and thus attains exceptional prominence. Its course north of St. Louis River is also over highlands and along the ridges of a Patrician moraine.

The prevailing type of drift in the Nickerson morainic system is clayey rather than sandy. From the State boundary westward to Kettle River it is chiefly heavy clay and has relatively few large stones embedded in it, and in places even small stones are scarce. It may include considerable material derived from lake beds which the ice passed over as it moved out from the Lake Superior Basin. On the northwest side of the Superior lobe from Kettle River northeastward there is a considerable amount of gravelly and loose-textured drift. From Otter Creek to Cloquet it is very largely gravelly. The till has a larger proportion of clayey drift northeast of St. Louis River than for a few miles southwest of that stream. Yet gravel knolls and ridges are not rare. In places where the morainic ridges of Patrician drift are overridden there are many exposures of the older drift in cuts of moderate depth, for the Superior drift is a relatively thin deposit. Though each drift is classed as red drift, there is a perceptible difference in color due presumably to a difference in the rock constituents.

The rock striations in this morainic system were partly produced by the Patrician ice and partly by ice of the Superior lobe. In some places striae of both ages are present on a single rock outcrop. In a cut on the Soo Line a mile south of Harlis, near the outer edge of the Nickerson morainic belt, the younger set bear S. 62° W. (magnetic) and the older set S. 20°–30° W. Outside the moraine 2 miles south of Harlis only the older set is present with magnetic bearing S. 20°–32° W. Near Moose Lake striae produced by the Superior lobe bear nearly due west, and in Duluth and westward past Carlton those formed by the Superior lobe in high ranges bear west or slightly north of west. Lower down along the slope toward the Lake Superior Basin they commonly bear a little south of west. North of Atkinson near Park Lake are striae bearing about N. 60° W., including heavy furrows an inch in depth.

OUTWASH DEPOSITS

Outwash deposits of considerable extent are found in many places in connection with the Nickerson morainic system. On the south side of the lobe there is an area of about 10 square miles south of Willow River lying between the Kerrick and Nickerson morainic belts which is occupied by rather sandy gravel. Another plain of sandy gravel covering several square miles lies on the north side of the most prominent moraine of this system and is probably a dependency of the Thomson moraine. It stands higher than the land to the north, which was covered by ice at the time this outwash was laid down and later by the waters of Lake Duluth.

At the end of the Superior lobe and the outer border of the Nickerson morainic system there are small areas of sandy gravel outwash, one east of Kettle River Station on the Soo Line and one east of Glassy Brook.

Outwash of coarser grade is found near Barnum, outside the Cloquet moraine. It extends south about to Moose Lake and extensive gravel pits have been opened in it by the Minneapolis, St. Paul & Sault Ste. Marie Railway Co. Another deposit inside the Cloquet moraine south of Atkinson covers about 3 square miles, and east of Atkinson is an area of about 10 square miles of gravelly outwash lying outside the Thomson moraine.

An area of undulating gravelly land covering about 3 square miles lies northwest of Park Lake, and farther north there are ridges of gravel in the vicinity of Sawyer station and northward to Big Lake. Although these areas are not outwash plains, they seem to have been developed by water action along the ice border, where conditions were not favorable for spreading out the gravel. The ice probably overlay much of these areas, for surface boulders are not uncommon on the gravel. Between Big Lake and Cloquet plains of outwash gravel occur in steplike succession from higher to lower toward Carlton either from Big Lake or from Cloquet. In each of these steps the tread is an outwash plain or glacial drainage line, and the steep slope down to the next step marks the correlative position of the ice border. In some places boulders and till or cobbly drift are to be seen in these steep slopes.

A conspicuous channel known as the Scanlon channel leaves St. Louis River at Scanlon and runs southwestward to Atkinson. There it branches; one branch is followed by the Northern Pacific Railway to Moose Lake and the other passes southward and turns west on the inner side of the Cloquet moraine. The southern branch is a slightly lower channel and was probably utilized as a line of glacial drainage after the one now followed by the Northern Pacific Railway had been abandoned. The Scanlon channel seems to have carried a volume of water considerably greater than the present St. Louis River and to have been a line of glacial drainage for a large area on the northwest side of the Superior lobe, and possibly it carried water from the melting of ice that came in from the northwest, whose southeast edge at this time seems to have been but a short distance from the northwest edge of the Superior lobe.

The glacial drainage of the Nickerson morainic system seems to have increased in strength with the development of each moraine. The drainage on the south down Willow River was weak and the streams do not seem to have been large at the time the morainic system was being started. There was also drainage of a similar sort in the west side of the lobe, through the meadows and swamps that extend southwestward from Big Lake to Kettle River. On Glassy Brook more vigorous drainage seems to have been in operation. In northern Carlton County and the region north of St. Louis River there seems to have been westward flow through low passages and swampy tracts, but the line of escape of the waters has not been worked out. While the Cloquet moraine was being formed the drainage on the northwest border of the Superior lobe became vigorous. The glacial streams flowed down the course now taken by the Northern Pacific Railway from Atkinson to Moose Lake, the ice at that time being present in the part of the Scanlon channel east of Atkinson. This drainage was fed from points as far northeast as Cloquet through the outwash strips noted above. The Scanlon channel and the channel leading south from Atkinson were formed as a result of drainage during the recession of the ice sheet to the Thomson moraine and the development of that moraine, and eventually the glacial stream flowed into Lake Nemadji and discharged through the Cloquet moraine past Moose Lake.

TILL PLAINS OR GROUND MORAINE

On the south side of the Superior lobe the Nickerson morainic system is not separated into distinct members with intervening plains. On the northwest side, where there are separate moraines, the intervening areas are partly occupied by outwash gravel and sand, partly by channels of glacial drainage, and partly by till plains. Between the Draco and Cloquet moraines a small till plain is found in parts of secs. 9, 16, 17, and 19, T. 46 N., R. 19 W., north and west of Moose Lake. The material is undulating till at the south, but this gives place toward the northeast to bare slate in sections 2, 3, and 10. Another till plain lies west of Mahtowa in secs. 6 and 7, T. 47 N., R. 18 W., and secs. 1, 11, 12, 13, and 14, T. 47 N., R. 19 W. Farther north, nearly west of Atkinson, is a narrow till plain that spreads out to a width of almost 3 miles and trends northward to the Northern Pacific Railway between Iverson and Sawyer station. An area of till plain nearly surrounded by outwash runs from the Draco moraine at the north end of Big Lake for 4 miles eastward and is about a mile wide. Above Cloquet on each side of St. Louis River there is a till plain which covers several sections in T. 49 N., R. 17 W., and the southeastern part of T. 50 N., R. 17 W., an area of about 12 square miles, of which 5 square miles is west and 7 east of the river. There is a small area of till plain between the Thomson and Cloquet moraines northeast of St. Louis River, though these moraines generally are close together there. Parts of secs. 7, 8, 9, 10, 11, 16, 17, 18, 20, and 29, T. 49 N., R. 16 W., may perhaps be better classed as till plain than as moraine. To the southwest from St. Louis River as far as the edge of Lake Nemadji the interval between the Cloquet and Thomson moraines is nearly all occupied by outwash plains and glacial drainage channels.

FOND DU LAC MORAINE (DEPOSITED IN WATER)

The Fond du Lac moraine, here named by the writer from Fond du Lac, Minn., is water-laid so far as it stands out separately from the morainic systems with which it connects at its two ends. It leaves the Highland morainic system that lies north of the west end of Lake Superior in the southwestern part of Duluth and crosses St. Louis River at Fond du Lac. Its inner slope is on the Wisconsin side of the State line opposite Fond du Lac but its outer border is in Minnesota. It leads southwestward through T. 48 N., R. 16 W., the northwestern part of T. 47 N., R. 16 W., and the southeastern part of T. 47 N., R. 17 W., and thence swings around to the southeast and east through the northeastern part of T. 46 N., R. 17 W., and the central part of T. 46 N., R. 16 W., and becomes merged with the Nickerson morainic system on the south side of the Superior lobe, near the State line. The part of this moraine running southwest from Fond du Lac has a relief of 75 to 100 feet on the inner border in much of its course but has scarcely any relief on the outer border. It rises less prominently on the inner border at the end of the lobe and on its south side. Ravines and railroad cuts in the prominent part southwest of Fond du Lac show a large amount of fine sand and nearly pebbleless clay capped by a few feet of boulder clay. The glacial material thus seems to be banked against and spread lightly over a thick deposit of water-bedded material. As the entire moraine lies within the limits of the highest shore line of glacial Lake Duluth and is below the level of that shore line, the ice lobe was probably bordered by ponded waters and dropped its boulders and till in deposits laid down by these waters.

The portion of the bed of Lake Duluth to the north of this moraine is generally covered with sandy deposits, but around the end of the lobe and on its south border the sand is much less conspicuous and red clay usually occurs at or near the surface. The district lying inside the moraine in Carlton County, Minn., is almost entirely a plain of red clay. In this red clay are embedded a few stones which suggest glacial derivation. It is a widespread deposit in northern Wisconsin and Michigan, as well as in Carlton County, Minn., and occurs in a narrow strip along the north side of Lake Superior from Duluth northeastward into Canada within the limits of Lake Duluth or of smaller lakes that preceded Lake Duluth. Its characteristics and probable relation to the Superior glacial lobe and to glacial lakes are considered more fully below.

HIGHLAND MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

MORAINAL DEPOSITS

The Highland morainic system takes its name from Highland station on the Duluth & Iron Range Railroad, in the southwestern part of Lake County, Minn. It is the equivalent of the entire series of moraines just described, from the Wright to the Fond du Lac, both inclusive. Northwest of Duluth it is separable into two great morainic belts, between which there is a till plain that surrounds Wild Rice Lake and occupies an area of about 50 square miles; but from the east side of Duluth northeastward for more than 60 miles it is a single massive morainic system from 4 to 6 miles in general width but in places reaching 7 to 8 miles. Its inner border is only 1 to 2 miles from Lake Superior back of Duluth, but thence bears inland and is 9 to 12 miles from the lake in Lake County. In the vicinity of Duluth its highest points are about 1,500 feet above sea level, or 900 feet above Lake Superior, and it covers the slope toward Lake Superior to a level below 1,200 feet. It increases gradually in altitude toward the northeast and reaches about 2,000 feet in eastern Lake County. In this highest part, in T. 59 N., Rs. 7 and 8 W., this morainic system meets a correlative morainic system formed by the southward-moving Patrician ice sheet, and its great prominence is due in some degree to the heaping up of drift at the junction of the two ice sheets. Some of the drift ridges there are 100 feet or more in height. The morainic system changes to a series of eskers or gravelly ridges near the corner of Tps. 59 and 60 N., Rs. 6 and 7 W., and these ridges continue northeastward into the western edge of Cook County and appear to mark the line of junction of the Superior lobe with the Patrician ice sheet.

The Highland morainic system is prevailingly of the strong knob and basin type, with knobs or ridges of drift rising abruptly to heights ranging from 25 to 75 feet or more above the intervening basins and low ground. Some of the basins and low swampy tracts are completely surrounded by higher land and have no drainage over the surface. Others are winding depressions through which drainage courses run. The lakes interspersed with the drift knolls and ridges of this morainic system are not so many nor so large as those found among the rock hills and ridges farther north, in Cook, Lake, and St. Louis Counties. Wild Rice Lake has an area of but little more than 2 square miles, and no others reach 2 square miles. The drift is generally loose textured and contains many cobblestones and small boulders. There is, however, enough fine material in the matrix to produce a rather loamy soil. The diabase of Beaver Bay, which forms a notable constituent of the drift, seems to have contributed material that weathers into a loamy rather than sandy soil. The soil is therefore classifiable as stony loam. This moraine has been brought under cultivation with good results in the vicinity of Duluth, but elsewhere it is largely undeveloped, and much of it is still in hardwood forest.

OUTWASH DEPOSITS

Outwash deposits are conspicuous on the border of the Highland morainic system for most of its course in Lake and St. Louis Counties, and Cloquet River now flows through the outwash district. The outwash is present for a few miles farther northeast than the head of the Cloquet River, but the line of discharge from the ice was down that valley. The outwash ranges in width from less than a mile to 4 or 5 miles. It consists in many places of rather coarse cobble and gravel, and little of it is fine and sandy. There were numerous points of discharge of water from the ice lobe, and at such places the material is exceptionally coarse. The ice in some places readvanced into the outwash area and introduced boulders and other morainic material and roughened the surface to some extent. Such disturbances were noted as far down as Brookston.

INNER BORDER TILL PLAIN

A strip of land 1½ to 3 miles or more in width having a gently undulating surface such as is characteristic of till plains lies on the inner or southeast border of the Highland morainic system in Lake County and the southeastern part of St. Louis County. Its soil is somewhat better than that of the moraine, and a considerable part of it has already been brought under cultivation.

LATER MORAINES IN NORTHEASTERN MINNESOTA

A narrow morainic strip, scarcely more than a mile in average width, was traced from Baptism River west of Finland southwestward for nearly 50 miles, or to a point within 8 or 10 miles of Duluth. Its drift is more knolly and of looser texture than that in the till plain back of it just described. This moraine may continue to the northeast beyond Baptism River, but rock knobs are so conspicuous there as to make its identification rather difficult and to break it up into isolated knolly spots or strips.

A later moraine than that just noted sets in on the Lake and Cook County line, only 2 or 3 miles from the shore of Lake Superior, and leads northeastward beyond the meridian of Grand Marais, Minn. It is generally 6 to 10 miles back from the lake shore and has a width of 1 to 2 miles. It passes along the north side of Devil Track Lake and was traced northeastward about 8 miles beyond this lake to Brule River. To the north of Brule River there is a rough rocky region in which it may be difficult to identify the moraine. This moraine lies back of the Sawtooth Range, in a district where the drift is heavy enough for the morainic features to stand out with some clearness. The drift is stony and loose textured and the area contains swamps of considerable extent and therefore has not been developed for agriculture.

A still later moraine was traced from a point near the mouth of Cascade River northeastward for several miles. This is thought to continue across Cook County to the Canadian border, crossing Brule River in the southwestern part of T. 63 N., R. 3 E., and passing west of Toms Lake and coming to Pigeon River in T. 64 N., R. 4 E. After passing Devil Track River it follows the eastern edge of a prominent rocky area and marks the west limit of a district with considerable drift and much swamp land. Immediately above the place where, according to Elftman,[5] the moraine reaches the Canadian border there is a lowland extending back several miles west from Pigeon River, nearly across T. 64 N., R. 3 W., in which the drift deposits are heavy. This lowland has a nearly smooth surface and is thus in contrast with the knolly moraine to the east and with the rock ridges to the north and south.

To the east of this moraine, in eastern Cook County, about half the surface is in rock ridges and the other half is in swamps and drift deposits of ground-moraine rather than terminal-moraine type. North of Grand Portage is an area in which lake clay occupies the low areas between the rock ranges, for it stands below the level of glacial Lake Duluth.

MORAINES OF NORTHERN WISCONSIN

OUTER MORAINIC SYSTEM

From a point near the Minnesota-Wisconsin State line eastward across northern Wisconsin the several moraines that have been traced around the end of the Superior lobe in Minnesota are combined into a massive system 8 to 15 miles in width whose members are distinct at only a few places where narrow strips of till plain and swamps or small outwash plains separate them. The outer or southern edge of this morainic system enters Wisconsin about 28 miles south of Superior, in the northern part of T. 44 N., R. 15 W.; the inner edge is 10 to 12 miles farther north, in the northern part of T. 46 N., R. 15 W. In its course across Douglas County the moraine lies mainly on the north or Great Lakes side of the divide, but in places it extends a short distance into the drainage area tributary to the Mississippi. Its general course is slightly north of east and its constituent ridges trend mainly in the same direction. In this respect they differ from the ridges in the district outside of this morainic system, which trend more nearly south. The drift is also somewhat different in character from that of the outlying district, containing more red clay. On the soil map of the northern part of northwestern Wisconsin that accompanies Bulletin 32 of the Wisconsin Geological and Natural History Survey the soil in the outlying district in western Douglas County is classed as Millen silt loam and that in the moraine is termed Millen loam. According to that map, the boundary between these two classes of soil follows very closely the southern edge of this morainic system for 8 or 9 miles east from the State line, but not farther east. It is the present writer's opinion, however, that distinctions in texture continue eastward to the Brule-St. Croix channel, though perhaps in less marked degree than in the part represented on the map cited.

In Bayfield County the prominent Bayfield Peninsula is occupied by an interlobate moraine belt for its entire length, and morainic features also appear on Oak Island, of the Apostle group. This morainic belt was formed between a sublobe that occupied the extreme west end of the Lake Superior Basin and another that projected into the lowland east of the peninsula, at the south end of the Chequamegon Bay. This interlobate belt consists of sandy and somewhat stony drift, which is classed, on the soil map of the Wisconsin Geological and Natural History Survey under three names—Vilas sand, Plainfield sand, and Superior sandy loam. Depressions extending back into this morainic system in the northeastern part of the peninsula contain a much heavier clayey drift, which is classed on the soil map as Superior clay. These depressions were almost entirely covered by glacial Lake Duluth, whereas only a small part of the loose-textured moraine was thus submerged. In the midst of this interlobate morainic belt there are strips of outwash plain filling the space between the ridges and knolls, but the greater part of the interlobate belt is characterized by sharp knobs and deep basins. The general width of this interlobate morainic system with its included outwash plain is about 12 miles. A great outwash plain extends from its south end to St. Croix River and to Eau Claire River a small eastern tributary of the St. Croix that drains the Eau Claire Lakes. This outwash plain fills a great recess at the junction of the two sublobes just noted and slopes southwestward from the edge of the morainic system.

From this interlobate area the morainic system continues southeastward into western Ashland County and thence eastward across Ashland and Iron Counties and northern Vilas County into Gogebic County, Mich. It covers the Penokee iron range as well as lower land both north and south of it in western Ashland County, but from Bad River eastward it lies

[5] Elftman, A. H., Am. Geologist, vol. 21, pl. 11, 1898.

mainly south of the iron range. Slender moraines north of the range in these counties were formed as the ice border was receding from the range into the Lake Superior Basin. One of these smaller moraines is merged with the main morainic system from Bad River westward but lies some miles north of it in the district east of Bad River.

The Millen loam is mapped by the Wisconsin Geological and Natural History Survey as the most extensive soil class in this morainic system in southeastern Bayfield County and Ashland County, but the soil in the vicinity of Long Lake is represented on the map as the Vilas sand. The morainic system there includes a few kames and gravelly ridges. In the district outside this morainic system the soil is classed mainly as the Vilas sand from Cable eastward into Ashland County and as the Kennan loam in the vicinity of Glidden.

Rock knobs and ridges of the Penokee iron range and also Keweenaw rocks crop out at many places in this morainic system from the north side of Namakagon Lake eastward to the vicinity of Mellen. East of Mellen the moraine lies mainly south of the ranges, and rock outcrops are rather rare.

On the soil map of Vilas County this morainic system is shown as consisting largely of the Kennan fine sandy loam, and in the district outside of it the main soil classes are the Vilas sand and the Plainfield sands. The change from the Kennan to the Vilas and Plainfield soils is made directly at the border of this morainic system or within a mile or so of it from the west border of the area included in the soil map (the line of T. 43 N., Rs. 2 and 3 E.) eastward to Donaldson, in sec. 33, T. 43 N., R. 10 E., or for a distance of 40 miles. A large outwash plain east of Donaldson covers the district north and west of Lac Vieux Desert on the border of this morainic system, in Gogebic County, Mich. The Vilas County soil map represents the Kennan series of soils as covering large areas south and east of Lac Vieux Desert outside the limits of this morainic system. The soil distinction between the morainic area and the outlying districts, which is so marked to the west, therefore seems not to be maintained east of Lac Vieux Desert, but in that region there is a noticeable difference in the constitution of the drift of the morainic system and that outside. The morainic system contains abundant Keweenawan rocks, which were brought in from the northwest, but in the outlying district such rocks are rare and the drift consists largely of materials from formations that crop out to the north or northeast.

This morainic system is a pronounced feature throughout its course across northern Wisconsin. Although many of its knolls are but 10 to 15 feet high, they are closely aggregated and form an intricate network that is in striking contrast with the greater part of the outlying district, in which slopes are smoother or less hummocky, even where the ridges are prominent. Some knolls of the morainic system are 75 to 100 feet high, and knolls 30 to 40 feet high are to be seen in nearly every township it traverses. The interlobate moraine of Bayfield County includes many large knolls, and they abound around Long Lake and in northern Vilas County along the Wisconsin-Michigan State line. In that area the swamps and lakes are 100 feet lower than the most prominent drift ridges and knolls on their borders.

To the west of the interlobate moraine that extends across western Bayfield County and Douglas County the morainic system includes some large swamps, in which a few low drift knolls are present. There is relatively less swamp land to the east of this interlobate tract within the morainic system itself, but very extensive swamps lie just outside of it in Vilas County and part of Iron County. A swamp covering 18 to 20 square miles on the inner border extends immediately south of the Duluth, South Shore & Atlantic Railway for several miles west from Bibon Junction.

Lakes are especially numerous in the morainic system in northern Vilas County, Wis., and the adjacent part of Gogebic County, Mich. Surrounded by wooded hills and well stocked with fish, they constitute attractive and popular resorts for summer tourists or persons seeking relaxation.

The drift throughout the Wisconsin portion of the morainic system is of reddish color, because it includes Keweenawan rocks of red tinge, as well as a liberal amount of the red sandstone of the Lake Superior region. Iron ore from the Mesabi range and slate from the western part of the Lake Superior Basin are well represented in the drift in Douglas County, but, as noted above, these constituents seem to have been brought in by an earlier ice movement than that which formed this morainic system and were worked over and incorporated in its drift. Limestone pebbles, which occur sparingly in the drift of this morainic system, as well as in that of the plain bordering the west end of Lake Superior, are not so easily traced to their source or interpreted in terms of ice movement. It is not yet known whether they have come from formations in Manitoba or from those bordering James Bay. Nor has it been determined to what extent limestone of Paleozoic age has covered the western part of the Lake Superior Basin. The presence of limestone formations near the head of Keweenaw Bay in Baraga County, Mich., and the widespread presence of chert from limestone formations in the region south of Lake Superior, give some support to the view that limestone formations may at one time have extended much farther west than their present known limits in this basin.

LATER MORAINES

The moraines in Wisconsin between the outer morainic system and the shore of Lake Superior are weak and fragmentary. A few isolated areas of rolling drift, surrounded by smooth plains of lower altitude, occur in the district west of the interlobate morainic belt on the Bayfield Peninsula, and a smaller number on the east slope of the peninsula. There are also long morainic spurs projecting out into the plain that borders Lake Superior. One of these spurs runs eastward through Mason about to the east line of Bayfield County, or fully 12 miles from the point where it connects with the great interlobate moraine east of Pike River station. It is only about 2 miles wide and stands only about 3 miles north of the inner edge of the main morainic system in eastern Bayfield County.

In the vicinity of Saxon there are two moraines separated by a narrow valley that served as a line of glacial drainage outside the inner or north moraine. The outer of these moraines runs southwestward to Bad River, about 3 miles north of Millen, and a short distance beyond that stream it becomes merged with the main morainic system. It has a general width of less than 2 miles, and its knolls are generally only 10 to 20 feet high, but they are closely aggregated. The inner moraine bears directly away from the outer one just west of Saxon and runs to the Lake Superior shore at Point Clinton, about 18 miles east of Ashland, Probably at the time this moraine was being formed, the ice extended over the Apostle Islands, and it may have covered the northeast end of the Bayfield Peninsula, but it appears not to have reached the present shore of Lake Superior between Point Clinton and Ashland. At that time there seems to have been a glacial lake, discussed below as Lake Ashland, which covered the low country in Ashland County and eastern Bayfield County and was drained across the Bayfield Peninsula near Pike River. It is thought that the lake outlet may have been forced to take this line of discharge because the ice was still resting on the north end of the Bayfield Peninsula, and that upon the opening of a passage around the north end of the peninsula the lake waters were drawn down a few feet, or to the level of the lake that occupied the part of the Lake Superior Basin west of the peninsula.

MORAINES OF THE WESTERN PART OF THE NORTHERN PENINSULA OF MICHIGAN

OUTER MORAINIC SYSTEM

The outer morainic system is more diffuse and complex in the western part of the northern peninsula of Michigan than in northern Wisconsin. It curves around from an eastward to a southward course in Iron County and neighboring parts of Houghton, Baraga, Marquette, and Dickinson Counties. In places it is spread over a width of 30 miles, in which narrow strips of till plain and gravel plain lie between morainic ridges.

The outer border comes into Michigan near State Line station of the Chicago & Northwestern Railway, in southeastern Gogebic County, and has a general eastward course across T. 44 N., Rs. 39 and 38 W., to the Iron County line, following the edge of the plain of outwash that lies northwest of Lac Vieux Desert in R. 39 W., but crossing over ridges of till northeast of that lake in R. 38 W. Upon entering Iron County the border turns abruptly to a north-northeast course which it follows for about 10 miles, keeping on the northwest side of a gravel outwash plain drained by headwaters of Paint River in Tps. 44 and 45 N., R. 37 W. It then turns eastward near the corner of Tps. 45 and 46 N., Rs. 37 and 36 W., and follows the course of Paint River eastward and southeastward to Brule River at the Wisconsin State line. In a few places its knolls lie on the south side of the stream, but generally the stream is in an outwash plain a mile or more outside the morainic border. There are also till ridges between this moraine border and Paint River in the southern part of T. 45 N. and northern part of T. 44 N., Rs. 34 and 35 W. Outwash strips from the morainic system fill the low places between the till ridges and connect with the outwash along Paint River in these townships. West of Crystal Falls the morainic border for a few miles is close to Paint River and in places south of it. South of Crystal Falls there are a few knolls in the outwash plain west of Paint River that may belong in this morainic system. The outwash greatly interrupts the continuity of the morainic border both east and west of Paint River from Crystal Falls southward to the Wisconsin State line. In places above Crystal Falls strips of outwash come through the outer portion of the morainic system from its middle part and thus break the continuity of the moraine.

In Gogebic County there are two prominent moraines in this morainic system which are separated by a strip of till plain 2 to 4 miles wide for a distance of 25 miles, from the eastern part of T. 45 N., R. 45 W., to the eastern part of T. 45 N., R. 41 W. Farther east, across T. 45 N., Rs. 40 and 39 W., the moraines are separated in places by strips of sandy outwash. The outer of these has a general width of about 8 miles and lies partly in Wisconsin. The inner moraine has a width of 2 to 5 miles or more and lies almost entirely in T. 46 N., Rs. 40 to 45 W. Its inner border passes the south end of Gogebic Lake. The village of Watersmeet, Mich., stands between the two moraines in the outwash plain just noted. The inner moraine for a few miles in the vicinity of Watersmeet covers the northern part of T. 45 N., Rs. 39 and 40 W.

In eastern Gogebic County, southeastern Ontonagon County, and northwestern Iron County the morainic system has exceptional width and prominence and is not so clearly separable into distinct moraines as in western Gogebic County. The inner border is irregular, with spurs of moraine projecting 2 to 4 miles into a plain in Ontonagon County and southwestern Houghton County. One of these spurs extends into the southeastern part of T. 48 N., R. 39 W. Still farther north, in eastern Ontonagon County, isolated morainic areas surrounded by plains lie between this morainic system and the later ones described below.

The morainic system again becomes divided into two strong moraines with an intervening outwash plain in northern Iron County and southern Houghton and Baraga Counties. The outer moraine of these two lies entirely in Iron County; nearly all of the inner one lies in Houghton and Baraga Counties. The intervening outwash plain lies along the borders of the three counties and occupies an area of 60 to 70 square miles. It is widest immediately outside the inner moraine, in southern Houghton County and southwestern Baraga County. (See pl. 5.) The outer moraine has a width ranging from 3 or 4 miles to fully 10 miles in northern Iron County and as far southeast as Crystal Falls, but east and south of that town it is poorly developed and buried in outwash. The inner moraine lies 1 to 3 miles south of the Duluth, South Shore & Atlantic Railway for the entire width of Houghton and Baraga Counties and runs to the west shore of Michigamme Lake in western Marquette County. It then bears southeastward across southwestern Marquette County and south ward along the line of Iron and Dickinson Counties to Menominee River above Iron Mountain.

In southern Marquette County and northern Dickinson County the ice moving southwestward from the vicinity of Marquette was opposed by the westward spreading of the Green Bay lobe. Several townships in the area of converging and conflicting ice movements have morainic features, and these should perhaps be included in the great morainic system under discussion. Among the morainic ridges there is a network of glacial drainage channels, now largely of swampy character but carrying deposits of sand or gravel in the drier parts. There are also narrow strips of clayey till plain, chiefly in the western half of Dickinson County. Areas with nearly bare rock surface are also present, including one that covers several square miles around the corner of Tps. 43 and 44 N., Rs. 28 and 29 W., and a still larger area in the southern part of the county, extending from Sturgeon River westward to Menominee River. A network of glacial drainage lines runs through both of these rocky areas and continues southward across Menominee River toward the end of the Green Bay lobe.

A part of this morainic system falls within the Perch Lake, Ned Lake, Witbeck, Iron River, Crystal Falls, and Sagola quadrangles and the Menominee special area, which are covered by contour maps of the United States Geological Survey. Although these maps are not up to the present standards of mapping by the Geological Survey, they show fairly well the amount of swampy land and the closeness or diffuseness of grouping of the drift knolls and ridges. The ruggedness of parts of the Menominee special area is due to rock ridges, and so are the hills near Mansfield, but elsewhere the rock ridges inside this morainic system are usually inconspicuous and less prominent than the morainic knolls. Few of the knolls exceed 50 feet in height, and most of them are 25 feet or less. They are generally without system in arrangement. In places they stand close together in groups, but as a rule they are rather diffusely scattered over swampy and nearly level tracts. In the outwash plains basins are numerous, some of which are well represented on the Perch Lake topographic map. (See pl. 5.)

The highest parts of this morainic system in the northern peninsula are more than 1,800 feet above sea level, and a considerable part is above 1,600 feet, as may be seen by reference to Plate 2. The high altitude is due to the prominence of the underlying rock, for the drift is estimated to have an average thickness of less than 100 feet. There are records of a thickness of 200 feet or more, but these are at places where borings have been sunk in preglacial valleys, and in such places the present surface is usually lower than on the interfluvial preglacial ridges. Were the drift to be stripped off this region it would show more difference between ridges and valleys than now appears. Thus in southern Baraga County, where the rock ridges reach an altitude of 1,800 feet above sea level, the rock beds of valleys near them lie at about 1,400 feet, or 200 feet lower than the present valley bottoms. The altitude of the rock surface decreases southward from Baraga County across eastern Iron County and neighboring parts of Marquette and Dickinson Counties. The inner or eastern part of the morainic system in Marquette and Dickinson Counties is also considerably lower than the outer part, the altitude being 1,400 to 1,500 feet in the outer part and 1,000 to 1,100 feet in the inner part in Dickinson County. In consequence of this eastward decline in altitude, the lines of ice-border drainage shifted eastward with the recession of the ice and so developed the complex network of channels referred to above. The southward descent along these lines of glacial drainage is more gentle than the eastward descent across the morainic system, but on account of the presence of the ice in the lower country to the east the only lines of escape for the glacial streams led southward. When the ice that then covered the Green Bay lowland disappeared the streams naturally took southeastward courses to Green Bay in the direction of steepest slope.

The drift of this morainic system throughout its course in the northern peninsula of Michigan is very largely of loose texture and very stony, especially in the morainic knolls and ridges. It is strikingly different from the drift in the plains to the north, which is in large part a heavy clay. It contains enough material from iron-bearing formations and from the red sandstones to give it a red tinge. There are a few short eskers in the midst of the morainic system, most of them not more than 25 feet high nor more than a mile in length. They are found mainly in the swampy strips that cross the moraines or wind about among the knolls and ridges.

OUTWASH DEPOSITS AND GLACIAL DRAINAGE

The outwash plain around the head of Wisconsin River and Lac Vieux Desert is mentioned above. This river served as the line of discharge for several miles of the ice border when the outer part of the morainic system was being formed. As the ice melted back to the inner part of the morainic system there was some outwash into low areas on its border, but the deposit is of sandy rather than gravelly character, and probably the discharge was not so free as that from the outer border. The sandy deposits are to be seen along or near the Chicago & Northwestern Railway from Watersmeet westward nearly to the south end of Gogebic Lake.

The Paint River Valley afforded a line of discharge for glacial waters from the outer part of the morainic system in Iron County, Mich. There is a gravelly plain 1 to 2 miles wide along the stream in the western part of the county and another plain fully as wide below Crystal Falls. But in central Iron County Paint River cuts across some outlying till ridges with north-northeasterly trend and also the troughs or swales that lie between the ridges. At the ridges the valley is narrow, but at the troughs it widens out, in some places to 2 or 3 miles or more. These low tracts seem to have been flooded and thus coated with deposits of sand at the time the morainic system to the north was being formed. Part of the sand and gravel in these troughs may have been laid down during the recession of the ice border prior to the development of this morainic system. In support of this view there are basins and also surface boulders in these strips of sandy gravel so far outside the border of the morainic system that they probably have no connection with it.

The portion of an outwash gravel plain that lies in the northwestern part of the Perch Lake quadrangle and the moraine north of it are shown in Plate 5. This plain is north of the present divide between the Lake Superior and Lake Michigan Basins, but as its altitude is a little higher than that of swampy channels which lead south and southeast across the divide, discharge through the channels probably took place during the development of this outwash plain and the moraine north of it. One channel leads southward past Marten Lake to Golden Creek, a tributary of Paint River 2 miles southwest of Perch Lake. It is slightly more than 1,520 feet above sea level, whereas the altitude of the outwash plain is 1,540 to 1,560 feet or more. Another channel that leads eastward from Perch River to Ned River about 2 miles south of the Baraga-Iron County line is less than 1,520 feet above sea level and probably carried part of the discharge from this outwash plain.

From southwestern Marquette County and western Dickinson County the Michigamme Valley afforded a southward line of discharge to the Menominee after the ice border had shrunk too far to the east to find a southward outlet down Paint River. Still later the Sturgeon River Valley served as a line of discharge, though the glacial drainage departed in places from the present course of that stream.

LATER MORAINES

The later moraines of the western part of the northern peninsula of Michigan form a system whose members are in places separated and in places combined into a single broad morainic belt. On the whole, the moraines are more distinctly separated than those in the outer morainic system. They have courses that were controlled to some degree by the topography and by the outline of the shore on the south side of the Lake Superior Basin. Thus the Porcupine Mountains held the ice in check sufficiently to give the moraines a northward turn both on the west and on the east of them. On the Keweenaw Peninsula a massive morainic belt was developed. Around Keweenaw Bay also the moraines are exceptionally strong. At the Huron Mountains and in the High area in eastern Baraga County the ice movement was held in check, so the moraines make a northward detour in passing over these highlands. Between the Huron Mountains and Marquette the moraines are split up into several more or less distinct members and are spread over a width of 15 to 20 miles. Because of the prominence of rock hills they are interrupted and have less continuity than in smoother districts to the west.

The two nearly parallel moraines in the extreme west end of the peninsula, from the Wisconsin line eastward to Presque Isle River, are clearly differentiated from the till plain between them and from the lake plain north of the inner one and also from a till plain south of the outer one. They are each about a mile in general width, but range from half a mile to nearly 2 miles. The hummocks or knolls rise rather steeply to heights of 15 to 20 feet or locally to 40 or 50 feet above the inclosed basins and irregular depressions. The border plains have a more gently undulating surface. Along or near the outer border of each of the moraines are channels marking the line of westward discharge of glacial waters on the border of the ice lobe. The Duluth, South Shore & Atlantic Railway runs in one of these channels for much of the way from Thomaston, Mich., to Saxon, Wis. This line of drainage served as the outlet for the glacial Lake Ontonagon, as shown below. A swampy strip outside the inner moraine marks the course of glacial drainage for much of the way from Black River to the Wisconsin line. A few of the morainic knolls contain beds or pockets of gravel, but till is the prevailing material in the moraines as well as in the bordering till plains. It is rather stony and ranges from close-textured clay matrix to a loose-textured till. In a few places rock hills rise above the general level of these moraines, but in general they are no more prominent than the drift knolls, and most of them carry a cover of drift of moderate thickness.

In the vicinity of Presque Isle River the moraines are in a more broken country than to the west, and this condition extends northeastward past the Porcupine Mountains. The ice moved southeastward or southward into this broken district on the west side of the Porcupine Mountains but southwestward on the east side, and the moraines have courses in harmony with these movements. In this broken country rock hills rise above the level of the morainic knolls or are but partly covered by the drift. The morainic features are prominent in a strip 2 or 3 miles wide extending southwestward to Presque Isle River and southeast to the north end of Gogebic Lake, thus occupying as wide a strip as the two moraines to the west would cover if combined. Directly north of Gogebic Lake the moraine fills a gap in the copper range 2 or 3 miles in width, lying partly in R. 41 W., and partly in R. 42 W. The moraine there is so high, however, that Gogebic Lake does not discharge through it but drains eastward along the south edge of the copper range. On each side of this gap the rock hills rise to a height of 50 to 100 feet above the level of the moraine, and thus the moraine filling is insufficient to conceal this break in the range. This gap seems to mark the place where the preglacial drainage of western Ontonagon County and eastern Gogebic County passed through this range to the Lake Superior Basin.

From Gogebic Lake northeastward across Ontonagon County the moraine follows the course of the copper range. It is strongly developed in low places on the range, but morainic knolls are scarce on the prominent parts. The altitude of the moraine here is higher than that of the country immediately south of it, and during the development of the moraine this lower country was covered by a lake which occupies a considerable part of the Ontonagon drainage basin and has therefore been named Lake Ontonagon. This lake and its outlet, which led westward from Gogebic Lake, are discussed below. The moraine is composed of stony till of rather loose texture, but the plain outside covered by Lake Ontonagon has a stiff clay subsoil. So also has a plain to the north, which became a lake bed (Lake Duluth) when the ice melted away from it.

Near Mass City the morainic belt that follows the copper range across Ontonagon County meets a strong morainic system, which encircles Keweenaw Bay, and the two are banked against each other from Mass City northward past the Winona mine to Misery River. Farther north the morainic belt seems to have been formed mainly by the Keweenaw Bay sublobe, for the striae in its midst bear westward. The striae in Ontonagon County and as far northeast as the Winona mine bear southward and were formed by ice to the west of the Keweenaw Peninsula. This morainic belt is very prominent as far north as the hill called Wheal Kate, west of the village of South Range. It is well defined northward from that point to the shore of Lake Superior, which it strikes between Redridge and the north canal entrance to Portage Lake. Northward from Mill Mine Junction it has been covered by glacial Lake Duluth, yet its morainic topography has been but slightly toned down.

Where the two moraines are united for a few miles northeast of Mass City the width of the morainic system is about 12 miles. From Misery River northward, where it was formed mainly by the Keweenaw sublobe, its width is 5 to 8 miles. A considerable part of the moraine from Mass City to Mill Mine Junction is 600 to 800 feet above Lake Superior, and Wheal Kate is about 900 feet above the lake. This prominence is due to the high altitude of the rock formations, as the drift is in general only about 100 feet thick. In this morainic belt there are rock hills that stand more than 700 feet above Lake Superior. From Mill Mine Junction northward the moraine is on a gentle downward slope west of the main rock ranges of the peninsula. There is, however, a conspicuous hill only a mile from Lake Superior near the corner of Tps. 55 and 56 N., Rs. 34 and 35 W., rising more than 400 feet above the lake.

The topography of the northern part of this moraine for about 16 miles south from the Portage Lake Ship Canal is shown on the contour map of the Houghton quadrangle. A comparison of the features to the north of Mill Mine Junction with those to the southwest (pl. 6) will make clear the difference between the part that was covered by lake waters and that which was not. In the part that was covered by the lake few of the knolls take more than one 20-foot contour, but in the part that was not covered many of them take two or three contours, and Wheal Kate takes 10 contours on its north slope and eight on other parts. This hill, 160 feet high, seems to be made up entirely of drift. As it occupies less than 40 acres, its slopes are exceptionally steep. Small lakes and marshy basins are inclosed among the knolls and ridges of this morainic belt, and the moraine has a strong expression for much of its length. The drift is stony, loose-textured till that includes much sand and gravel. There are very few places where it is a clayey till. The moraine is thus in striking contrast with the plain west of it, which is generally underlaid by a stiff clayey drift.

As the ice border was receding eastward across the Keweenaw Peninsula it formed moraines, but they are generally of weak expression, for they are very largely below the level of glacial Lake Duluth. Some of the knolls and ridges, however, have considerable sharpness of prominence. Groups of such drift knolls occur immediately west and northwest of Calumet, in secs. 10, 15, 16, 21, and 22 T. 56 N., R. 33 W. They are brought out clearly in the contours of the Calumet special map. Their highest points are about 60 feet lower than the upper limit of glacial Lake Duluth, but lower beaches of Lake Duluth are found on their slopes. There is considerable drift between the ranges and on the southeast slope of the copper ranges from the Allouez Gap, near Mohawk, northeastward past Gratiot Lake, and in places it is knolly and ridged in morainic fashion. But for about 15 miles from the east end of the peninsula there is very little morainic drift. Southward from Mohawk past Torch and Portage Lakes and on each side of Sturgeon River to the edge of Baraga County the drift is morainic but shows very gentle swells. It is looser textured in the morainic strips than in the bordering clay plains but contains enough fine material to make farm land of fair quality.

The strong morainic belt that was traced northeastward from Mass City to the north end of the Portage Lake Canal continues southeastward from Mass City to Sturgeon River, below its great bend near the line of Houghton and Baraga Counties, in a belt 6 to 8 miles wide. This is at the end of the Keweenaw sublobe of the Superior ice lobe, which moved southwestward 25 to 30 miles beyond the limits of Keweenaw Bay. The moraine is bordered by extensive outwash plains of sandy gravel. Pori station, on the Chicago, Milwaukee & St. Paul Railway, stands in the midst of one outwash plain. Another extends from Frost Junction southeastward to Sidnaw. From Sidnaw northeastward across Sturgeon River and for several miles on the north side of the westward flowing part of that stream there is a broad outwash tract along the outer edge of the morainic belt. This belt was partly covered by Lake Duluth after the ice had disappeared, but the outwash plains just mentioned and fully half the width of the moraine were too high to be covered by the lake waters. The portion that was submerged is nearly as strong in morainic expression as that above the lake level. It is strikingly in contrast with the smooth clay plain that lies between its inner border and the head of Keweenaw Bay. The morainic belt also consists of much looser textured drift than this clay plain. The outwash plains around Pori and from Frost Junction to Sidnaw extend down on the west to the clay plain that was covered by Lake Ontonagon, and that lake was contemporary with the outwash. The limits of westward and southwestward distribution of the outwash were probably determined to some degree by the presence of the lake, for the outwash slopes down at the edge about to the level of the lake shore.

Beyond Sturgeon River the morainic belt takes a north of east course and maintains it across Baraga County. It is banked on a steep slope south and southeast of Keweenaw Bay and its inner border is close to the bay for several miles on the east shore. The waters of Lake Duluth later covered this slope up to a height of about 600 feet above Keweenaw Bay. A considerable part of the morainic belt, however, stood above the lake level. The knolls and ridges of drift that were covered by the lake are in general not so sharp as those that were not covered. Notches on the lakeward side of the knolls and the filling of recesses on the shore by material cut from salient points mark the chief effects of the lake action. The drift in this part of the morainic system is generally very stony and loose textured, yet it carries enough loam to make a fair soil. It is thick enough to conceal a considerable part of the rock surface, but not a few prominent hills and ridges of rock rise above the surrounding drift knolls. The rock ridges and knolls are much more conspicuous and the land is of poorer quality for farming outside this moraine in central and eastern Baraga County than along it. But in western Baraga County, along the south side of Sturgeon River in the vicinity of Covington, the drift is less stony, and on the whole better suited for farming than along the moraine.

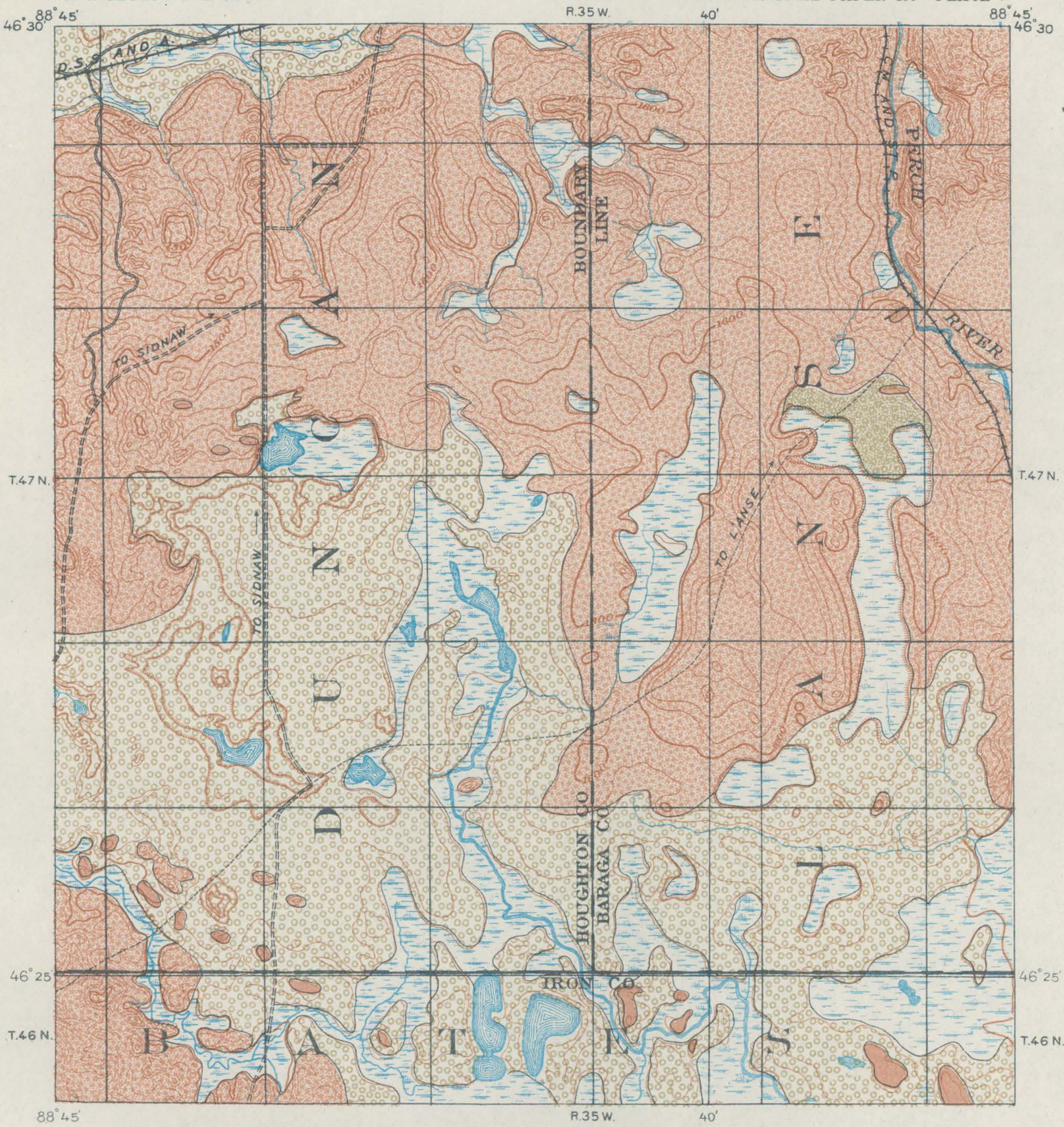
The relations of the ice border to Lake Duluth on the east side of Keweenaw Bay have not been fully deciphered. It is known that Lake Duluth extended eastward from the bay about to the Marquette County line, but traces of its shores have not been found farther east, nor any other evidence of submergence at altitudes corresponding to those covered by the lake in Baraga County. The ice therefore appears to have covered northern Marquette County until about the time the waters in the western part of the Lake Superior Basin were drawn down to lower levels, and it was the recession of the ice border in northern Marquette County that permitted an eastward discharge for the water in the western part of the Lake Superior Basin. When the ice stood high enough in Marquette County to close the eastern line of discharge it probably still covered lower districts in northern Baraga County along the borders of Huron Bay and Keweenaw Bay. An effort was made by the writer to find a moraine or other evidence of ice occupancy there that could be correlated with the moraine or ice border in Marquette County that shut out the waters of Lake Duluth. A strip of drift with slightly undulating surface was found leading westward from the Huron Mountains in Marquette County to Skanee, on the east shore of Huron Bay. It is a mile or more in width and lies 2 to 4 miles inland from the Lake Superior shore. Its knolls are only 10 to 15 feet high and have gentle slopes, but if it was formed in ponded waters its expression is fully as strong as can be expected. The number of boulders appears also to be somewhat greater in this undulating strip than on bordering plains both north and south of it. The thickness of the drift probably averages not more than 20 feet. This slight thickness, however, seems not to preclude its marking an ice border, for in parts of the morainic system above the limits of Lake Duluth in eastern Baraga County and along the moraines in northern Marquette County the drift has an average thickness not much greater than 20 feet. On the whole, therefore, it seems probable that the ice sheet occupied northern Baraga County and if so a considerable part of Keweenaw Bay down to the time when the recession of the ice in northern Marquette County opened an eastward discharge for the waters of the western part of the Lake Superior Basin.

In Marquette County the members of the later set of moraines are more widely separated than in Baraga County and trend south of east and in places nearly south. The outermost member is not far from the headwaters of the streams that flow directly into Lake Superior, and glacial drainage from this moraine found passages across the divide into headwaters of Michigamme and Escanaba Rivers. This moraine is rather poorly developed from Silver Lake northwestward to the Baraga County line, but its knolls are present among rock hills and fill the space between Yellow Dog and Dead Rivers in the central and eastern parts of T. 50 N., R. 29 W. From Silver Lake the moraine takes a course but little east of south and is well defined all the way to Escanaba River, a distance of 20 miles. The Duluth, South Shore & Atlantic Railway crosses it near Greenwood. For about 13 miles in its course across Tps. 48 and 47 N., R. 28 W., it is on the divide between the Escanaba River and streams flowing to Lake Superior. It is 1 to 2 miles wide, and rock knobs are not conspicuous along its course. Its drift is of very loose texture and comprises gravelly knolls and ridges and sandy to stony loam soil. In the southern part of T. 48 N., and entirely across T. 47 N., R. 28 W., there is on its western border a strip of outwash gravel which reaches in places to Escanaba River. Considerable outwash is present farther north, in the vicinity of Silver Lake, and it is probable that some of the waters that formed this deposit discharged to Michigamme River through a swampy channel that crosses the divide between the Dead River and Michigamme drainage basins in sec. 22, T. 49 N., R. 29 W. The headwater part of the Escanaba also probably drained into the Michigamme, at that time one line of discharge being through a channel now followed by the Chicago & Northwestern Railway across T. 48 N., R. 29 W.

A moraine branches off from the one just described 5 or 6 miles northwest of Ishpeming and runs southeastward into the extreme southwestern part of that city. It is only about half a mile in average width, but has a strong expression, with steep slopes in the knolls and ridges. It consists of loose-textured material with some gravelly knolls. Outside this moraine, from the point where it parts from the other moraine to its southeast end at Ishpeming, there is an outwash plain of sandy gravel, which fills the space between it and the outer moraine.

The outer moraine ends at the south in a gravelly plain, which covers a wide area south of Escanaba River in T. 46 N., R. 27 W. A probable continuation of this outer moraine of the later system is found south of Escanaba River in a moraine that runs southeastward from the southern part of T. 46 N., R. 27 W., to the Princeton mine. The moraine is from 1 to 3 miles wide and is very prominent in the northeastern part of T. 45 N., R. 27 W., and the western part of T. 45 N., R. 26 W., its altitude there being about 1,500 feet above sea level, but it declines to about 1,200 feet near the Princeton mine. There is an outwash plain south of this moraine, in the southern part of T. 45 N., R. 26 W., and the southwestern part of T. 45 N., R. 25 W., which extends southward into T. 44 N., Rs. 25 and 26 W. In this outwash, as well as in the moraine, there is very little limestone material. It is thus in striking contrast with the drift in till plains and moraines lying immediately southwest of the outwash plain, for that drift contains a large amount of limestone. This moraine and its outwash were formed by ice that was moving southward or but slightly west of south, directly from the Lake Superior Basin, and which did not encounter the Paleozoic limestone formations of the eastern part of the northern peninsula of Michigan. But the till plains and moraines to the south are the products of ice which was spreading westward in passing across the peninsula from the Lake Superior Basin to the Green Bay Basin and which thus encountered the limestone formations. This moraine seems to be traceable no farther southeast than the Escanaba Valley at the Princeton mine, for on the east side of this valley the outwash from one of the later moraines comes in from the north and follows down that side of the river, as shown below. This moraine presents sharp ridges and knolls, but in the main immediately west of the Princeton mine there are gently undulating tracts alternating with sharp ridges or chains of knolls, and these are deeply indented by basins. A string of basins several miles long separates the south edge of the moraine from its outwash apron, forming a fosse of unusual length. Small lakes fill some of the basins. The morainic ridges north of this string of basins rise sharply to heights of 75 to 100 feet above the basins.

There are some indications of an ice border running from Silver Lake southeastward to Ishpeming and Negaunee. For about 6 miles southeast from Silver Lake, along Dead River, the country is a combination of outwash and morainic knolls, in which the outwash plains are the more conspicuous. For the next 3 or



GEOLOGIC MAP OF PART OF PERCH LAKE QUADRANGLE, MICHIGAN

Scale $\frac{1}{62,500}$

1 ½ 0 1 Mile

Contour interval 20 feet.

EXPLANATION

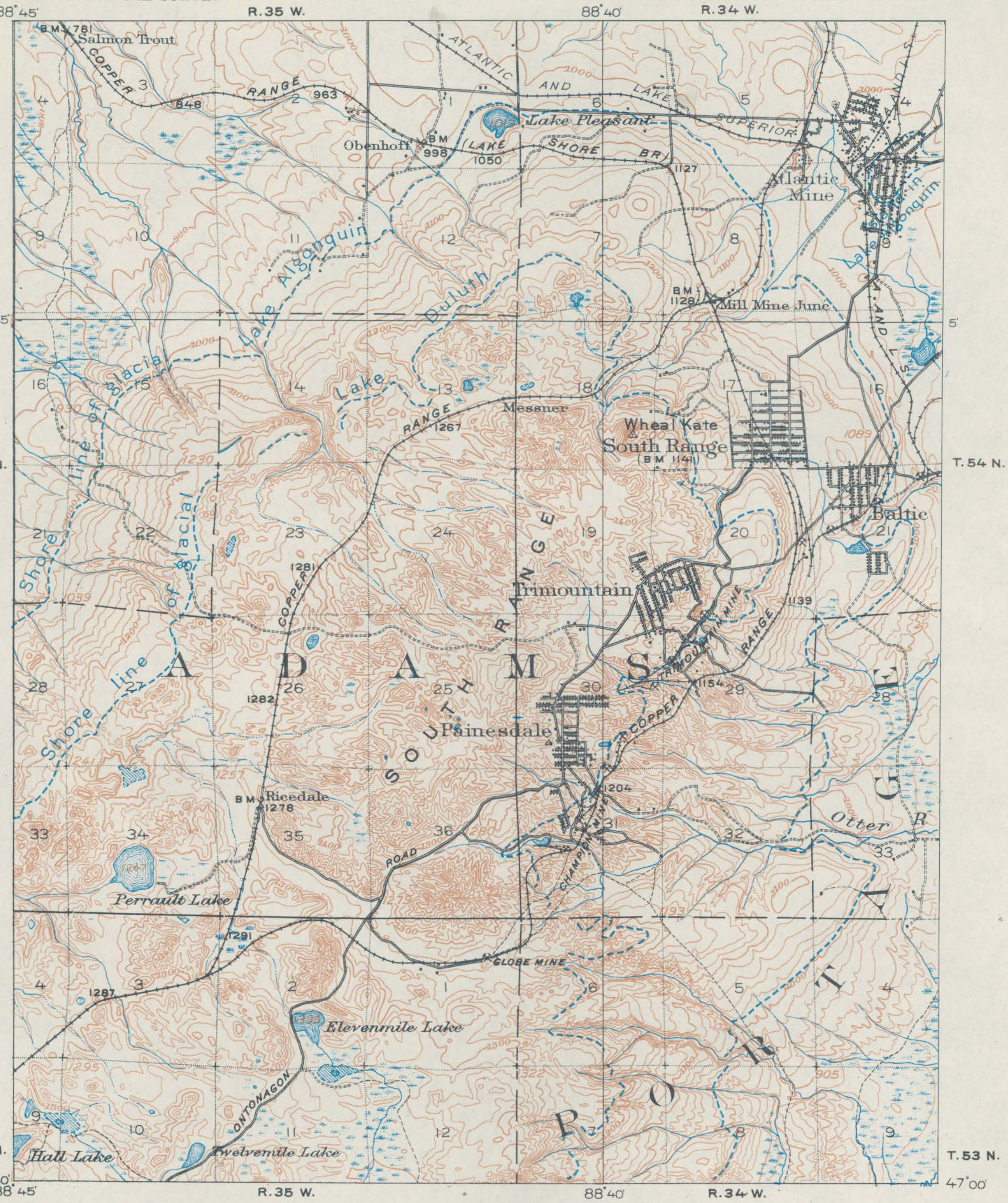
Rock outcrops

Terminal moraine

Till plain, or ground moraine

Sandy gravel plain, or outwash

Peat and muck, or swamp



Base from Houghton quadrangle

MAP OF PART OF HOUGHTON QUADRANGLE, MICHIGAN
Showing Shore Lines of Glacial Lakes

Scale $\frac{1}{62500}$

1 ½ 0 1 Mile

Contour interval 20 feet.

1929

4 miles morainic features are well developed in a strip about 2 miles wide extending from sec. 36, T. 49 N., R. 28 W., to sec. 16, T. 48 N., R. 27 W. Among the morainic knolls and ridges are cedar and spruce swamps. The moraine here as well as to the northwest consists largely of loose-textured sandy drift. Rock hills are prominent in the line of this ice border in the southern part of T. 48 N., R. 27 W., but in section 34 morainic knolls become conspicuous, and a narrow moraine with an outwash plain of sandy gravel on its southern border leads southeastward through the northern part of Ishpeming into Negaunee. The outwash plain covers much of secs. 2 and 3, T. 47 N., R. 27 W. In the southern part of Negaunee rock hills become prominent, and this ice border was not identified beyond that point.

A moraine of more prominence than those just described enters Marquette County from Baraga County in the southwestern part of T. 51 N., R. 29 W., and extends slightly south of east for about 15 miles to the northeastern part of T. 50 N., R. 28 W. An outwash plain about 2 miles in average width and fully 12 miles in length lies between this moraine and Yellow Dog River. At the east end of the outwash plain, in secs. 14 and 23, T. 50 N., R. 28 W., the moraine crosses to the south side of Yellow Dog River, and thence it runs east of south for about 20 miles to Negaunee. It traverses the eastern part of T. 50 N., R. 28 W., and the adjacent part of T. 50 N., R. 27 W., and runs diagonally across T. 49 N., R. 27 W., from northwest to southeast. Near the center of the last-named township an outwash plain of sandy gravel covering about 2 square miles stands in the line of the moraine. The moraine crosses Dead River in the northwestern part of T. 48 N., R. 26 W., and its main part runs southeastward along the south side of the river and then turns south and comes to the Duluth, South Shore & Atlantic Railway at Eagle Mills. This railway is in a lowland, which seems to have been occupied by ice at that time as far west as Negaunee, or about 3 miles from Eagle Mills. At the west end of this lowland the moraine is strongly developed, and an outwash plain extends west from it to the east end of Teal Lake. There is also an outwash area covering several square miles in the recess in the moraine northeast of Negaunee.

The ice border probably crossed the hills south of Eagle Mills, but drift knolls are rare among these hills. At the south side of the hills the ice seems to have extended westward in a lowland about to Palmer. It formed a moraine on the south side of this lowland from Palmer eastward about 4 miles, through the south edge of T. 47 N., R. 26 W. Outwash plains of a later moraine here set in, and to the south there is a tract in which rock hills and ridges rise above a gravelly or stony drift deposit with nearly plane surface. A definite continuation of the moraine was not found in this tract, and possibly it was buried under the outwash of the later moraine to the east.

From the inner or eastern border of the moraine whose course has just been outlined a branch starts at the north side of Dead River and another south of Yellow Dog River. The latter was traced for only 5 or 6 miles southeastward as a rather indefinite moraine in a tract of rock ridges. The former is also ill defined and interrupted by rock ridges in its course through T. 48 N., Rs. 26 and 25 W., except in an area of 3 or 4 square miles in the northeastern part of T. 48 N., R. 26 W., where it has some prominence. It becomes a conspicuous feature where it passes out of the rock ridges in the northern part of T. 47 N., R. 25 W. A double moraine is traceable across this township. The outer or western moraine runs in a course slightly east of south across sections 5, 8, 9, 16, 17, 20, 21, 28, 29, 33, 34, and 35; the inner one covers the northeastern part of the township from sections 9, 15, 23, and 26 eastward. An extensive outwash plain lies outside the outer moraine. Between the moraines is another plain covering the greater part of sections 15, 16, 21, 22, 26, 27, and 28 of this township, and a narrow channel separates them in sections 35 and 36. They become united into a single bulky moraine near the corner of Tps. 46 and 47 N., Rs. 25 and 24 W. This moraine covers a width of 3 to 6 miles or more and runs south-southeastward through T. 46 N., Rs. 24 and 25 W., and T. 45 N., R. 24 W. It is bordered on the west through this distance of 12 miles by an extensive outwash plain, which extends to Escanaba River. Immediately south of this plain, in T. 44 N., Rs. 23 and 24 W., the moraine turns to the southwest, and this marks the beginning of the Green Bay lobe. The continuation of this moraine is discussed below as a feature of that lobe.

The moraines in Marquette County whose courses have been outlined all stand above the level of glacial Lake Duluth and are not connected with the shifting of the discharge of the lake to an eastward course from the western part of the Lake Superior Basin. There was also but little ponding along the ice border in Marquette County outside these moraines for passages among the outlying hills were low enough and numerous enough to carry the discharge from the ice border into valleys that drained southward. When contour maps of this region are available it may be possible to work out details of drainage.

On the whole, the drift in these moraines in Marquette County is very loose textured and full of stones of all sizes, as is to be expected where ice has passed over so rugged an area. The drift is thick in some of the low places among the rock hills but is generally very scanty on the hills. Notwithstanding the filling of low areas, the region is still very rough and broken, and rock prominences are far more conspicuous than the drift knolls and ridges. The strips of moraine just outlined mark places where there is a closer aggregation of drift knolls and a somewhat thicker drift coating than on intervening strips, but in places there is very little difference between the morainic strips and the intervening strips not classed as moraine. The outlines of the courses of moraines given above, however, are thought to indicate the approximate positions held by the ice border from time to time in the course of its recession from this district.

Outside this series of moraines in western Marquette County and eastern Baraga County about to Lake Michigamme and the Duluth, South Shore & Atlantic Railway there is a very high district with a relatively light coating of glacial material, though the rock knobs are rubbed so smooth in places by glacial action that they glisten in the sunlight. From commanding points in this district can be seen many hills that seem nearly destitute of drift coating or even of soil. The depressions among the hills are swampy, and some of them seem to have functioned as lines of glacial drainage.

On the slope toward the Lake Superior Basin all the way from the Huron Mountains to Marquette morainic features are weak and the morainic lines are greatly interrupted by rock hills. In places there is a heavy drift deposit filling depressions among the hills and some knolls of morainic type, but ordinarily the filling is light and is lacking in morainic expression. The best development of moraines is at relatively low altitudes only a short distance back from the shore of Lake Superior. A moraine traverses the southwestern part of the Marquette quadrangle at an altitude between 1,000 and 1,100 feet above sea level in much of its course. It is generally only about a quarter of a mile wide and has a relief of about 20 feet on its outer side. It is best defined from Dead River in secs. 7 and 18, T. 48 N., R. 25 W., southeastward to the north base of Mount Mesnard, in the southern part of Marquette. A lower moraine sets in at the base of granite hills west of Granite Point and runs northward past Birch station to Yellow Dog point, east of Lake Independence, or a distance of about 15 miles. Its northward continuation would carry it inside the limits of Lake Superior. In most of its course between Yellow Dog Point and Granite Point it is near the shore of the lake. From Birch northward it is not banked against the granite hills so closely as to the south. Its general width is about a mile. The surface is gently undulating rather than sharply morainic, but it seems to have been developed along the ice border as a terminal moraine. This moraine is at a lower altitude than the highest shore of glacial Lake Algonquin, but immediately outside of it for part of its course the granite hills rise above the level of that lake. The waters of the western part of the Lake Superior Basin may therefore not have been drawn down fully to the level of Lake Algonquin until the ice border receded from this moraine.

When it became evident to the writer that the lowering of the waters of the western part of the Lake Superior Basin from the level of Lake Duluth to that of Lake Algonquin was dependent upon the recession of the ice from the hilly slope between the Huron Mountains and Marquette an attempt was made to trace lines of ice-border drainage through which this lowering took place. It was found that the topography of this border district is such that the streams in places became expanded and in other places flowed through narrow passages between hills. It is only in these narrow sections of the stream courses that cutting or aggrading was definite enough to be traceable. In the broad places there were pools which were not filled with fluvial material and whose borders are not marked by definite shore features. Short sections of graded stream beds were found that seem referable to this ice-border drainage, the highest at about 1,200 feet above sea level and others down to about 1,000 feet. When the waters had become lowered to this level there was ponding of water between the ice border and the hilly slope, and a faint shore line is traceable through the southwestern part of the Marquette quadrangle along or near the 1,000-foot contour. It is best defined on the inner slope of the moraine above noted from Dead River southeastward for 3 or 4 miles, through secs. 18, 20, and 28, T. 48 N., R. 25 W., and eastward through the southern part of Marquette. This shore line appears to be a little higher than the highest shore of Lake Algonquin east of Marquette and thus marks an interruption of the lowering from Lake Duluth to Lake Algonquin, which indicates that the ice dam was still blocking the discharge at some place east of Marquette not yet fully determined. As the district north of Dead River is largely occupied by granite hills at the level of this shore line, it was not traced far in that direction. It was, however, identified about to the 1,000-foot contour at the west side of the Marquette quadrangle.

CORRELATIVE MORAINIC SYSTEMS IN THE LAKE MICHIGAN AND LAKE HURON BASINS

PORT HURON MORAINIC SYSTEM

At the time the outer morainic system of the Superior lobe was forming the ice appears to have occupied the Lake Michigan Basin as far south as Milwaukee, Wis., and Muskegon, Mich., and to have completely occupied the Lake Huron Basin. The morainic system is described under the name Port Huron morainic system in Monograph 53 of the United States Geological Survey in the description of its course through the southern peninsula of Michigan, where it borders the Huron, Saginaw, and Michigan Basins. In eastern Wisconsin this morainic system is scarcely so prominent as in the southern peninsula of Michigan but is split up into several parallel moraines between which are narrow strips of gravel plain that were developed as lines of glacial drainage or as outwash on the border of the ice lobe.

RED DRIFT OF EASTERN WISCONSIN

The portion of the Port Huron morainic system lying in eastern Wisconsin from latitude 44° southward has been studied in some detail by W. C. Alden,[6] who shows that it marks the limit of a readvance of the ice that left in its path a red drift, which is different from the underlying and outlying drift of Wisconsin age. North of latitude 44° there has been only a small amount of detailed mapping of the moraines and associated gravel plains in eastern Wisconsin. Part of this district is sparsely settled and has few roads and much forest or brushy land difficult to work. Dr. Samuel Weidman and the present writer made some investigations there both jointly and individually, but the mapping is of the nature of rough reconnaissance and the correlations are tentative. Such data as have been obtained as to the position and course of moraines in that part of Wisconsin and the probable limit of the ice at this readvance are shown in Plate 1. Description is deferred to a time when more detailed studies have been made. The several moraines and their associated border drainage lines become successively lower from the western or outer one eastward to later ones. They also each individually increase in altitude from north to south toward the end of the ice lobe.

When the later system of moraines of the western part of the northern peninsula was being developed the ice apparently extended some distance beyond the eastern part of the peninsula, into the basins of Lake Michigan and Lake Huron. It reached at least to Escanaba and possibly to Menominee, on the west side of Green Bay. It probably covered the Beaver Islands and perhaps the Manitou Islands in Lake Michigan and rested on the edge of the southern peninsula as far south as Little Traverse Bay on the Lake Michigan side and some distance beyond Cheboygan on the Lake Huron side.

After it had receded from these lake basins the ice border made prolonged stands and developed strong moraines on the eastern part of the northern peninsula, and these give a clue to the general direction of recession toward the east end of the Lake Superior Basin. The ice appears to have persisted there after it had uncovered the east end of the peninsula and the part of Canada immediately east of St. Marys River.

GREEN BAY LOBE

MORAINES OUTSIDE THE MENOMINEE DRUMLIN DISTRICT

The Green Bay lobe was developed principally to the west of the Green Bay Basin, though its axial movement seems to have been through the basin. This asymmetry is perhaps due to the crowding of the Lake Michigan lobe against it on the east side. In the northern part of the Green Bay lobe moraines were built up mainly on the western border, there being scarcely any morainic material along the line of junction of the Green Bay and Michigan lobes, either on the Garden Peninsula of Michigan or on the Door Peninsula of Wisconsin and the islands lying north of Sturgeon Bay between these two peninsulas. The interlobate moraine has its north end near latitude 44° 30′. There was, however, an extensive deposition of outwash and some morainic development at the junction of these ice lobes to the north of Green Bay in Delta, Alger, and Schoolcraft Counties, as shown below.

On the west side of the Green Bay lobe the striae have a westward to southwestward bearing. Locally they are deflected to a course north of west, as was noted near Norway, Mich., by Russell, and near Kate, just north of the Dickinson-Marquette County line, by the present writer. Near Mountain, in Oconto County, Wis., the striae bear about northwest. In Michigan westward-bearing striae are found as far west as eastern Iron County. In the axis of the lobe the movement was southward or slightly west of south. Near Escanaba the striae bear nearly due south. On the east side of the lobe there should theoretically have been a southeastward movement, and striae bearing southeast have been noted as far north as the Garden Peninsula, east of Big Bay de Noc.

The moraines of southern Marquette County and northern Dickinson County, Mich., were developed at the line of conflict between southward-moving ice from the Lake Superior Basin and westward-moving ice across the northern peninsula from the Lake Superior Basin into the Green Bay Basin. (See p. —.) The inner part of this morainic system continues southward from Dickinson County through the western edge of Menominee County as far as the great bend of Menominee River near Koss, Mich., covering a strip 2 to 5 miles wide on the east side of the river. It crosses into Wisconsin immediately above Koss and continues in a course nearly parallel with the west shore of Green Bay and 20 to 25 miles distant from it through Marinette, Oconto, and Shawano Counties into Outagamie County, and is traceable as far as the north end of Lake Winnebago, near Neenah, Wis. There is considerable outwash on the western border of this inner moraine, as well as in connection with earlier members of this great morainic system. It is present along and west of Sturgeon River in Dickinson County and along Menominee River from the Dickinson County line southward to the bend a few miles west of Koss.

THE DRUMLIN DISTRICT AND ASSOCIATED FEATURES

The plain that lies between the great morainic system and the later moraines of the Green Bay Basin is diversified with drumlins, which are conspicuous over the greater part of Menominee County and

[6] U. S. Geol. Survey Prof. Paper 106, 1918.

adjacent parts of Dickinson, Marquette, and Delta Counties. It is about 50 miles long from north to south and about 20 miles in greatest width. The drumlins have been noted as far north as the central part of T. 43 N., R. 26 W., in southern Marquette County, and almost as far south as the south end of Menominee County. The eastern limit is near the ancient shore line of glacial Lake Algonquin from a point opposite Escanaba southward, in Delta and Menominee Counties. The western limit is near Sturgeon River in southeastern Dickinson County and near Menominee River farther south. A few drumlins were noted west of Menominee River in Marinette County, Wis., some 10 to 15 miles above the mouth of the river. I. C. Russell gave considerable attention to this drumlin district in the annual reports of the Michigan Geological Survey for 1904 and 1906.

The drumlins are somewhat unevenly distributed, some single square-mile sections containing several and others none. There are, however, only a few places where there is a space of more than a mile between drumlins. The number of drumlins is probably twice as great as the number of square miles in the district. A representative township in the drumlin district is shown in Figure 7.

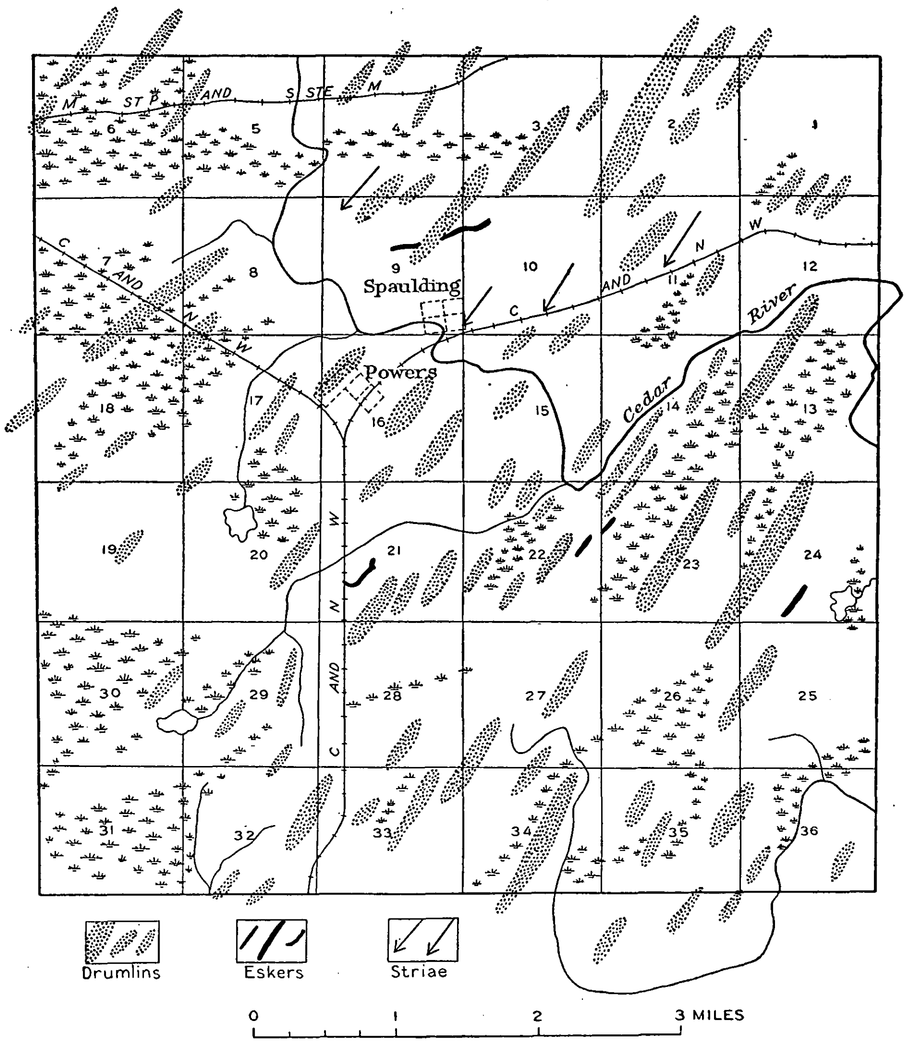


FIGURE 7.—Map showing drumlins, eskers, and striae in T. 38 N., R. 26 W., Menominee County, Mich.

The length of individual drumlins ranges from less than a quarter of a mile to fully 1½ miles and the height from less than 10 feet to more than 100 feet. Neighboring drumlins differ markedly in height as well as in length. Russell stated that he found places where the tops of drumlins came up to a general level, but the present writer was not able to discover such a tendency, and the condition cited by Russell certainly is not widely prevalent in this district. The length is generally from three to five times and in a few drumlins ten times as great as the width. A few of the drumlins have an oval shape, much like one-half of an egg cut lengthwise, but the prevailing form is lenticular.

The trend of the longer axis of each drumlin is in the direction of ice movement, being in rather close correspondence with the bearing of the glacial striae. (See fig. 7.) At the north end of the district the trend is westward, but toward the south end it shifts through southwestward to a course only a few degrees west of south.

The drumlins are composed of till of rather loose texture and of a red tinge. Russell states that some of them include lenses and beds of sand and gravel, but such inclusions appear to be rare.

It was thought by Russell that the till sheet which makes up the body of the drumlins was laid down by an earlier ice advance than the one which shaped them into drumlin form. Most of the drumlins have an arched surface and a slope in all directions from the culminating point. In a few there is a sculpturing or shaping of the sides or the lower part of the slope into the regular contours of the drumlin but the upper part is flat-topped or has a surface with irregularities not consistent with the drumlin form. Russel interpreted these as incompletely developed drumlins. He also cited the occurrence of chunks of copper and of iron ore in the drift of which the drumlins consist as evidence that this drift was laid down by ice moving southeastward toward the Lake Michigan Basin, or nearly at a right angle with the movement that shaped the drumlins. He thus referred it back to an ice movement that was pre-Illinoian as well as pre-Wisconsin. An early ice movement in the Kansan or pre-Kansan stage of glaciation carried the copper ores of the Superior region as far southeast as the Scioto Basin, in central Ohio. The deposits laid down at the early glacial stage were, however, gathered up to a large degree and redeposited by the later ice movements in both Illinoian and Wisconsin time, and copper is now found in drift of undisputed Wisconsin age all over the southern peninsula of Michigan and in neighboring parts of Indiana and Ohio. The presence of copper and iron ore in the drumlins, therefore, does not prove that the drift sheet in which they occur is as old as the pre-Illinoian southeastward ice movement.

An examination of the degree of weathering, leaching, and other changes to which the drift forming the body of the drumlins has been subjected was made in 1919 by the present writer and no place was found in which it is essentially different in aspect, so far as weathering and leaching are concerned, from the drift of the morainic knolls and ridges of that region. In both classes of knolls and ridges it is the fresh Wisconsin drift. The till varies in texture in different drumlins or even within a single drumlin. The sandy or loose-textured till, however, greatly predominates over the clayey compact till. Little of the material is so clayey as to show any lamination. The coarse stones in the till are largely of local derivation from rock formations that crop out around the north end of Lake Michigan. This local material in places makes up 85 to 90 per cent of the coarse rock of the till. The limestone slabs and other coarse blocks seem to be embedded at various angles in the till, though in some exposures a tendency to lie with the broad side downward was noted; many of these blocks, however, stand on edge.

Eskers or gravel ridges are found in all parts of the district occupied by drumlins, but, they are far less numerous than the drumlins. Those that have been mapped in T. 38 N., R. 26 W., appear in Figure 7. They range in length from a fraction of a mile to 3 miles or more. Their trend is in the same general direction as the longer axis of the drumlins or the bearing of the striae, but in some eskers the trend differs a few degrees from that of neighboring drumlins. A few show marked changes in trend when followed from end to end. They are generally low, a height of more than 20 feet being exceptional, and the usual height is only 10 to 15 feet. They usually contain gravel of the sort needed in highway construction and thus are coming to be valuable assets in the region they occupy. In nearly all the eskers, however, sandy beds appear either between gravel beds or at the same horizon, for the coarseness of the material deposited depended upon the force of the current and the nature of the material that was undergoing transportation by the stream that formed the esker. This stream evidently was confined by ice walls and the material in the esker was derived from the melting of the dirt-laden ice along the path of the stream.

The relation of the eskers to the drumlins shows that some of them were formed after the drumlins had been built up or shaped. They commonly lie in the smooth troughs between the drumlins. These troughs appear to have been scoured by ice movement in connection with the development of the drumlins. Here and there the course of the stream that formed the esker led across a drumlin and a notch was cut in the drumlin by the stream. A good illustration of notching of this sort was noted by Russell in a drumlin north of Spaulding, in the NE. ¼ sec. 9, T. 38 N., R. 26 W. (Fig. 7.) That the stream which cut this notch was near the bottom of the ice sheet is evident from the fact that the crest of the drumlin across which it cut the channel is not more than 20 feet above the bordering till plain. The notch here is cut near the end of the drumlin. A notch was cut across the middle part of a drumlin immediately north of Harris, but here the esker is not so well developed as that near Spaulding. A low irregular-shaped gravelly ridge comes to the notch from the east but is not continued to the west of the drumlin.

In some places an esker is superimposed on a drumlin. Russell called attention to such an occurrence which he found south of Wilson. The esker lies on the crest of the drumlin and follows it for about a mile. The drumlin extends a little farther south than the esker. The top of the esker on the highest part of the drumlin is 70 to 80 feet above the bordering plain at the base of the drumlin.

On some drumlins there are irregular-shaped gravelly knolls which appear to have been deposited after the shaping of the drumlins had been completed. It is also not rare to find hummocks of drift in the shallow troughs between the drumlins. These features seem to indicate that the drumlins were developed and shaped while the ice was in active movement, but that the eskers and other drift deposits laid down on drumlins and in drumlin troughs may represent the work of the ice and the accompanying drainage at a time when the ice sheet had become relatively stagnant.

At a few places in the midst of the drumlin district drift hummocks are rather closely aggregated and are lined up in such a way as to suggest a moraine, but the writer was unable in the time given to this investigation to work out any definite ice-border lines in the drumlin district such as Alden has traced across drumlin districts in southern Wisconsin.

The drumlins, as above indicated, are usually present clear to the edge of the area later covered by glacial Lake Algonquin in southwestern Delta County and southern Menominee County, and there are several drumlins which stood as islands in Lake Algonquin in southwestern Delta County. However, for a distance of about 20 miles north from the mouth of Menominee River in southern Menominee County there is a strip of land 1 to 2 miles wide just outside the limits of Lake Algonquin which has a series of low ridges and swells that are not definitely shaped into drumlin form and which in places has a morainic aspect. This strip stands a little higher than the land immediately west of it, which is traversed by Little River. It may therefore represent a weak moraine or a brief stand of the ice border in the course of its retreat toward Green Bay. It seems to be a little older and also weaker than the moraine discussed below, which is traceable along the east side of the drumlin district about as far south as the mouth of Ford River. It was identified no farther north than the vicinity of Hayward Lake, in T. 34 N., R. 26 W.

LATER MORAINES

In Marquette County a strong morainic belt was traced southeastward to the vicinity of Little Lake, as described above. Attention was also given to a broad outwash plain that lies outside the moraine which is traversed by the Chicago & Northwestern Railway from the vicinity of Cascade southeastward to Little Lake. Directly opposite Little Lake the moraine turns southwestward and forms the western border of the Green Bay lobe.

For a few miles there is a large amount of swamp land in the morainic belt, and the ridges and knolls rise like islands above the level surface of the swamp, conspicuously in T. 44 N., R. 24 W., but less so farther south. From the southwestern part of that township the moraine runs southward for about 10 miles along the east side of Escanaba River in a strip scarcely 2 miles in average width. The river there crosses to the inner edge of the moraine and both take a southward course into Delta County. The moraine comes to Ford River in the central part of T. 40 N., R. 24 W., and, crossing to the west side of the stream, follows it somewhat closely to its mouth. There are strips or small areas with morainic aspect east of the river in the southern part of T. 40 N., R. 23 W., and the northern part of T. 39 N., R. 23 W., which are regarded as spurs on the inner border of the morainic belt. The moraine is weak where it lies within the limits of glacial Lake Algonquin near the mouth of Ford River. It has not yet been determined whether the ice border passed within the limits of Green Bay a short distance south of the mouth of Ford River or continued farther south along the west side of the bay to embrace the strips of dry land that rise a few feet above the swamps in the bed of Lake Algonquin. Some of these dry strips consist of till, but others are sandy. It seems, on the whole, more probable that the ice border passed into Green Bay near the mouth of Ford River, and this is as far south as morainic features are definitely preserved.

The moraine is composed of till, with sufficient clay and pulverized limestone to make a soil of fair quality. Surface boulders are not so numerous as to render it difficult to cultivate the land. The swamps greatly interrupt the moraine for a few miles southwest from Little Lake, but elsewhere they are no more extensive than on the bordering till plains, so the greater part of the land is cultivable.

At the time this moraine was formed the Green Bay lobe seems to have covered the north end of Green Bay and the two arms known as Big Bay de Noc and Little Bay de Noc and to have extended as far as the Garden Peninsula, east of Big Bay de Noc. Striae with southeastward bearing along the west side of that peninsula appear to be referable to the Green Bay lobe. The Michigan and Green Bay lobes may have been merged together at this time in the northern part of the Lake Michigan Basin. However, at a time somewhat later, when the end of the Green Bay lobe barely reached the northern part of Little Bay de Noc, the Green Bay and Michigan lobes were yet sufficiently differentiated to the north of the Garden Peninsula to give clear evidence as to the limits of each lobe.

A few miles north of the Garden Peninsula, in the northeast township of Delta County, there is a very high tract of moraine and outwash which appears to stand at the junction of the Green Bay and Michigan lobes. The outwash plain occupies the central and southeastern part of the township; the morainic tract borders it on the east, north, and west. The moraine on the west seems to be the product of the Green Bay lobe. It is traceable southward to the head of Big Bay de Noc. Sturgeon River crosses it in the southwestern part of T. 42 N., R. 19 W., and follows the east side of the moraine southward past St. Jacques to Big Bay de Noc. The part of the moraine south of Sturgeon River is below the level of Lake Algonquin and has a gently undulating surface, which in places is diversified by ridges of wind-blown sand. It stands 20 to 25 feet above the bordering plains and for several miles from its south end is scarcely a mile in average width. The part of the moraine northeast of Sturgeon River is mainly above the limits of Lake Algonquin and consists of sharp ridges and knolls, some of which are 50 feet or more in height. This prominent part of the moraine is made up largely of loose-textured sandy to very stony drift with scarcely any clayey material. The part that stands below the Lake Algonquin level contains some clayey till, as shown by wells in the vicinity of St. Jacques, but seems to be generally sandy. The ice when this moraine was formed may have covered much of Big Bay de Noc and Little Bay de Noc and the peninsula between these bays, but no definite limits appear to be traceable.

A sharply morainic tract directly north of the outwash plain above noted, extending several miles northward into Schoolcraft County, seems to be a spur between the Green Bay and Lake Michigan lobes. It occupies nearly all of T. 43 N., R. 18 W., and the southern part of T. 44 N., R. 18 W. The knolls and ridges are sharp and some of them rise to heights of 50 to 60 feet or more. The material is very stony and gravelly drift, such as one would expect to find in an interlobate spur.

A moraine leads southwestward from a point near the north end of this spur and seems to mark the position of the southeast side of the Green Bay lobe at a later time than the one above noted. This moraine is crossed by Sturgeon River just south of the Alger-Delta county line. It is only about a mile in width northeast of the river, but to the southwest it widens out and extends a spur westward along the county line to the east branch of Whitefish River. It again narrows about 3 miles south of the county line and lies a short distance east of Whitefish River from that point nearly to the head of Little Bay de Noc. It dies out in a high outwash plain that lies east of the northern part of this bay. Along much of its course it consists of sharp ridges and knolls of gravelly drift 20 to 50 feet or more in height. On the west side of Little Bay de Noc a high outwash plain fills the interval between the bay and Escanaba River. It seems not improbable that the ice lobe was occupying the north end of the bay while this outwash was being deposited at its borders. The outwash plains bordering Little Bay de Noc were built up about to the level of the highest stage of Lake Algonquin, which was nearly 150 feet above Green Bay opposite Gladstone. The material in the plain west of the bay is largely fine sand; in places search is required to find a pebble over a quarter of an inch in diameter. The sand has a depth that varies considerably because of the unevenness of underlying beds of till and clay, but in places it is 75 feet thick. Under it there are places where bouldery till has been exposed. There are also deposits of red laminated clay nearly free from pebbles that seem to have been laid down by the waters of Lake Algonquin before the sandy outwash was deposited by water issuing from the ice lobe. This clay has been noted on both sides of Little Bay de Noc and reaches an altitude 50 to 75 feet or more above the level of the bay.

The correlative moraine formed at the west side of the Green Bay lobe is well developed for a few miles northwest from the outwash plain and is especially strong in the vicinity of Perkins, where knolls 30 feet or more in height occur. In places between Perkins and Lathrop along or near the Chicago & Northwestern Railway small drift knolls abound and the surface appears morainic, but the writer's studies were not sufficiently detailed to determine whether a definite moraine is traceable all along the western border of the ice lobe.

TILL PLAIN IN THE AXIS OF THE GREEN BAY LOBE

In the northwestern part of Delta County, the southeastern part of Marquette County, and the western part of Alger County there is an extensive till plain across which the ice border receded after forming the moraines just discussed. It is about 18 miles wide from west to east and about 35 miles long. Its eastern limits are at the Au Train-Whitefish Valley and its western limits at the moraine that was traced through eastern Marquette County and western Delta County to the shore of Green Bay below the mouth of Ford River. It seems to lie entirely in the path of the Green Bay lobe. This plain has a loose-textured reddish till much like that of the drumlin district of Menominee County and southern Marquette County. There are only a few drumlins on it, and these are not in the part nearest the drumlin district, but in the vicinity of Chatham and Eben Junction. The percentage of swamp land in this plain is also not greatly different from that of the Menominee County drumlin district. The amount of limestone material incorporated in the till becomes less and less from south to north, for the northern part has only a calciferous sandstone from which such material can be derived, but the southern part is in a district in which relatively pure limestone formations are present, and the till contains a large percentage of material from these formations. Here and there are short eskers a fraction of a mile in length and low ridges with a large number of local rock slabs embedded in poorly assorted material. Many of the slabs show but little rounding by water action. The drumlins near Chatham and

Eben Junction are steep-sided ridges 20 to 30 feet high and half a mile to a mile or more in length. Their trend is nearly south. They contain a large amount of slabs and flat pieces of the local rock in a rather loose textured matrix.

A short gravel ridge of the esker type is crossed by the highway about 5 miles south of Chatham, at the highest point on this road between Chatham and Trenary, 946 feet above sea level. This esker trends east-southeast and is thus directed toward the east side of the lobe and suggests that the axis of the lobe was farther west. Its length is less than a mile. About 2 miles southwest of this esker is a sandy ridge with easterly trend which is crossed by the Rapid River branch of the Soo line. Its altitude is about 950 feet above sea level, and it rises 10 to 15 feet above the bordering till plains. This may prove to be a wind-formed ridge rather than glacial, for the slight exposures found in it revealed only fine sand. It is about 90 feet higher than the highest shore of glacial Lake Algonquin, 4 miles to the east.

The strong morainic system bordering Lake Superior, described below, shows a slight lobation at the Au Train-Whitefish lowland, which marks, perhaps, the latest definite work of the Green Bay ice lobe. It seems more convenient, however, to consider it in connection with the remainder of the morainic system than to give it separate description here.

OUTWASH PLAINS EAST OF THE AU TRAIN WHITEFISH LOWLAND

Of the outwash plains connected with the moraines of the Green Bay lobe in northeastern Delta County and neighboring parts of Schoolcraft and Alger Counties the highest one and the earliest to be formed occupies a considerable part of the northeast township of Delta County. The ice on its north and east sides pertained to a lobe that covered the Manistique drainage basin and represented the closing phase of the Lake Michigan lobe; that on the west side pertained to the closing phase of the Green Bay lobe, as indicated above. This plain slopes southeastward and appears to have been built by outwash from both of these lobes.

Another outwash plain lies between the two moraines of the Green Bay lobe above described. It is east of Sturgeon River for a short distance north and south of the Alger-Delta county line, in Tps. 44 and 43 N., R. 19 W., but west of that stream from a point near the center of T. 43 N., R. 19 W., southwestward to the east side of Little Bay de Noc, opposite Gladstone. It seems to be a little above the level of glacial Lake Algonquin in northern Delta County and southern Alger County, but farther south its level seems to be very nearly the same as the highest Algonquin water level. In much of its course from the Soo Line near Ensign station northeastward to the center of T. 43 N., R. 19 W., its east edge appears to be at Lake Algonquin level, the ponded water being the limiting agent in the eastward transportation from the edge of the ice lobe. The plain was thus extended to a distance of 2 or 3 miles outside the moraine that marks the position of the ice border. There is along Sturgeon River a low strip 1 to 3 miles wide which probably because of this ponding was not filled by the outwash.

After the ice began to recede from the moraine that lies on the east side of Whitefish Valley in northern Delta County the slope toward the valley was shaped into steps that become lower and lower from the moraine down to the valley. It might be assumed that these steps are merely the work of the waves of Lake Algonquin and that they mark successively lower levels of the lake waters, but the tread or level part of each step carries basins and irregularities that are not consistent with the cutting into a slope by wave action, and the riser or bluff part has spurs and recesses such as are characteristic of the ice contact where the higher plain was built up outside the ice while the lower plain lay beneath it. There may have been some work by the waves of Lake Algonquin in connection with these steps, but it seems probable that the steps mark successive positions of the retreating ice border.

There is a very conspicuous outwash plain outside a strong moraine in Alger County from the Au Train-Whitefish Valley eastward which may have been formed in large part during the recession of the ice border across the area it occupies, for the plain has a general width of 6 or 7 miles. It is full of basins and irregular-shaped depressions, which seem to mark the places where detached masses of the ice sheet persisted after the active ice border had melted back beyond them. These depressions, with the great width of the outwash district, support the view that the outwash was largely built in the course of the ice recession.

The outwash on the west side of the Green Bay lobe in southern Marquette County and western Delta County is very meager compared with its extent on the east side in the same latitude and on the west side farther north in Marquette County. From Little Lake northward to a point within 5 or 6 miles of Marquette, as already shown, the outwash is very extensive. This tract, however, is above the place where the Green Bay lobe became differentiated from the ice of the Lake Superior Basin.

CLAY DISTRICTS

North of Big Bay de Noc there are small areas of clay. One lying east of the Sturgeon Valley embraces 30 to 40 square miles and comes to the border of Big Bay de Noc near Isabella. The clay is red, has very few pebbles embedded in it, and appears to be a water-laid rather than a glacial deposit. Parts of this area have a thin coating of sand on the clay, but in much of it the clay is so near the surface as to be within reach of the plow. Another clay area lies west of Ogontz Bay and runs northward along the west side of Ogontz River beyond the Soo Line. It is about 10 miles long from north to south and about 3 miles in average width. These clay areas are low next to Big Bay de Noc but reach an altitude of 100 feet or more above the level of the bay in their northern parts. They lie much below the level of glacial Lake Algonquin. They seem to be in places where sandy and gravelly outwash from the Green Bay lobe did not reach. At the north ends of these clay areas there is a steep rise to the outwash plains.

AREAS OF VERY THIN DRIFT

On a considerable part of the peninsula between Big Bay de Noc and Little Bay de Noc and on the Garden Peninsula limestone lies near the surface and in places stands a few feet above the general level of the drift filling. These peninsulas were almost entirely covered by the waters of Lake Algonquin and show the effects of the submergence in the gravelly bars and in bare wave-washed ledges. The general thinness of the drift, however, seems to be due in larger degree to scanty deposition by the ice than to removal by subsequent wave action.

Along the lowest part of the Au Train-Whitefish depression there is a strip of nearly bare rock from the crossing of the Munising, Marquette & Southeastern Railway southward to the head of Little Bay de Noc. Here the rock may have been denuded of some of its drift cover by the passage of lake currents through the narrow strait that in Lake Algonquin time led from the Lake Superior Basin to the Green Bay Basin, as shown more fully in the discussion of Lake Algonquin (pp. 63 to 68).

LAKE MICHIGAN LOBE

The ice that formed the Lake Michigan lobe crossed the northern peninsula east of the meridian of Munising and covered it about as far east as the meridian of St. Ignace. At the time the outer morainic system of the western part of the northern peninsula was being formed by the Superior lobe the Port Huron morainic system seems to have been in process of development by the Lake Michigan and Huron lobes. The Port Huron morainic system has been described in Monograph 53. The full limit and fluctuation of the Lake Michigan lobe during the period in which the later system of moraines of the west end of the northern peninsula was being formed can not be stated definitely, but it seems not unlikely that the ice for a part of that time reached the Manitou Islands and encroached slightly in the northern part of the southern peninsula. The Cheboygan moraine and a small moraine bordering Little Traverse Bay may be correlated with the outer member of this later system. These moraines also are described in Monograph 53. The Beaver Island group, in the northern part of the Michigan Basin, seems to have been buried under ice at that time, but was uncovered, perhaps, before the later members of this younger morainic system were formed. By the time the moraines and outwash plains north of Big Bay de Noc were being developed the ice may have entirely disappeared from the Lake Michigan Basin. Its border then may have been at a moraine traversing the southern part of the peninsula, across Schoolcraft and Mackinac Counties. A slight protrusion of the ice southward over the great swamp in the Manistique River drainage area seems to be the successor of the Lake Michigan lobe when the ice no longer reached the Lake Michigan Basin.

HURON LOBE

ICE MOVEMENTS AND DRIFT CHARACTERISTICS

There appears to have been considerable complexity of ice movement over the east end of the northern peninsula. The striae indicate a west-southwestward movement across the high limestone ridges east of Trout Lake and Ozark and on the shore of Lake Michigan near Point Epoufette. They show a southeastward movement near Hessel and Les Cheneaux Islands and a southward movement across Drummond Island and neighboring parts of Canada. There was thus a wide divergence of ice movement in the part between Point Epoufette and Les Cheneaux Islands and a convergence in the district east of those islands. Whether these wide differences represent differences in direction of ice movement at the same time or at different times is not yet determined. The dominant direction of movement into the northern part of the Lake Huron Basin seems to have been southward, yet there is clear evidence of vigorous southeastward movement not only in the bearing of striae but also in the trend of drumlins on Les Cheneaux Islands and neighboring parts of the mainland. In other areas drumlins appear to have been formed where ice movement was vigorous, and the same thing seems likely to have taken place here. This southeastward movement seems also to be inconsistent with the direction of movement a few miles to the north of this drumlin area. Several moraines between the Cheneaux drumlin area and Sault Ste. Marie trend in nearly the same direction as the drumlins and thus appear to have been formed by a southwestward ice movement. The movement that produced these moraines extended up to and in places beyond the brow of what is known as the Niagara escarpment, the outermost of the moraines being in part on the top of the escarpment and in part on its southern slope. The southeastward-bearing striae and the drumlins are confined to low ground on the immediate border of Lake Huron. Possibly the depth of the Lake Huron Basin was sufficiently greater to the southeast from Les Cheneaux Islands than to the southwest to cause a local deflection southeastward, for the basin is relatively shallow to the southwest, in the vicinity of the Straits of Mackinac. The extent of the movement past the Cheneaux drumlin area into the Lake Huron Basin is not known. The ice may have reached the position marked by the Cheboygan moraine, which lies near the edge of the southern peninsula from Mackinaw City southeastward past Cheboygan. The Cheboygan moraine is described in Monograph 53, and attention is therefore given here only to the features on the northern peninsula.

In the Carp River drainage basin there is a large amount of swamp land in which the rock is not far below the surface. The swamps seem to be underlain by sand rather than clay, and sandy ridges are found in them at short intervals. The high land within this drainage basin consists largely of bare limestone ridges and hills. They seem to have been swept clean in some places by the wave action of Lake Algonquin, to which they were exposed at nearly all levels in the course of the uplift which was in progress during Lake Algonquin time and which caused the water to take lower and lower positions on the slopes of these limestone hills.

Southwest of the headwaters of Carp River, along the border of Lake Michigan from Brevoort Lake westward for about 12 miles, there is a high tableland of sandy gravel, which is probably an outwash deposit from ice that was covering the Carp River drainage basin. The strip is 2 or 3 miles wide and stands about 700 feet above sea level, or 120 feet above Lake Michigan. As the height of this table-land is more than 100 feet below the highest level of Lake Algonquin, it was probably formed in deep water. There is, however, some likelihood that ice persisted in stagnant condition in the deep north end of the Lake Michigan Basin down to a time when the border of the moving ice had been melted back to some position on the northern peninsula. In that case the Lake Algonquin waters may not have had access to this area and the level to which it was filled may have been controlled by local conditions between ice masses on its borders.

In the Pine River drainage basin there is a large amount of clay land, and this borders the west side of St. Martin Bay for a few miles beyond the mouth of Pine River. The conditions are thus strikingly different from those in the Carp River drainage basin. Much of this clay seems to be lake sediment laid down by the waters of Lake Algonquin. Some clayey till, however, is found beneath the lake deposits.

On the east side of St. Martin Bay and on the islands in the bay there is a large amount of sand, and the hills consist of bare limestone. This condition extends to the edge of the drumlin district at Hessel.

Only a few small areas along the brow of the Niagara escarpment rose above the level of Lake Algonquin, but with two exceptions these areas have very little drift. One east of Trout Lake has an altitude of more than 100 feet above the highest Algonquin beach, yet there are only a few pebbles and boulders on it, and deep unfilled fissures occur in the limestone. Its appearance is that of a fiercely wave-swept tract. Possibly in the complexities of ice movement and melting the waters became locally ponded here to a height much higher than the limits of Lake Algonquin. Another very prominent tract of bare limestone lies east of Pine River 6 to 8 miles southeast of Rudyard. On this tract also there are deep unfilled fissures in the limestone which make treacherous pitfalls for stock grazing on it. This tract is encircled by the highest beach at a level more than 50 feet below its highest point. Between these two prominences of bare rock ledges there is another prominent area fully 100 feet above Lake Algonquin which carries a deposit of drift heaped into morainic knolls and ridges. This deposit occupies several square miles east and northeast of Round Lake in T. 43 N., R. 4 W. It seems probable that the moraine was formed between ice lobes that protruded southward in the low lands on each side and converged on the high land that carries the moraine.

Another morainic area that stood above Lake Algonquin lies directly north of Hessel on the line of Tps. 42 and 43 N., R. 1 W. It embraces only 3 or 4 square miles and has a strong morainic expression. This moraine is traceable southeastward into the central part of T. 42 N., R. 1 E., at levels below the limits of Lake Algonquin. In that area it has a very subdued expression, but the thickness of the drift along it is much greater than on either side, and boulders are conspicuous. Northeast of this submerged part of the moraine, in the northern part of T. 42 N., R. 1 E., there is a prominent limestone strip which was swept bare by lake action, as it stands just below the upper limits of Lake Algonquin. There is a similar prominent limestone strip in the western part of T. 42 N., R. 2 E.

LES CHENEAUX DRUMLIN DISTRICT

The drumlins on Les Cheneaux Islands and the adjacent part of the mainland are among the most conspicuous features produced by the ice in this part of the northern peninsula. They were studied and described by Russell[7] in 1904. The prevailing trend of the drumlins is about S. 50°–55° E., or very nearly the same as the latest striae on the rock ledges near them. They are much elongated, some of them being about a mile long; the width is ordinarily one-eighth of a mile or less. The height ranges from 10 or 15 feet in the smaller ones to 40 or 50 feet in the larger ones. About 50 of these drumlins were mapped by Russell, and he estimated that nearly as many more

[7] Russell, I. C., Michigan Geol. Survey Ann. Rept. for 1904, pp. 69–71, 1905.

may be present in the uncleared land which he did not examine in detail. Those on the mainland are within about 2 miles of the shore of Lake Huron and are present from Hessel eastward a short distance beyond Cedarville. Some of the islands consist of single drumlins; others of groups of drumlins. The till in the drumlins is rather compact and clayey and has a reddish color. Part of the large stones embedded in it are local limestone, and part are crystalline rocks brought in from Canada. Russel reported that a highway cut through a drumlin in Cedarville, showed the till to be distinctly laminated in the upper 5 or 6 feet, but the lamination is less evident at greater depth. The laminae are concentric with the convex surface of the hill. Russell suggested that lamination of this sort may be produced either by the pressure of the ice or by a plastering or surface accretion by the ice in its passage over the hill. On the surface of many of the drumlins boulders are very numerous. Russell suggested that a concentration of boulders may have been produced by lake waves and currents working on the drumlins and removing the fine material from their surface. In their present condition they are thus washed drumlins. There are also notches and terraces on the slopes which are especially conspicuous at the level of the highest Nipissing beach, about 40 feet above Lake Huron.

MORAINES AND OTHER FEATURES OF EASTERN CHIPPEWA COUNTY, MICH.

In the eastern part of Chippewa County there are several bouldery ridges which trend in general from northwest to southeast and appear to have been formed by ice moving southwestward across St. Marys River. The direction of ice movement changed to southward toward Drummond Island. The ice movement that formed these morainic ridges differed strikingly from that which formed the drumlins in Les Cheneaux Islands, though those islands lie directly south of these moraines. In forming these moraines the ice appears to have made a more vigorous movement from the uplands at the east end of the Lake Superior Basin and advanced into an area that had been in the path of a movement southeastward from this end of the basin. These moraines are considered in order from south to north in what appears to have been their order of development.

KINROSS MORAINE

The Kinross moraine, here named by the writer from Kinross station, on the Soo Line, which stands on it, becomes a definite feature at the northwest in sec. 11, T. 45 N., R. 1 E., and leads southeastward for about 20 miles, passing by Stalwart and Gatesville and coming to the Lake Huron shore about 6 miles southeast of Gatesville, in T. 41 N., R. 3 E. Its general width is between 1 and 2 miles, but for a few miles southeast from Kinross it expands into a boulder-strewn tableland about 4 miles wide. In the vicinity of Gatesville and southward to Lake Huron the moraine and a gravelly plain on the southwest, which seems to be outwash from it, occupy a strip about 4 miles in width.

In altitude the moraine ranges from 700 to 800 feet or more above sea level, except near its southeast end, where it drops below 700 feet. It is highest between Kinross and the Munuscong Valley, where it stands about 100 feet above the bordering plains. This highest part is deeply indented by basins and has a nearly plane surface, like an outwash apron. It is underlain to a considerable depth by cobble and gravel beds, but its surface is thickly strewn with boulders. Perhaps this occurrence of surface boulders is due to an advance of the ice over its outwash of such a character as to cause but little change in the topography of the outwash plain. The moraine and the outwash plain were eroded and terraced to a marked degree by the waves of Lake Algonquin as it was dropping to lower and lower levels. The crest also carries an Algonquin beach in the vicinity of Gatesville. The highest level of the Algonquin waters was nearly 100 feet higher than the highest part of this moraine. It is therefore somewhat surprising to find that the moraine has so much relief. The relief was probably somewhat greater than now when the ice sheet melted away, for the plains bordering the moraine have received a deposit of clay from the waters of Lake Algonquin.

Wells along the ridge generally penetrate about to the level of the base of the loose-textured deposits to strike water, as there appears to be no clay or impervious bed to check downward percolation. The boulders on the ridge are largely crystalline rocks from Canada, there being only a few limestone and sandstone slabs from the local formations. The cobblestones and small pebbles include a larger percentage of local rocks.

On the south side of the Kinross moraine, from its northwest end to the Niagara escarpment at Stalwart, there is a heavy filling of laminated red clay; but southeastward from Stalwart the outer border district is rough and broken, with bare limestone hills separated by swampy lowlands. From Stalwart northwestward the main settlement has been on the plain south of the moraine, and only a few farms have been cleared along the moraine. But from Stalwart southeastward the moraine is largely under cultivation, and but few farms have been opened south of it.

On the north side of the Kinross moraine there is a belt of sand and swamp land 2 or 3 miles wide extending from the west end to Mud Lake, at the mouth of Munuscong River. It is largely a barren waste. South of Mud Lake a large cedar swamp lies between the lake and the moraine, but it is diversified by a few limestone hills. From a point opposite Gatesville southeastward to Detour the district between the moraine and St. Marys River includes some fair farm land, mainly in the depressions between limestone ridges. It has a stony clay loam on which surface boulders abound. Several clearings have been made and turned into meadow or pasture.

LATER MORAINES

The part of Chippewa County lying in the bend of St. Marys River, from the head of the river to Neebish Island, is nearly all covered by a deposit of red laminated clay such as occurs south of the Kinross Ridge. A few narrow ridges and small knolls rise a few feet above the level of the clay plain. They do not appear to be superimposed on the plain, but instead they seem to be ridges that were partly buried by the deposition of the red clay. They carry some remnants of the red clay deposit on their crests and slopes. This feature seems to indicate that they were at one time covered more completely with the clay, but owing to the steepness of their slopes much of the clay has been washed down and spread over the bordering plain, or where the ridges are composed of gravel the clay has been carried down into them.

A conspicuous sharp gravelly ridge immediately southwest of Sault Ste. Marie, known as Larke Hill, is about 3 miles long, a quarter of a mile wide, and 15 to 50 feet high. It runs south from a point near the southwestern limits of the city of Sault Ste. Marie about to the line between Tps. 46 and 47 N., R. 1 W. The north end has been opened extensively for road ballast and to supply a stone crusher. These pits all show gravel with beds dipping sharply westward, on the east slope as well as on the west slope and the crest. On the west side of the ridge is a nearly smooth tract standing 10 to 20 feet or more above the plain east of the ridge, but itself descending westward within a mile to a level as low as the plain east of the ridge. As exposures in this tract show the presence of stony material at a depth of 10 feet or less, it is thought to be a low glacial ridge on the top of which the gravelly ridge has been built. An examination of the matrix or fine material of the gravel beds shows a notable amount of red clay, which it is thought may have worked down into the deposit from a capping of clay that has now nearly all disappeared from the surface. The material in the gravel ridge is rather coarse, cobblestones and small boulders being abundant wherever pits have been opened, and the surface is strewn with stones 6 to 10 inches or more in diameter. The ridge has a range in altitude amounting to about 100 feet, the highest point being at the Larke Lake Survey station, which is 800 feet above sea level, and the lowest near the south end, where, according to an aneroid determination, its altitude scarcely reaches 700 feet. The residents commonly regard this ridge as an old lake beach, or bar, but its great size, its range in altitude, and its structure are more consistent with aqueoglacial than with lake action.

A system of small ridges and knolls leads southeastward from Dafter past Barbeau post office to St. Marys River opposite Neebish Island. These ridges rise from 10 to 40 feet or perhaps slightly more above the bordering plains. They are spread over a strip 2 or 3 miles in width but occupy much less than half the surface, there being clay plains of considerable extent among them. They are thickly strewn with boulders, nearly all derived from Canada. The ridges vary greatly in constitution, some being composed of clayey till, some of sandy till, and some apparently of gravel. There are a few sandy ridges, but they are perhaps the result of subsequent lake action. The usual trend of individual ridges is northwest to southeast, or in harmony with the trend of the system as a whole. In the vicinity of a church and schoolhouse about 3 miles south of Rosedale, in secs. 4 and 5, T. 45 N., R. 1 E., there is a plexus of gravelly ridges inclosing basins and giving the surface an exceptionally rough appearance. These ridges are probably of fluvioglacial origin in stagnant ice and are similar to eskers in mode of development, if not simply a network of eskers. There happens to be an old lake level at about the same altitude as the highest parts of the system of ridges, but the beaches formed by the lake seem to be confined to small terraces and to spits and small ridges much smaller than the ridges forming this network.

Between the Dafter-Barbeau system of ridges and Charlotte River there is a strip 2 or 3 miles wide in which very few knolls and ridges appear. But on the north side of Charlotte River from the vicinity of Rosedale northwestward for several miles is a practically continuous ridge standing 20 to 30 feet above the bordering plains and having a breadth of nearly a mile. It contains a clayey till, but the surface is in places coated with sand as well as strewn with boulders.

This ridge flattens out 4 or 5 miles south of Sault Ste. Marie, near the meridian line of the land survey. It may, however, continue northward in very flattened form as far as St. Marys River in the western part of Sault Ste. Marie. In the plain that lies south of Sault Ste. Marie there is a barely perceptible westward rise toward this supposed line of continuation. The plain is coated with lake clay to a considerable depth. Exposures in Sault Ste. Marie seem to indicate that its sloping surface is the masked slope of a glacial ridge. Near the tannery in the western part of the city a stony clay is found up to an altitude about 100 feet above Lake Superior, but in exposures farther east, in the southern part of the city, the stony clay is not present, though some of them extend down to a level about 60 feet above the lake. At large clay pits near the tannery the upper 10 feet is a distinctly laminated red clay with very few embedded stones, below which is a somewhat stony clay apparently of glacial origin. In this stony clay are pockets of gravel and sand. There is also some lamination, as if it were till deposited in water. These exposures seem to indicate a close connection between the decidedly stony clay and the nearly pebbleless laminated clay that overlies it, as if the latter followed immediately upon the former. It is probable that on the plain south of Sault Ste. Marie a change from the lake clay to the stony and sandy glacial deposit occurs at about the level where water is obtained in wells, which is at a depth of 30 to 50 feet.

There are two ridges of morainic aspect in the northern part of Sugar Island, in St. Marys River. One on the west side of the island is about a mile in average width and 6 miles in length. Its crest ranges from about 785 to 844 feet above sea level, or 200 to 260 feet above St. Marys River, and is generally distant but a mile from the river. It therefore appears very prominent when viewed from the west side. It rises, however, only 50 to 60 feet above a plain east of it, but that plain has a clay coating 20 feet or more in general depth. The Mirron Lake Survey station stands on the highest point, 844 feet, and this is occupied by a lake beach. Lake beaches also occur on the slopes of the ridge. The surface of this ridge is thickly strewn with boulders and smaller stones, some of which may have been stranded on it during the lake occupancy.

In the northeastern part of Sugar Island is another ridged belt about 3 miles long and 1 to 2 miles wide. Its west border is about 1½ miles from the east edge of the ridge just described. It rises somewhat abruptly about 60 to 75 feet above the plain that lies between the two ridges, the highest points reaching an altitude of more than 860 feet above sea level. Lake beaches occur on its crest and slopes. It is very thickly strewn with boulders and smaller stones, and the drift is a sandy till.

On the plain between these ridges farms have been opened, but the ridges are scarcely at all cleared. At the farms wells usually obtain water at depths of 20 to 25 feet in sandy and stony deposits that underlie the lake clay. Some of the ravines have cut down through the lake clay and exposed a stony surface under it, with some very large boulders. The contrast here between the glacial and lake deposits is much more striking than in the exposures in the western part of Sault Ste. Marie noted above.

MORAINES AND ACCOMPANYING FEATURES OF THE EASTERN PART OF THE NORTHERN PENINSULA OF MICHIGAN

In the eastern part of the northern peninsula of Michigan there is a complex system of moraines which are in some places crowded together and in others separated by plains or swamps several miles in width. There are generally two strong moraines and associated with them some weaker ones. At the beginning of the development of this system of moraines the ice appears to have melted away from the Huron and Michigan lake basins to the south, or if it persisted in any part of these basins it probably became an inactive or stagnant mass, disconnected from the moving ice to the north of the basins.

This morainic system is in part above and in part below the level reached by the waters of Lake Algonquin. The part below that level has a much stronger morainic expression than is commonly exhibited by moraines laid down in water, such as those of the Saginaw and Erie Basins. The effect of the lake has been remarkably slight in toning down the morainic features. The basins are only partly filled and the knolls bear only slight notches cut by the lake waves.

Sandy ridges on the slopes of the moraines add considerably to their roughness. These ridges seem to be different from ordinary dunes, as they support heavy growths of hardwood timber, yet excavations in them show only fine sand with no clayey mixture. Nor are there pebbles or rocks that would require water or glacial action. The moraines are bordered in places by plains of sandy gravel, which by their situation as well as the character of their material appear to be outwash aprons, yet most of them are considerably lower than the highest level of Lake Algonquin. These will be considered in connection with the description of the moraines.

The southernmost member of this morainic system in general lies a few miles from the shore of Lake Michigan. The outlying district is largely a tract of limestone with very thin drift cover. Its highest parts are fully 200 feet above Lake Michigan, and in a few places—for example, in a limestone tract west of Indian Lake in southwestern Schoolcraft County—they stand above the upper limits of Lake Algonquin. There are gaps in the limestone which are generally occupied by low sandy plains, but in places are filled to the general level of the limestone surface.

MORAINES SOUTH OF THE MANISTIQUE AND TAQUAMENAW SWAMPS

From the reentrant angle in the ice border in northeastern Delta County and neighboring parts of Schoolcraft and Alger Counties, described on page 43, the ice border seems to have had a slight lobation in the Manistique drainage basin and crossed Manistique River about 10 miles northeast of Manistique, in the northwestern part of T. 42 N., R. 14 W. Morainic features are prominent along the Schoolcraft-Delta county line and along the Manistique & Lake Superior Railroad for several miles eastward from the morainic complex. Low sandy plains and swamps then interrupt the moraines for several miles, but in the northern part of T. 43 N., R. 16 W., moraines reappear and a definite moraine runs southeastward for about 12 miles. This morainic tract is about 150 feet above Lake Michigan, and along part of its south border there is a table-land of sandy gravel, which seems to be an outwash apron. This table-land is nearly free from boulders, but the morainic strip has numerous boulders and smaller stones scattered over its surface. It also has a more productive soil than the outwash plain. In this strip is the farming community known as Hiawatha Settlement.

On the east side of Manistique River for several miles above its mouth there is a sandy table-land standing 120 feet or more above the level of Lake Michigan. Where the highway rises to this table-land about 2 miles east of Manistique, near the corner of secs. 4, 5, 8, and 9, T. 41 N., R. 15 W., there is a great depth of sand exposed, in which pebbles are very rare, but at the top of the deposit is a more pebbly sand a few feet thick. The upland is a sandy plain thence northward to the westward-flowing part of Manistique River in T. 42 N., R. 15 W. On this plain there are scattered boulders. The deep filling with sand appears to extend eastward only to a small stream that runs north through secs. 27 and 22, T. 42 N., R. 15 W. East of that stream rock is near the surface, and a few boulders and coarse stones are about all there is of definite glacial material. There seems to be very little morainic material in T. 42 N., Rs. 14 and 15 W., but in eastern Schoolcraft County, in Tps. 43 and 44 N., R. 13 W., there is strong morainic development, apparently in the line of continuation of the moraines west of Manistique River. From the southeast border of this morainic area, in the southern part of T. 43 N., R. 12 W., a plain of sandy gravel extends northeastward as well as eastward into western Mackinac County over the greater part of T. 43 N., R. 12 W., and the northwestern part of T. 43 N., R. 11 W. The morainic belt also bears northeastward across the northwestern part of Mackinac County into the southern part of Luce County. The Manistique Lakes lie in it, and its north edge is near the Duluth, South Shore & Atlantic Railway across the entire width of southern Luce County. There is a sandy outwash plain outside of the moraine in the headwaters of Mille Coquins River and east of Mille Coquins Lake which runs southeastward to the shore of Lake Michigan near Naubinway. The outer part of the morainic system turns southeastward and runs past Gilchrist to Lake Michigan. This part carries sandy ridges, which conceal much of the surface of the moraine. A plain of sandy gravel sets in on the north shore of Lake Michigan a few miles farther east, but morainic features are weak to the north of it. This outer member of the morainic system is a definite feature as far east as the southwestern part of T. 43 N., R. 7 W. There are scattered morainic knolls a few miles farther back from Lake Michigan along or near the Soo Line from Gilchrist nearly to Trout Lake.

The main part of this morainic system lies still farther north and runs eastward across southern Luce County into Chippewa County, keeping south of the great Taquamenaw Swamp. There are two conspicuous recesses in the north border of the moraine in Luce County, one from 1 to 4 miles west of Newberry and the other from 4 to 10 miles east of that town. In the first recess a low clay plain extends about 3 miles south of the Duluth, South Shore & Atlantic Railway, and in the second about 5 miles. Along the St. Ignace branch of this railroad there is a low sandy plain rising gently southward to the divide between Lake Superior and Lake Huron, 3 miles northwest of Trout Lake. Near the line of Luce and Schoolcraft Counties the moraine is greatly interrupted by swamps for about 6 miles south of the railroad. These swamps appear to be underlain by sand, and so does the great swamp that occupies much of the drainage area of Manistique River in Schoolcraft County. Near Eckerman the moraine under discussion becomes merged with a later one, which continues northeastward nearly to the head of the outlet of Lake Superior at Point Iroquois.

There are few places where this morainic system is developed at a level less than 150 feet above Lake Michigan. Where the land stands lower along its course there are usually sandy plains and swamps. Some of the highest points are found at the west end, in the interlobate tract in western Schoolcraft County, where the altitude reaches fully 950 feet above sea level, or about 370 feet above Lake Michigan. A single knoll near Rexton is also 950 feet above sea level, and a knoll a mile south of McMillan reaches about 1,000 feet. The altitude of the greater part of the moraine is between 800 and 900 feet. The highest level of Algonquin waters in this district is not far from 900 feet above the sea, being a little above that level in western Schoolcraft County and a little below in southern Luce and Chippewa Counties and in Mackinac County. The islands rose but little above the lake and were of slight extent.

The relief of the moraines on the outer or south border is generally very slight, being ordinarily only 20 to 30 feet. The inner-border relief is much greater, as a low swamp lies along the border in Schoolcraft and Luce Counties and western Chippewa County. The lowest part of the swamp in southern Manistique County is less than 650 feet above sea level, and the altitude is only 720 feet at the divide between the Manistique and Taquamenaw drainage basins. The altitude is low as far east as Soo Junction. Eastward from that point the swamp rises to 800 feet at Eckerman and about 825 feet at Strong station. In places a narrow plain lies along the south side of the swamp in Luce County, and the morainic features set in at 750 to 800 feet above sea level, or 20 to 70 feet above the level of the swamp. The village of Newberry stands on this plain.

Throughout much of its course the moraine has a strong expression. The basins are especially conspicuous. The swells have usually rather gentle slopes, but a few of them are steep and rise high above the surrounding part of the moraine. Thus the highest points of a chain of knolls about 1½ miles north of Garner are about 100 feet above the rest of the moraine, and a knoll north of Rexton rises 90 feet. The moraine in western Schoolcraft County has many sharp knolls and ridges 60 to 75 feet high. Some of the basins are very large. The one occupied by Manistique Lake has an area of about 15 square miles. The neighboring morainic knolls and ridges rise 60 to 80 feet above the lake. Some small basins are very deep. Those in the Hiawatha Settlement which contain small lakes have rims about 40 feet above the lakes, and the lakes are said to be 60 to 75 feet in depth. As a rule, however, the lakes along this morainic system are shallow, and there are many basins that are occupied by swamps or have dry bottoms. The basins are nearly all in the part of the morainic system that was covered by the waters of Lake Algonquin. The basins are preserved where they lie near the level at which strong wave action seems likely to have occurred, as well as where they were deeply submerged.

A considerable part of this morainic system has been built up to about the level of the highest part of the Niagara escarpment where it lies along the crest of the escarpment. The drift is thus rather thin where the rock stands high and thick where it stands low. The drift is very thick to the north of the escarpment. The moraine lies mainly north of the escarpment, though its outer part extends to and in places beyond the escarpment from the vicinity of Hendrie westward to Manistique River. The rock has been struck north of the escarpment in only a few borings, as shown in the following list:

Deep borings along or near the moraine north of the Niagara escarpment

Location	Altitude	Depth	Remarks
	Feet	*Feet*	
Van Leuven estate, sec. 25, T. 47 N., R. 4 W.	825	140	No rock struck.
Strong (Turner's mill)	840	220	Rock at bottom. Drift mainly clay to 175 feet; gravelly hardpan, quicksand, and sandy gravel below.
Strong (Turner's boarding house)	845	203	Sand 7 feet at top, then clay to 175 feet, below which is gravelly hardpan and quicksand
Near Soo Junction	720	172	Rock at bottom. Drift largely a gummy clay. Thin bed of gravel on the rock.
Newberry asylum	870	186 245 457	One well, 245 feet, from gravel. Four wells, 186 feet. Rock at 320 feet. Drift entirely sandy or gravelly material. Water obtained from upper part of limestone, drift water being cased out. Shale in lower 70 feet.
Newberry waterworks	775	110	Three wells. Entirely in sand to gravel at 90 feet.
Newberry chemical works	765	92–128	Ten wells, 92 to 108 feet; test well, 128 feet; sand, 5 feet; clay, 16 to 18 feet; fine sand extending to 90 feet, coarser sand to bottom of wells, and in test well to rock at 126 feet.
Newberry Furnace	765	80	Section as in well at chemical works.
Ryberg well, ½ mile east of Newberry	760	140	Black muck, 5 feet; clay, 80 feet; quicksand and gravel to bottom.
Dollarville, Danaher Lumber Co.	725	120–140	Four wells; rock struck at 130 to 140 feet. Flowing wells.
J. Watson, sec. 4, T. 45 N., R. 12 W.	760	106	Hardpan and clay, 120 feet; sand and gravel at bottom.
School house sec. 9, T. 45 N., R. 12 W.	850	192	Largely through sandy drift.
J. Templeton, sec. 10, T. 45 N., R. 12 W.	850	196	Do.
A. Carlson, sec. 10, T. 45 N., R. 12 W.	850	150	Do.
J. Hunter, sec. 9, T. 45 N., R. 12 W.	740	103	Red clay, 40 feet; sandy slush to gravel at bottom. Flowing well.
A. Pentland, sec. 10, T. 45 N., R. 12 W.	740	103	Largely red clay to sand at 90 feet. Flowing well.
J. Swanson, sec. 2, T. 45 N., R. 12 W.	750	84	Entirely through sand. Flowing well.
J. Peterson, sec. 11, T. 45 N., R. 12 W.	740	53	Mainly red clay to sandy slush at bottom. Flowing well.
About 3 miles southeast of Newberry	860	170	Well at a wood camp penetrated sandy drift 100 feet; blue hardpan, 65 feet; sand, 5 feet.
McMillan (at schoolhouse)	785	80	Water from sand under clay.
Helmer post office, by Manistique Lake	705	70	Water from gravel below clay. Flowing well.
Schoolhouse, sec. 29, T. 45 N., R. 12 W.	775	96	Limestone at 40 feet.
Charles McKenna, sec. 29, T. 45 N., R. 12 W.	765	86	Do.
Jerry Holland, sec. 30, T. 45 N., R. 12 W.	730	85	Limestone at 18 feet.
J. Richards, sec. 21, T. 45 N., R. 12 W.	775	76	Rock at bottom.
Mr. Stafford, west of Manistique Lake	770	80	No rock struck.
Blaney, Wm. Mueller Lumber Co.	750	214	Drift 113 feet, shale 101 feet. Drift was as follows: Clay loam and sand, 15 feet; quicksand, 26 feet; gravel, 4 feet; blue clay with sand streaks, 65 feet.

On the long stretch of moraine between Iroquois Point and Manistique River the only notable amounts of clay or clayey till are found either on the inner border or in a few townships in southwestern Luce County, northwestern Mackinac County, and eastern Schoolcraft County. The clay on the inner border beneath swamps is reported to have very few pebbles. It is commonly red at the surface but is said to become blue in some places at considerable depth. The red color may be due to the incorporation of material from the red layers of sandstone. The red color is pronounced in the vicinity of Manistique and Whitefish Lakes and westward to Manistique River. Considerable coarse material is incorporated with the sandy material that forms the great bulk of the moraine, which should be classed ordinarily as a sandy till rather than as assorted material (sand and gravel). Boulders are not usually conspicuous on the surface either between Point Iroquois and Manistique River or west of the Manistique Swamp. There are places, however, where cobblestones from 4 to 10 inches in diameter abound.

In the Hiawatha Settlement, north of Manistique, the hardwood tracts are in places thickly strewn with cobblestones, and small boulders are not rare. Cobblestones are very numerous also on a table-land east of Scotts Camp, in the southern part of T. 45 N., R. 17 W. The ridges in western Schoolcraft County and southern Alger County are only in places thickly strewn with boulders.

The most extensive farming district on this moraine is found in the tract of clayey till in southwestern Luce County, northwestern Mackinac County, and eastern Schoolcraft County, though a fair-sized area has been developed in the Hiawatha Settlement, and there are some good farms on the inner slope of the moraine in the vicinity of Newberry. In all these farming districts, except the Hiawatha Settlement, there is more or less clay, but the soil in that settlement is a gravelly loam.

MORAINES NORTH OF THE MANISTIQUE AND TAQUAMENAW SWAMPS

There is a strong morainic system north of the Manistique and Taquamenaw Swamps which is combined with the one south of these swamps from the east end of the swamp near Strong station eastward to Iroquois Point. It runs westward along the north side of the Taquamenaw Swamp through Luce County and the north side of the Manistique Swamp in Alger County and northern Schoolcraft County. It continues westward about to the meridian of Munising and then swings around to the south on the east side of the Au Train-Whitefish Valley and dies out about 3 miles north of the Alger-Delta county line. Its general width from Munising eastward is 5 or 6 miles, but here and there it expands to 10 miles or more. It lies near the Lake Superior shore from Munising to Grand Marais, but in the part between Grand Marais and Emerson the inner border of the main moraine is 5 to 10 miles from the shore and a small inner member fills part of the space between it and the lake. Eastward from Emerson it again borders the lake shore closely.

In the portion of the moraine east of Munising the crest generally stands not far from 900 feet above sea level but ranges from less than 800 feet up to about 1,000 feet. Along the inner slope, on the south shore of Whitefish Bay, the morainic contours extend down within 50 feet of the Lake Superior level, or 650 feet above the sea, but farther west they rarely reach so low a level, and the inner border is generally at an altitude between 700 and 800 feet. The outer border is only 700 to 720 feet above sea level in the lowest part of Taquamenaw Swamp but reaches about 840 feet near Strong station, at the point of divergence from the outer morainic belt. The altitude is still higher along the outer border in the Manistique drainage basin, being usually not far from 900 feet. The edge next an outwash apron south of Munising stands at 1,000 to 1,020 feet for a few miles, but it falls to about 850 feet at the border of the Whitefish Valley.

This morainic belt, like the outer one, has a rolling surface, with numerous basins inclosed among the knolls. The larger basins contain lakes or swamps, but many of the smaller ones are dry, the water table being below the level of their bottoms. The most prominent knolls rise 100 feet or more above neighboring sags and basins, and a height of 40 to 60 feet is common along the moraine from Iroquois Point to Au Train River. The prominent knolls occur commonly in clusters, which tower above neighboring parts of the moraine. Although the moraine is several miles wide, it does not seem to admit of separation into two or more constituent ridges but is a great and intricate mass of rolling drift.

The portion of this moraine east of Munising is composed very largely of sandy till, the clayey till and laminated clay being almost entirely confined to its inner border and present even there only in a few places. Indeed, the writer observed clayey till in only two localities, one between Taquamenaw River and Salt Point, west and south of Emerson, and the other in the vicinity of Munising. Clayey till occurs on the inner border of the moraine east of Munising, and a laminated clay near Hallston, south of Munising. It is not unlikely, however, that clayey till occurs elsewhere along the moraine at points not found by the writer.

In the district east of Au Train River the drift has considerable thickness except on the border of Lake Superior along the Pictured Rocks, or for 18 to 20 miles northeast from Munising. Thin drift is present north of the moraine on Train Point, west of Munising, and also on Grand Island, north of Munising.

The only rock outcrops east of Grand Marais appear to be those along Taquamenaw River between the upper and lower falls, near the line between Luce and Chippewa Counties. There are a few small outcrops near Grand Marais, but none of much consequence occur east of the Pictured Rocks, whose east end is in T. 48 N., R. 17 W. Outcrops are nearly continuous along the Lake Superior shore from this township westward to T. 43 N., R. 23 W.

But few well records were obtained along this moraine. A well at Stillman station, on the Munising, Marquette & Northeastern Railway, is 90 feet in depth. It penetrated some clayey hardpan, but at the surface there is a sandy drift. The soil in this region is clay loam, and the well is thought to have penetrated some clay as well as sand. A well at Robert Gogarn's farm, about 2 miles northeast of Munising, in sec. 6, T. 46 N., R. 18 W., is about 20 feet deep. It is only half a mile from the shore of Lake Superior and about 135 feet higher. A well in sec. 33, T. 47 N., R. 18 W., put down by Henry Russell, of Munising, entered rock at only 12 feet, though at an altitude more than 200 feet above Lake Superior. A well near the outer border of the moraine east of Mud Lake, in sec. 31, T. 45 N., R. 20 W., is 72 feet deep and is entirely in sandy drift. Two miles farther south, on slightly lower ground, rock was struck at 20 feet. A well at a lumber camp on the outwash apron south of Wetmore, in sec. 36, T. 46 N., R. 19 W., is 104 feet deep and is entirely in sandy drift. The altitude is about 965 feet above sea level.

From Iroquois Point southwestward nearly to Trout Lake a plain of sandy gravel lies along the southeast border of this morainic system. It is 880 to 930 feet above sea level next to the moraine but slopes rapidly to the southeast.

From its point of separation from the outer morainic belt near Strong station westward as far as the meridian of Newberry there is a swamp on the immediate outer border of this moraine. An outwash apron of gravelly sand appears in a recess of the moraine 6 to 12 miles west of the meridian of Newberry, chiefly in T. 47 N., R. 11 W., but extending southward into T. 46 N., R. 11 W. This outwash apron appears to have been built in successive steps from south to north as the ice border receded, there being more than one plain of filling. The ice contact at the north edge of each plain is marked by a low blufflike rise, the northern edge of each plain being a little higher than the southern edge of the next one and being trenched in places by the passage of streams across it from the next later plain.

West of this outwash apron a morainic spur extends as far south as the southern edge of the apron, and from both there is a steep descent over a bluff to the Taquamenaw Swamp, which is there only 2 or 3 miles wide and was traversed by a strait of Lake Algonquin.

West of this spur, on the west edge of Luce County, an outwash apron of gravelly sand sets in which borders the moraine entirely across the north end of Schoolcraft County, though broken up more or less by swamps at the west in T. 47 N., R. 16 W. The outwash apron extends southward from the moraine for several miles and gradually drops down to the marsh drained by Manistique River and its tributaries.

For the next 18 or 20 miles, or nearly to the meridian of Munising, swamps are conspicuous on the outer border of the moraine, and dry sandy plains are of very slight extent. But about 2 miles east of Wetmore, or 5 miles southeast of Munising, there is a high outwash apron of gravelly sand with an abrupt border on the east, next to the swamp, having a relief of 100 feet or more. From this point west and south to the Whitefish Valley there is a continuous outwash apron. The absence of the filling of outwash in the district to the east may be attributable to the ponded condition along that part of the ice border. The parts where outwash plains occur were high enough to stand above Lake Algonquin or were very close to the upper level of the Algonquin waters.

In the district west of the Au Train-Whitefish Valley there does not appear to be a definite morainic belt in continuation of the one under discussion. Most of the surface is gently undulating, like ground moraine. In a few places groups of sharp knolls are present, but these do not seem to line up into a definite morainic belt. It seems likely, therefore, that in the district west of the Au Train-Whitefish Valley the ice border did not hold any position long enough to build up a definite moraine. The drift is very thin in the part covered by the waters of Lake Algonquin from Au Train River westward about to Chocolate River. This is a strip from 6 to 10 miles in width next to the Lake Superior shore. In places the surface is strewn with slabs of the local rock formations in such numbers as to render the soil difficult to till. There are, however, small farming settlements on this lake-washed land where conditions for cultivation are better.

In the district east of Grand Marais there is a rather weak moraine which farther west is combined with the stronger one but which is here separated from it by a space of 2 to 6 miles. It runs eastward across northern Luce County and comes out to the Lake Superior shore near the Luce-Chippewa county line. Its width is 1 to 2 miles and its inner border is only 1 to 4 miles back from the shore of Lake Superior. Its altitude is 75 to 150 feet above the level of Lake Superior, and it stands 15 to 30 feet above the plain at its south edge. The plain, however, rises southward within a short distance to an altitude higher than any part of the moraine. This moraine has a subdued swell and sag topography, and there are very few basins on it. It carries more boulders than are commonly present on the bordering plains. It is on the whole very loose textured. The more clayey parts of the moraine carry maple and other hardwood forest; the lighter or sandy parts are timbered with pine.

The trend of this moraine compared with that of the strong moraine outside of it suggests a northwestward recession of the ice border from the southeast end of Lake Superior. It is the latest moraine developed in the district under investigation, and the further history of the ice retreat must be looked for in Canadian territory. It is probable that a study of the eastern shore of Lake Superior will throw considerable light upon the method of retreat of the ice from the Lake Superior Basin.

THE LAKE FEATURES

PREDECESSORS OF GLACIAL LAKE DULUTH

In the course of the melting and shrinking of the Superior lobe within the area that now drains to Lake Superior water became ponded along the ice border in several independent small lakes, to which names have been applied that correspond usually to the drainage districts in which they stood. Thus glacial Lake Nemadji occupied much of the headwater part of the Nemadji River drainage basin, glacial Lake Brule occupied a part of the Brule River drainage basin, and glacial Lake Ontonagon part of the Ontonagon River drainage basin. These lakes were all in the district west of the Keweenaw Peninsula. East of that peninsula the ice drained to the basins of Green Bay or Lake Michigan along the glacial drainage channels noted above in the description of the moraines of the western part of the northern peninsula of Michigan. Glacial Lake Duluth, however, extended a few miles farther east than the Keweenaw Peninsula, to the border of the Huron Mountains, east of Keweenaw Bay. In the early part of the recession of the ice front Lake Duluth, with an outlet from the Brule River Valley through the St. Croix River Valley, was present in the western part of the Lake Superior Basin. A little later the ice border retreated sufficiently to allow the small independent lakes to become a part of Lake Duluth or to be drained by the lowering of the water level, for in general the water level was lowered as these lakes became merged with Lake Duluth.

GLACIAL LAKE ST. LOUIS

One of the bordering lakes was present when the Superior ice lobe was at its full extent. It stood in the part of the St. Louis River drainage basin northwest of the border of the Superior lobe. (See pl. 2.) It was held between that ice lobe and the Keewatin ice that came in from the northwest to a position a little to the east of Mississippi River. This lake was briefly described by N. H. Winchell,[8] and its highest stage was named Lake Upham and a lower stage Lake St. Louis. As it preceded the other small lakes on the border of the Superior ice lobe, it will be discussed first.

This lake, which occupied the central part of the St. Louis River drainage basin, was thought by Winchell to have had at its highest stage a westward discharge to the Mississippi and at a lower stage a discharge down the St. Louis Valley to Scanlon, Minn., where it came to the ice edge and was deflected southwestward in a course along or near the edge of the ice lobe into tributaries of St. Croix River. Winchell had no idea that at the highest stage of this lake the Keewatin ice from the northwest was still occupying the Mississippi Valley along the west side of the lake, and so he assumed that there was free discharge from the lake to the Mississippi. It is a question, therefore, whether two names are neccessary and whether the early and highest stage of the lake should be called Lake Upham. The name Lake St. Louis is self-explanatory and seems in every way suitable for all stages.[9] There is still some uncertainty as to the course of drainage while the ice border retreated to a position in which the outlet could take the course past Scanlon, above noted. It is likely to have been through some of the many swampy depressions along or near the edge of the ice lobe in southern St. Louis County and neighboring parts of Carlton and Aitkin Counties. Data are not available as to the relative altitude of these swamps, and the course of the drainage may remain unsettled until such data are available.

The head of the outlet that leads down St. Louis River is near Mirbat, about 3 miles below Floodwood. A well-defined beach comes to this outlet from the west along the south side of East Savanna River. Its altitude is about 1,275 feet above sea level. This is nearly as high as the divide between East Savanna and West Savanna Rivers at the place where Winchell supposed the lake had a westward discharge. A survey for a canal from St. Louis River to the Mississippi crossed this divide at an altitude of 1,282 feet.[10] This does not give quite so low a passage across the divide as is found along the line of the railroad that runs from Swan River station on the Great Northern Railway southwestward to the Mississippi at Jacobson, the summit there being about 1,275 feet above sea level. There may be places on the divide with still lower altitudes. The divide is occupied by a great muskeg swamp, which so far as the writer is aware has not been surveyed except along the two lines just noted. West of the divide there is a complex system of glacial knolls and ridges, many of which rise to a greater height than the divide, but among them are low tracts through which water now drains from the western part of the muskeg swamp westward to the Mississippi. The east front of the Keewatin ice is thought to have been standing near these ridges while the glacial lake was forming its beach south of the East Savanna and to have persisted during the recession of the west front of the Superior ice lobe to Scanlon and the opening of the St. Louis Valley outlet.

Differential uplift has raised the northern part of the district covered by this glacial lake to more than 1,300 feet above sea level. There may be some significance in the fact that a change from silt to sand occurs on

[8] Glacial lakes of Minnesota: Geol. Soc. America Bull., vol. 12, pp. 109-128, 1901.

[9] The writer and Sardeson have used the name Lake Upham for the most expanded stage in their discussion of the features of this lake in Bulletin 13 of the Minnesota Geological Survey. This was done because the water body had an extent similar to Winchell's conceptions, whereas Lake St. Louis, as conceived by Winchell, was much smaller water body.

[10] 54th Cong., H. Doc. 330, p. 13, 1896.

that border at about 1,300 feet. It is thought that the sand may indicate only a shallow depth of water. The silt, on the other hand, seems to have been laid down in deeper water, where waves and currents did not have a disturbing influence. The banks of streams traversing this old lake bed show thick deposits of nearly pebbleless silt. Silt-laden water may have come partly from the neighboring ice sheet on the west. Probably there was also a large amount of silt brought down St. Louis River from a great recess in the ice at the headwaters of its drainage basin. The lake became so filled with silt that it was very shallow in the final stage of its history. Only a few feet of deepening in the outlet would have been required to drain it completely. It is therefore an open question whether the lake persisted long enough for the ice barrier at the west to have given way and thus opened a passage into the Mississippi.

It has not been feasible to trace the shore of this lake in the district east of St. Louis River or, indeed, anywhere except for the few miles along the south side of East Savanna River, for that is the only place on the whole circuit of the shore of the lake where the country has been cleared and drained. The northward differential uplift suggested above is an inference from the observed northward rise of the shore lines of glacial Lake Aitkin, in the Mississippi Valley (pl. 2), as well as of glacial Lake Duluth, in the neighboring part of the Lake Superior Basin.

The outlet stream followed down the course of the present St. Louis River to Scanlon, near Carlton. But there it was turned aside by the front of the Superior ice lobe, took a southward course to Kettle River, in northern Pine County, and followed down that stream to the St. Croix and thence to the Mississippi. After turning away from the St Louis Valley the outlet soon crossed the present divide between the Great Lakes and Mississippi drainage systems. This crossing was near Atkinson, at an altitude of 1,170 feet, or about 100 feet lower than the head of the outlet near Floodwood. Later, when the border of the Superior ice lobe had been melted back to the line of the Thomson moraine, a slightly lower passage became available south of Atkinson between the Thomson and Cloquet moraines. This was stated by N. H. Winchell[11] to be 1,125 feet above sea level at the divide. Still later there was discharge to a small marginal glacial lake in the Lake Superior Basin at Wrenshall. A thick deposit of calcareous clay in the vicinity of Wrenshall may have been brought in by drainage from the Keewatin ice and its calcareous drift.

The bed of the outlet in its course along St. Louis River is one-third of a mile or less in width and has the appearance of a scourway, for in places it is literally paved with boulders. On leaving St. Louis River at Scanlon the stream entered a line of glacial drainage in which deposits of sand and gravel had been laid down. It cut into these deposits and near Barnum reached the underlying rock at an altitude of about 1,100 feet above sea level.

[11] Geology of Minnesota, vol. 4, p. 19, 1899.

GLACIAL LAKE NEMADJI

In his report on Carlton County in volume 4 of the "Geology of Minnesota" Winchell called attention to the channel that leads westward from the west end of the Lake Superior Basin to Moose Lake, where it joined the outlet of Lake St. Louis. Later he applied the name Lake Nemadji to the small body of water that stood between the receding ice border and the head of this outlet, for its bed is now largely drained by Nemadji River.[12] The head of the outlet is about 1,070 feet above sea level, and there is a moderate fall in the 5 miles to Moose Lake, where it joins the Lake St. Louis outlet. The width of the outlet averages only about one-sixth of a mile and where greatest is scarcely one-fourth of a mile. The channel was cut to a depth of 10 to 20 feet. The small size of the outlet indicates that the lake which discharged through it was rather small.

The Thomson moraine marks the position held by the ice edge for a considerable part of the time when this outlet was in operation. The area of the lake bed outside this moraine is only about 20 square miles. The part of the melting ice lobe that discharged into this lake may also have been very small. A few miles to the east of the Moose Lake outlet the Brule-St. Croix outlet received the discharge from the ice border. It is probable that the transfer of the entire drainage of the west end of the Lake Superior Basin to the Brule-St. Croix outlet and the beginning of Lake Duluth did not take place until after the Fond du Lac moraine had been formed and the ice edge began to recede from its inner slope. In that case the area of Lake Nemadji may have reached a maximum of about 50 square miles.

The part of the lake bed outside the Thomson moraine is nearly all coated with a thin deposit of fine sand and there is sand on part of the bed between the Thomson and Fond du Lac moraines. It is thus in contrast with the district inside the Fond du Lac moraine, which has a stiff red-clay soil with only a few small sand-covered spots. This sand was probably laid down in part as outwash from the ice, though some was due to wave action on the shores of the lake.

Lake Nemadji formed a well-defined sandy beach along its northwest shore, which traverses a farming district and is thus open to study. In places there are two small ridges, the inner 5 to 10 feet below the outer. The south shore, on which there has been very little clearing of forest and brush, can not be followed so readily. It was possible to determine the lake border easily, however, by the abrupt change to strong

[12] Geol. Soc. America Bull., vol. 12, p. 121, 1901.

moraine. The lake seems to have cut into the morainic ridges in places and thus formed steep bluffs 20 feet or more in height. These cuts, as well as the well-defined beaches of the northwest shore, indicate that the lake endured for a considerable time.

GLACIAL LAKE BRULE

There was a small lake in the part of the Brule River drainage basin south of the copper range that seems to have preceded Lake Duluth and used the outlet to the St. Croix Valley before the waters of the larger lake had been turned into this outlet. The ice at this time was resting on the copper range in eastern Douglas County, Wis., and also covering the northern part of the Bayfield Peninsula in Bayfield County. Lake Brule received not only the waters escaping directly from the part of the ice border crossing its drainage basin but also the discharge from the melting ice for many miles to the east, probably from as far as Baraga County, Mich. It is not improbable, therefore, that the outlet was measurably deepened by this discharge before the waters of Lake Duluth began their work.

Lake Brule covered an area of about 20 square miles between the copper range and the Duluth, South Shore & Atlantic Railway. A large part of this lake bed is swamp land, but drift hills occur in and around the swamps and give the impression of roughness of surface that at first seems inconsistent with a lake bed. Some of the hills were completely submerged, so that no wave work was done on them. Others stood a little above lake level and bear marks of wave cutting on the slopes. A conspicuous hill of this sort is to be seen east of Brule River south of the village of Brule. Traces of lake action reach there an altitude of 1,125 to 1,130 feet above sea level as determined by a line of hand levels run from the railway near by. Evidence of a similar altitude was found in the northwestern part of the lake bed in the vicinity of Bellwood and Blueberry stations. Lake deposits are inconspicuous on the borders of this little lake basin. The silt seems to have settled in its deeper part along Brule River at a level 100 feet or more below the highest shore. The features of the Brule outlet are taken up in the discussion of Lake Duluth. The head is near the line of the Duluth, South Shore & Atlantic Railway, although the present divide between the Great Lakes and Mississippi drainage basins is some 14 miles to the southwest, or immediately north of upper St. Croix Lake. The open waters of Lake Duluth had their southern limit 6 miles farther north, where Brule River breaks through the copper range, or about 20 miles by direct line northeast from the present divide. (See fig. 7.)

GLACIAL LAKE ASHLAND

Glacial Lake Ashland occupied several townships in northwestern Ashland County, Wis., and extended west in Bayfield County to the eastern slope of the Bayfield Peninsula. It discharged across the peninsula along the line of the Duluth, South Shore & Atlantic Railway as far as Pike Lake and then took a westward course to Muskeg, passing south of Iron River village. From Muskeg it followed the course of the Northern Pacific Railway westward into the Brule Valley.

The highest shore line is crossed about 3 miles north of Mellen by the Soo Line. It has a storm beach at 1,128 feet above sea level and an ordinary beach at 1,123 feet. The head of the outlet at Pike Lake is at very nearly the same altitude, being about 1,125 feet above sea level on a terrace and 1,110 to 1,115 feet in a narrower channel cut into the terrace. The valley, including the terrace, is about one-third of a mile wide, and between Pike Lake and Iron River the valley is in places nearly 50 feet deep. The deeper inner channel is scarcely half as wide as the outer channel. It is not entirely certain that the lake outlet excavated the broader channel, for that may have been cut by glacial drainage while the ice border was pressing against the eastern slope of the peninsula close to the head of the outlet. Moreover, the smaller channel seems consistent with the small size of the lake.

The limits of the lake on the northeast seem to have been at a moraine that runs northward to the Lake Superior shore at Clinton Point, about 18 miles east of Ashland. The ice seems to have covered the Bayfield Peninsula about as far south as the ridge west of the fish hatchery, 3 to 4 miles southwest of Bayfield, and to have stood at the north edge of the sandy pine plain or outwash apron in the northern part of T. 49 N., R. 6 W., and the southwestern part of T. 50 N., R. 5 W. It appears to have held its position here long enough for a marked deepening of the Brule-St. Croix outlet, for the highest beach formed to the north of the moraine above noted is lower than the highest one in the Lake Ashland and Lake Brule areas. It is about 1,115 feet above sea level at Saxon, Wis., or 8 feet lower than at Coria, on the south side of Lake Ashland. This figure, however, does not measure the full amount of difference in lake level, for this district has been subjected to northward differential uplift. Saxon is about 15 miles northeast of Coria, and the uplift in that direction is likely to be not less than 15 feet, for in the 40 miles from Saxon northeast to the Porcupine Mountains it amounts to 48 feet, or from 1,115 to 1,163 feet above sea level. It is probable, therefore, that the Brule-St. Croix outlet was deepened about 20 feet while Lake Ashland was an independent lake.

The bed of Lake Ashland consists very largely of red clay. There is a sandy coating in parts of the border of the lake at levels a little below the highest beach. The soil on glacial ridges in the lake is also of looser texture than that on the plains between them. It is doubtful if this red clay was wholly the deposit of Lake Ashland and its successor, Lake Duluth. It may be glacial in large part and may even be older than the latest ice invasion, though this is an open question. Lake Ashland gave place to Lake Duluth when the ice had receded from the Bayfield Peninsula far enough to open water communication there.

GLACIAL LAKE ONTONAGON

Glacial Lake Ontonagon occupied much of the Ontonagon drainage basin in the northern peninsula of Michigan south of the copper range, the position of the ice border for a considerable part of its existence being along the copper range. The south shore is easily traceable across northeastern Gogebic County, southern Ontonagon County, and southern Houghton County. This shore is about 1,320 feet above sea level at the west end of the lake and 1,335 to 1,340 feet at the east end; the greater height at the east is due to the eastward component of the differential uplift. As the north shore was an ice wall, there is no record preserved to give a measure of the northward component of the uplift, but it is greater than the westward component, for the direction of tilting was about south-southwest. It is not improbable that the ice sheet had some attraction and raised the lake waters higher at the east end of the lake than at the west end, for the east end of the lake extended into a recess in the ice sheet where it was bordered by thicker ice.

Over the bed of this lake there is generally a thin coating of fine loamy material on a red clayey till. In the eastern part of the lake bed from Trout Creek village northward to Pori there are sandy deposits, and at its northeastern limits, in southern Houghton County, there is a gravel plain which extends from Frost Junction to Sidnaw. This great gravel plain seems to have been formed as an outwash from the ice into the edge of this lake. There are high rolling tracts within this lake area that rose about to the level of the surface of the lake. They have a looser-textured soil than the bordering plane tracts.

The outlet of this lake is a small shallow channel one-eighth to one-fourth mile wide and 20 to 40 feet deep. The outflow crossed from Gogebic Lake to the Presque Isle River Valley near the line of the Duluth, South Shore & Atlantic Railway. It then followed the course of the present river northward a few miles but was turned back southward in a sharp loop by the ice front and came to the line of the railroad again a short distance west of Thomaston. From this point the railroad runs in the outlet channel much of the way westward to Saxon, Wis. The fall in the outlet is rapid, being 200 feet in 40 miles from Gogebic Lake to the Wisconsin State line. The fall is not uniform, stretches of gentle gradient alternating with those of steep gradient, but precise data as to the differences in the rate of fall have not been obtained. The fall is especially rapid from the meridian of Thomaston westward to North Bessemer, being about 100 feet in 6 miles (from 1,270 to 1,170 feet above sea level).

The ice border was only a few miles north of this outlet, probably at a moraine that lies within 2 to 5 miles of the shore of Lake Superior from the Porcupine Mountains westward to Clinton Point in Wisconsin. In that case Lake Ontonagon was a contemporary of Lake Ashland, and its outlet led to Lake Ashland in the northwestern part of Iron County, Wis. The Brule outlet received at this time not only the drainage from land areas tributary to Lake Ashland and Lake Ontonagon and the lake areas themselves but also the waters coming from the melting ice front from the Keweenaw Peninsula westward past the Bayfield Peninsula.

From Baraga County eastward the waters from the melting ice were discharged toward the Lake Michigan Basin into Lake Chicago down to the time when the waters of Lake Duluth were admitted to the district bordering Keweenaw Bay. In Marquette County there was ice-border drainage southward to the Lake Michigan Basin down to the time of the greatest expansion of Lake Duluth. Lake Chicago, however, appears to have given place to Lake Algonquin before the waters of Lake Duluth were drawn down to the Algonquin level.

GLACIAL LAKE DULUTH

LIMITS OF THE LAKE

The lake which had been discussed by Upham[13] as the "Western Superior Glacial Lake" was later, through a suggestion of F. B. Taylor,[14] named Lake Duluth. Its beaches are especially prominent in the city of Duluth and have long been recognized as old shores. As already indicated, it was preceded by a string of small lakes on the border of the Superior ice lobe. With the shrinking of the ice lobe these independent lakes became confluent at a level in harmony with the outlet to the St. Croix Valley. It is probable that several small glacial lakes, Nemadji, Ashland, and Ontonagon, became lowered to the level of Lake Brule and its outlet in the order named. In Lake Nemadji and Lake Ashland the lowering was very slight, probably somewhat less than 20 feet. But Lake Ontonagon was lowered nearly 200 feet and much of its bed became a land surface. Narrow bays of Lake Duluth, however, extended a few miles up each of the tributaries of Ontonagon River south of the copper range.

On the north side of the Lake Superior Basin Lake Duluth extended eastward step by step with the recession of the ice border. This recession seems to have

[13] Upham, Warren, Minnesota Geol. Survey Twenty-second Ann. Rept., pp. 54–66, 1894.

[14] A short history of the Great Lakes, in Dryer, C. R., Studies in Indiana geography, 1st ser., p. 10, fig. 1, 1897.

taken so long a time that the outlet became materially deepened. As a result the highest beach of the eastern part of the north shore does not correspond with the highest beach of the western part but is the continuation of one of the lower beaches. The same is true of the beaches on the south shore, the highest beach in Michigan being too young and too low to be correlated with the highest beach west of the Bayfield Peninsula. In the present state of the country, with few roads and much of the surface still in brush, it has not been feasible to map in detail each of the higher shore lines and clear up its relation to the moraines. But there seems no question that a correlation such as has been worked out on other glacial lakes will some day be established here.

The eastern limits of Lake Duluth on the south shore have been found to be at the Huron Mountains, in northwestern Marquette County, Mich. When the ice melted away from the northern and eastern slopes of these mountains border drainage channels were opened, which took not only the discharge from the melting ice but also the waters of Lake Duluth and carried them into the Lake Michigan Basin. Lake Duluth was thus lowered step by step as lower and lower lines of border drainage were opened by continued recession of the ice border. Eventually the waters were lowered to the level of Lake Algonquin, and that body of water occupied the western part of the Lake Superior Basin as well as the basins of Lake Michigan and Lake Huron and finally the eastern part of the Lake Superior Basin. The eastern limits of Lake Duluth on the north coast of Lake Superior have not been determined. It is known, however, that the lake extended at least to the Kaministikwia River Basin back of Fort William, Ontario, and it may have extended considerably farther. It is probable that there was a protrusion of the ice into Keweenaw Bay at the time of greatest expansion of Lake Duluth, and the east end of the Keweenaw Peninsula may have been beneath the ice down to the time the Lake Duluth waters were drained eastward. (See fig. 7.) This idea was suggested by observations on the southeastern slope of the peninsula near Gratiot Lake, where the moraines fail to show strong lake action at the high levels at which it is displayed around Calumet, a few miles to the west. Whether the ice protruded into the lake between the Keweenaw Peninsula and Isle Royal or between Isle Royal and the Canadian shore depends upon the amount of iceberg formation that took place. The depth of water was in places more than 1,000 feet, or sufficient to favor the breaking off of icebergs. Whether the ice persisted on Isle Royal to the end of Lake Duluth time is not known. No part of the island rises high enough to record Lake Duluth shore lines.

BEACHES NEAR THE OUTLET

Lake Duluth formed several beaches in the vicinity of its outlet in Douglas County, Wis., which show little or no splitting of beaches as a result of differential uplift. These beaches, therefore, owe their difference in level mainly to the deepening of the outlet. The altitudes of beaches crossed by the Duluth & Minneapolis branch of the Soo Line in western Douglas County, a few miles west-northwest from the head of the outlet, were determined on the ground with the railroad profile in hand. The upper limit of wave action, with a rather indefinite beach, is 1,100 feet above sea level, and strong gravelly beaches occur at 1,070–1,076, 1,040–1,044, and 1,017–1,022 feet. The floor of the outlet at the present divide north of upper St. Croix Lake in T. 45 N., R. 11 W., is 1,022 feet above sea level as determined by a canal survey by United States Army Engineers.[15] Here the floor has but a thin cover, scarcely 5 feet, of muck and peat. It is evident, therefore, that the beach at 1,017–1,022 feet is the lowest that could have opened into this outlet. It is possible that the faint shore at 1,100 feet is older than Lake Duluth and represents the work of Lake Nemadji. The gravelly beach at 1,070–1,076 feet is evidently the product of Lake Duluth, and this is 50 feet above the bed of the outlet. It is certain, therefore, that the outlet was deepened 40 to 50 feet during the life of Lake Duluth. If the weak shore at 1,100 feet pertains to Lake Duluth the deepening of the outlet was about 75 feet.

The present divide in the outlet is in a part of the channel that was cut in an outwash gravel plain just outside the limits of the outer morainic system of the Superior lobe. The gravel plain was built up to an altitude of about 1,140 feet in the vicinity of this divide north of Upper St. Croix Lake. This is higher than any of the shore work of Lake Duluth or of its small forerunners (if due allowance is made for subsequent differential uplift). Some trenching of the gravel plain, therefore, seems to have preceded the discharge of lake waters across it. Streams flowing direct from the melting ice edge might easily have produced the amount of trenching here displayed. It was not more than 40 feet at the time Lake Brule began its discharge. It may have reached 60 to 65 feet before Lake Brule gave place to Lake Duluth, and it was 110 to 120 feet at the end of the Lake Duluth discharge. There was markedly deeper excavation just south of the present divide in the part of the channel occupied by Upper St. Croix Lake. The bed of this lake is in places only 993 to 995 feet above sea level, and the lake may have been filled to some extent by wash into the basin since the Lake Duluth waters ceased flowing through the channel.

[15] 54th Cong., H. Doc. 330, 1896.

The bed is 18 to 20 feet lower than the floor of the valley immediately south of Upper St. Croix Lake. The overdeepening here is, therefore, at least 20 feet. It occurs at a place where the outlet is only one-fourth to one-third mile wide, or scarcely more than half the usual width. It is but natural, therefore, that the outlet should have been scoured deeply when a stream of such great volume as was discharged by the expanded Lake Duluth was thus restricted.

BEACHES OF THE NORTH SHORE

Around the west end of the Lake Superior Basin there are usually three strong beaches with intervals of about 25 feet between them. They seem to correspond with the three observed on the Soo Line in western Douglas County, Wis. In the central part of the city of Duluth the highest of these beaches is about 1,135 feet above sea level and the lowest is not more than 1,085 feet. The series have an altitude here about 60 feet greater than on the south side of the basin, though the intervening distance is only about 24 miles. There thus appears to have been a northward differential uplift of 2.5 feet to the mile. A weak shore line is found at 1,160 feet above sea level in Duluth, which may be correlated with the weak shore at 1,100 feet on the south side of the basin in western Douglas County.

Near the west line of Lake County, Minn., the Duluth & Northern Minnesota Railroad crosses the highest well-defined beach of Lake Duluth at Higgins station at 1,165 feet above sea level, whereas the lowest of the Duluth series of beaches stands at about 1,110 to 1,115 feet. There is evidence of faint shore action at 1,190 feet. A similar series was noted east of Waldo, but only barometric readings were taken there. The same is true on a line from Beaver Bay westward to Beaver station, where the beaches are present west of a rock range as well as on its eastern slope. This full series does not seem to extend much farther northeast, and probably the highest strong line as well as the faint shore line above it terminated west of the moraine that runs into the Lake Superior Basin in eastern Lake County. To the east of this moraine, in the southwest end of Cook County, a road survey crosses the highest beach at 1,191 feet and one just below it at 1,175 feet. The next definite beach is at 1,126 feet, but it is doubtful if this beach belongs in the series made by the lake that discharged through the Brule-St. Croix outlet. The outlet may thus have been cut within 20 feet of its full depth before the ice had receded to this district east of the moraine.

Definite levels farther east are available on two lines. One is the survey of Poplar River, which reaches the highest shore at about the level of the dam, at 1,224 feet above sea level. The other line was run from Grand Marais by Axel Berglund, surveyor of Cook County, under the writer's direction, and reached the highest shore at 1,275 feet. There are strong gravelly beaches on the line by Grand Marais at 1,250 feet and at 1,206–1,209 feet. Beaches are faint from 1,200 feet down to 1,006 feet, where one thought to be the highest beach of glacial Lake Algonquin occurs. Barometric observations were taken on a prominent hill northwest of Hovland, in sec. 6, T. 62 N., R. 4 E., which made the upper limit of lake action fully 1,300 feet. There were beaches at short intervals on the slope below this level.

Observations were also made with aneroid barometer on McKay Mountain, south of Fort William, Ontario, which indicate lake action up to 1,350 feet above sea level, or about 200 feet below the top of the mountain. A beach was noted near milepost 57 on the Canadian Northern Railway, in the Kaministikwia River Basin, at an altitude of about 1,370 feet, and another west of Shabakwa station at about 1,300 feet, as well as lower beaches that probably pertain to Lake Algonquin. The upper limits of Lake Algonquin here probably reach at least 1,100 feet above sea level. It is probable that the highest beach of Lake Duluth in Cook County, Minn., and in the Kaministikwia Basin in Ontario was formed after the outlet had been cut nearly to its full depth, or to what is now about 1,020 to 1,025 feet above sea level. In that case the amount of differential uplift between the isobase of the head of the outlet near Upper St. Croix Lake and Kaministikwia River is not far from 350 feet. This does not measure the total uplift, for the head of the outlet itself has suffered an uplift of perhaps 250 feet, the precise amount being as yet undetermined.

BEACHES OF THE SOUTH SHORE

At the extreme west end of the lake, in Carlton County, Minn., beaches of Lake Duluth are crossed by the Duluth & Moose Lake branch of the Soo Line at 1,062, 1,052, and 1,027 feet above sea level. The inner slope of the lowest beach drops down rapidly to 1,018 feet, and at that level the sand rests on a clayey till.

At Holyoke the Great Northern Railway profile shows the altitude of the highest beach as about 1,065 feet, with a bluff back of it rising to 1,075 feet. Other beaches are crossed at 1,050 feet and at 1,021–1,025 feet. The next railway to the east is the Soo Line, running south in western Douglas County, Wis. Along this line there is evidence of wave action up to 1,100 feet, but, as noted above, the definite beaches are at 1,070 to 1,076, 1,040 to 1,044, and 1,017 to 1,022 feet. The Duluth & Chicago branch of the Soo Line runs out of the Lake area in Douglas County in a valley, and the limit was not accurately determined. But on the Chicago, St. Paul, Minneapolis & Omaha Railway, which runs only about 2 miles farther east where it leaves the lake area, the upper limit of lake action seems to be at 1,118 feet. As a faint beach at Hines is 1,113 feet above sea level, the limit of 1,118 feet may mark storm levels rather than the ordinary stage. A strong beach at 1,085 feet is crossed by the Northern Pacific Railway at Wiehe, 10 miles farther east. Above this are notches on the slope of a moraine near Maple at 1,106 and 1,128 feet. There are beaches at about 1,060 and 1,040 feet just south of this railroad near Poplar. The Chicago, St. Paul, Minneapolis & Omaha Railway from Ashland to St. Paul crosses the Duluth beaches near Grandview (Pratt post office), Bayfield County, and reaches the highest gravelly beach at 1,080 feet. There are notches higher up, on morainic knolls, at 1,100 and 1,120 feet. In the village of Grandview the Duluth beaches are finely exhibited at 1,055 to 1,060 feet and at 1,075 to 1,080 feet. The Soo Line from Ashland to Milwaukee crossess the Duluth beaches between Highbridge and Coria, Ashland County. These beaches were examined by the writer after the new survey of this line had been made and while the figures that had been painted on posts along the right of way to show the altitudes were still preserved. A beach that is referred to glacial Lake Ashland was noted at 1,123 feet, with a storm beach at 1,128 feet. The highest gravel beach of Lake Duluth is at 1,102 feet and the base of the cut bank back of it at 1,107 feet. A sandy ridge at the southeast end of Coria switch is at 1,091 feet. The next strongly marked shore line below this is at 1,038-1,040 feet near Davis switch. There is a beach at 1,015 feet nearly a mile east of Highbridge, but this seems rather low to belong to the Duluth series. It is, however, well defined. The main street in Highbridge is on a beach ridge at 990 feet. There are no definite beaches between this one and the highest shore line of Lake Algonquin, near South York, at 860 feet, though there are faint shore lines in this interval.

At Bayfield the exhibit of beaches is especially full because of the exposed situation. The highest beach of Lake Duluth, as determined by F. T. Thwaites, who ran a line of spirit levels up to it along the main highway from the Lake Superior shore, is 1,148 feet above sea level. It is a gravelly bar at that place, but usually it is a cut bluff, as are also lower shores. The present writer ran a line of hand levels across the series farther east in private roads and through fields and found the upper limit at 1,153 feet and lower beaches at 1,130, 1,075, 1,055, 1,035, 995, 972, and 915 feet (the last the highest beach of Lake Algonquin). Thwaites noted beaches at 1,148, 1,119, 1,067, 1,042, 1,012, 993, 962, and 915 feet (the last the highest of Lake Algonquin). The error in hand levels is very slight, amounting to less than the variation usually displayed by a single beach. Some lack of correspondence is due to the development of a cut bank in one place at a level where one was not developed in the other.

On the inner or north slope of the moraine north of Saxon, Wis., the highest beach of Lake Duluth is at about 1,115 feet above sea level. There is a second beach at about 1,104 feet. Lower beaches are very indefinite and probably lower than the Brule-St. Croix outlet. In the northern peninsula of Michigan the level of the highest beach has been determined at several points west of the Keweenaw Peninsula, and the topographic maps of the Houghton and Calumet quadrangles serve to show the limits on part of that peninsula. A line of levels by the Michigan Geological Survey in the Porcupine Mountains, as reported by A. C. Lane, makes the highest beach at 1,163 feet in sec. 15, T. 51 N., R. 43 W. The highest beach has the same altitude where crossed by the Chicago, Milwaukee & St. Paul Railway 1 mile south of Pori. An isobase connecting these places trends about N. 74° W., thus making the tilt line N. 16° E. in this part of the Lake Superior Basin. The upper limit of Lake Duluth is somewhat definitely known at Bruce Crossing and Ewen, 1,134 feet; Rockland, 1,178 feet; Greenland, 1,192 feet; Twin Lakes, near the Winona mine, 1,215 feet; the Taylor mine switch, south of L'Anse, 1,215 feet; near Toivola, 1,240 feet; near Mill Mine Junction, 1,250 feet; and on Centennial Hill, in Calumet, 1,305 feet. An isobase for 1,215 feet connecting the Taylor mine switch and Twin Lakes bears N. 58° W., thus giving the tilt line a bearing N. 32° E. This isobase projected across Lake Superior strikes the north shore near Lutzen, where the highest beach is at 1,224 feet. It is also about in harmony with the isobase of the Nipissing Great Lakes for this same district.

In numerous places lower shores of the Lake Duluth series and of the transition to Lake Algonquin are well displayed. It is only in the Calumet and Houghton quadrangles, however, that much effort was made to determine their altitudes. The facts that these beaches have been tilted 2 feet or more to the mile and that shores are found at slightly different altitudes in neighboring places, as shown above in the Bayfield records, make it difficult to establish correlation except by continuous tracing. Such work is impracticable in much of the area because of its brushy condition. In exposed situations, as on the northwest slope of the Keweenaw Peninsula, there is a beach for about every 20-foot interval, and in places the interval is but 10 or 15 feet. But in protected situations there is only here and there a shore feature distinct enough to be easily recognized or followed.

GENERAL CHARACTER OF THE LAKE BED

Wherever the bed of Lake Duluth has a plane surface the prevailing soil is a heavy red clay with few pebbles, covered by remarkably little sand or loose-textured material. The clay is sufficiently calcareous for the development of numerous calcareous nodules, and there are a few limestone pebbles embedded in it. Were there no limestone pebbles the nature of the clay might seem to be due entirely to the precipitation of calcium carbonate from the lake. But their presence indicates that some of it is due to glacial agencies that brought in calcareous material from limestone areas. The source of the limestone pebbles is not fully determined. They may have been brought in wholly or in part from the northwest at a pre-Wisconsin glacial stage. Or they may have been brought in from the James Bay region by a movement in the Illinoian or the Wisconsin stage. There is also a possibility, if not a probability, that some limestone outliers, such as the one west of Baraga in the Keweenaw Basin, were distributed here and there over the region and that they have supplied calcareous material. Chert derived from limestone is a common feature in the drift over nearly the whole of the area bordering Lake Superior on the south. Some of the calcareous material is probably due to the precipitation of calcareous sediment on the lake bed during the period of lake occupancy. On rough areas that were covered by the lake, such as the slopes of the Bayfield and Keweenaw Peninsulas and much of the north shore, the soil is largely stony till, with only a small amount of the red clayey till at the surface. The stony till in places rests on a red clayey till somewhat similar to the red clay in the lake bed. The beaches of Lake Duluth on the entire circuit of the lake are developed on this stony till, the red clayey till generally not being conspicuous above the lowest of the beaches that open into the Brule-St. Croix outlet. For this reason they are gravelly and sandy ridges, with only here and there a cut bank. In very exposed situations, however, as in the Bayfield and Keweenaw Peninsulas, cut banks are common features, and they connect with bars built out into the recesses of the old shore.

At a few places the shores were of bare rock with insufficient drift cover to be shaped by the waves. Such places, however, embrace scarcely 1 per cent of the old coast. It is usually not difficult to trace the limits of lake action across these rock areas by pebbly deposits built in the coves and by the clearing out of earthy material from cracks and openings in the rock surface as a result of wave action. On the whole, the shore records are clear, and it is only because of the brushy condition of the land surface that they have not been traced through continuously.

THE DIFFERENTIAL UPLIFT

The entire area of Lake Duluth was subject to tilting in late Pleistocene time, and it seems probable that the head of the outlet now stands about 250 feet higher than at the time the lake discharged through it. It was hoped that the study would clear up definitely the part of Pleistocene time embraced in this uplift, expressed in terms of lake history, as has been done in the basins of the lower Great Lakes. The complexity of the shore lines of the western part of the Lake Superior Basin, which are coupled partly with the shore lines of the forerunners of Lake Duluth and partly with the recession of the ice step by step while the outlet was in process of deepening, makes it difficult even to set off by themselves the beaches that open into the Brule-St. Croix outlet, much less to determine whether uplift and splitting of beaches had begun before the outlet had shifted to the east. As indicated in the description of the shore lines, the full series of the Lake Duluth features seems not to extend on the north shore to the east edge of Lake County, Minn., and on the south it may not pass around the north end of the Bayfield Peninsula. It seems advisable, therefore, to take only this restricted district into consideration in the first step toward the determination of the tilting of the shore lines. In part of this district the shores of Lake Nemadji have to be separated from those of Lake Duluth.

The uplift of the Lake Duluth beaches on the north shore may be determined by considering the rise of the lowest member as well as the rise of the highest. In some respects the lowest is of chief importance, for it is sure to be related to a definite height of the outlet—namely, the height at the time when it came to be abandoned. The highest shore line is not so easily correlated with a given altitude of the head of the outlet.

If, then, we take the lowest of the Lake Duluth shore lines we find it rising from about 1,022 feet above sea level at the southwest end of the lake in Carlton County, Minn., to about 1,115 feet on the meridian of Two Harbors, near Higgins, in western Lake County, a distance of 55 miles in a direction N. 50° E., or 20.4 inches to the mile. The direction of maximum tilting, however, in the highest well-defined beach in the part of the Lake Superior Basin west of the Bayfield Peninsula seems to be about N. 20° E., or at a right angle with the 1,135-foot isobase connecting Duluth, Minn., and Bena, Wis. (See fig. 8.) In a direction N. 20° E. from the isobase of 1,022 feet in the lowest beach opening into the St. Croix outlet to the 1,115-foot or corresponding beach near Higgins the distance is 44 miles, which makes the rate of tilting 25.63 inches to the mile. The isobase of 1,022 feet, like that of 1,070 feet for the highest beach, runs near the head of the outlet. There is a rise in this lowest beach of 55 feet (to 1,077 feet) in the first 22 miles from the isobase of the outlet to the isobase running from Duluth to Bena, or 30 inches to the mile, and only 38 feet (to 1,115 feet) in the 22 miles from that isobase to Higgins, or 20.73 inches to the mile. From this isobase opposite Higgins to one passing through the beach on the highway west of Schroeder at 1,175 feet there is a rise of 60 feet in 42 miles, or 17 inches to the mile. In Cook County, as shown by Figure 8, the tilt line trends about N. 30° E. From the highway west of Schroeder to Grand Marais on a tilt line of N. 30° E. the rise of 34 feet to 1,209 feet is made in 30 miles, or at a rate of 13.6 inches to the mile.

The highest beach in Cook County, Minn., and that on the part of the northern peninsula of Michigan with corresponding isobases (fig. 8) probably represent one of the intermediate beaches of the west end of the lake basin, but they show a markedly higher rate of rise toward the north-northeast than the lowest Lake Duluth beach in this part of the Lake Superior Basin. Uplift was thus in progress there before the lowest beach was formed. At the highest beach in Cook County, Minn., the rise from the beach at 1,191 feet on the highway west of Schroeder to that on Poplar River is 33 feet in 13.3 miles, or 30 inches to the mile along the course of the beach. The rate would be about 3 feet to the mile if calculated along the tilt line. The rate is nearly as great from Lutsen to Grand Marais and to a hill northwest of Hovland, where the highest beach is about 1,300 feet above sea level by barometric measurement. The available data suggest that the rate of uplift is not so high in the adjacent part of Canada. If the tilting were continued at this rate to the Canadian Pacific Railway the highest beach at the railway should be about 1,450 feet above sea level, but the highest one noted there is at 1,370 feet. The highest beach there may, however, be a lower member of the series than the highest beach in Cook county, for it stands in the direction of the recession of the ice border and may have been covered with ice at the time the highest beach in Cook County was forming.

The amount of the uplift at the head of the Brule-St. Croix outlet is roughly calculated by determining the amount of uplift of the neighboring Lake Algonquin beach. Near the isobase of the Brule outlet the Lake Algonquin beach stands at about 850 feet. The altitude of the Port Huron outlet of Lake Algonquin is 605 feet. The uplift of the Algonquin beach on the isobase of the outlet of Lake Duluth is therefore about 245 feet. The uplift of the head of the Brule-St. Croix outlet is at least that much, and if some uplift took place before the Algonquin beach was formed it is that much more. It is doubtful, however, whether much uplift took place until the time of Lake Algonquin. We may therefore provisionally leave the amount at about 245 feet.

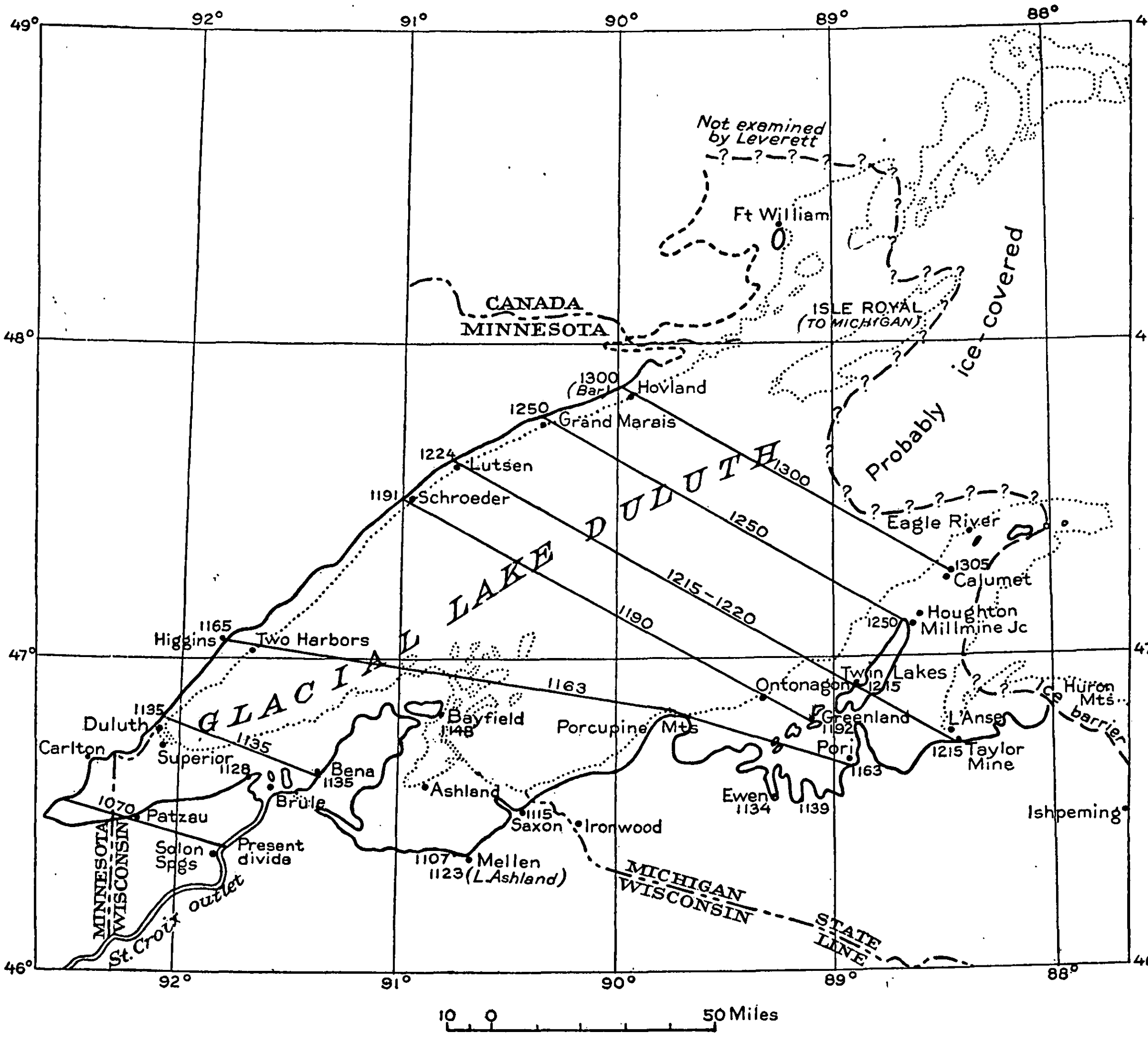


FIGURE 8.—Map showing isobases of the highest beach of glacial Lake Duluth. Figures indicate altitude above sea level.

Deducting this from 1,022 feet, the present altitude of the head of the outlet, we have 777 feet as the altitude of the outlet when it was in operation. It is probable that the uplift affects St. Croix River at least as far down as St. Croix Falls, but with diminishing amount downstream. The river below the falls is now 687 feet above sea level. At the mouth of Trade River, 12 miles upstream, it is at 753 feet. The distance by stream from the outlet of Upper St. Croix Lake to the mouth of Trade River is 101 miles and that from the divide north of the lake is about 105 miles. There may have been only 24 feet of fall in that distance before the uplift occurred. The Kettle River rapids head 33 miles above the mouth of Trade River and now stand 850 feet above sea level. It is not unlikely that a considerable part of the estimated fall of 24 feet took place at these rapids and that the outlet was cut to a very low grade down to that point. The rapids may have been as high as 770 feet, or within 80 feet of their present altitude. By whatever amount the St. Croix Falls have been uplifted the fall of the stream must have been greater than 24 feet. There is now a descent of 15 feet in the 20 miles from the foot of the falls to the mouth of Apple River. This may be largely a result of uplift. If we assume an uplift of 15 feet in 20 miles and extend the estimate up to the mouth of Trade River, 12 miles farther, we have not less than 25 feet of uplift there. In that case the fall would have been 49 feet instead of 24 feet between the head of the outlet and Trade River. This would give room for the rapids at Kettle River to have had some prominence during the operation of the outlet.

On the Keweenaw Peninsula and in Keweenaw Bay and on its eastern border the trend of the tilt line seems to be about N. 30° E. The rate of tilting seems to be somewhat uniform at about 2.7 feet to the mile from Ewen or Bruce Crossing to Calumet, a distance of 63 miles. Intermediate points, such as Greenland, Twin Lakes, and Toivola, fall into the plane almost exactly.

To the west, between the Porcupine Mountains and Keweenaw Peninsula, the tilt line seems to trend about N. 17° E., and it is similar in the district westward from the Porcupine Mountains to the Bayfield Peninsula and as noted above about N. 20° E., between the Bayfield Peninsula and the northwest shore of the lake. The axis of tilting appears to curve toward the south in passing to the southwest end of the basin. Thus the southeast shore appears to have experienced a more rapid rate of uplift than the northwest shore, and the isobases converge in passing from the northwest shore to the southeast, as indicated in Figure 8.

It will be a matter of much interest to determine whether this differential uplift is in correspondence with ice weighting, the greater resilience being where depression by ice weighting was greater. It is very probable that the district northwest of Lake Superior, being at the west edge of the Labrador ice field and at the east edge of the Keewatin ice field, was subject to very slight ice weighting in the part of the Wisconsin stage under discussion, which followed the withdrawal of the Patrician ice sheet. On the other hand, the southeast shore of the lake was subject to converging ice movements and a resulting heaping of ice. The ice was moving southward in the district west of the Keweenaw Peninsula and southwestward to westward in the district east of the peninsula. There is thus enough correspondence between the ice accumulation and the degree of uplift at least to suggest causal relationship.

TRANSITION FROM LAKE DULUTH TO LAKE ALGONQUIN

The strong movement of the ice up the slope to the Huron Mountains and the district to the southeast prevented the lowering of the waters in one single drop to the level of Lake Algonquin. Instead there was at first border drainage at levels but little below the Brule-St. Croix outlet. Lower and lower passages for border drainage were opened from time to time as the ice melted back. But we may infer from the strength of the beaches formed in the western part of the Lake Superior Basin at levels between the Lake Duluth and Lake Algonquin shores and controlled by the level of the heads of border drainage channels that the ice margin may have held a given position for considerable time.

The water reached the Lake Michigan Basin and swelled the lake in that basin. It is probable that at first the water was poured into Lake Chicago, for it is doubtful if the ice had melted away from the district south of the Straits of Mackinac sufficiently to allow the waters of Lake Algonquin of the Lake Huron Basin to become confluent with Lake Chicago and thus initiate the greater Lake Algonquin. Eventually, however, this connection was opened and Lake Algonquin took possession of the Lake Michigan Basin as well as the Lake Huron Basin. The part of the northern peninsula between Lake Michigan and Lake Superior and the eastern part of the Lake Superior Basin were still occupied by the ice when this occurred.

There seems to have been a brief period when the flow from the Lake Superior Basin went southward through the Au Train-Whitefish Valley while the ice was still occupying the part of the south shore of Lake Superior to the east. It is probable that the waters were not brought to the level of Lake Algonquin in the Lake Superior Basin until the withdrawal of the ice from that part of the Lake Superior shore.

The courses of the border drainage channels have been followed for short stretches and crossed at frequent intervals, but a complete tracing has not been attempted. Contour maps and careful leveling in the district traversed by these channels are needed to serve as a basis for definite correlation of channels.

In places near Marquette there are faint shore lines that were formed at levels higher than the Algonquin water plane. One of these at 985 to 990 feet was traced from Dead River in sec. 7, T. 48 N., R. 25 W., southeastward to the Mount Mesnard Range, south of Marquette. Its precise altitude was determined on some knolls in the southern part of section 21 by reference to the United States Geological Survey bench mark near by and found to be 985 feet. The altitude seems to increase slightly toward the north-northwest and to be not less than 990 feet in section 7, where tracing began. The same shore line was noted also north of Dead River, where a road running west in the southern part of section 6 crosses it just below the 1,000-foot level. It can be traced but little farther, as rock hills set in on whose slopes there was scarcely enough drift material to allow the waves to form a beach. The only direction in which the body of water that formed this shore line could have discharged was eastward, and the outlet must have been north of the "Calciferous" escarpment in eastern Marquette County and western Alger County, for the escarpment rises above 1,000 feet. On the Marquette-Alger county line it could not have been farther south than the north edge of secs. 11 and 12, T. 46 N., R. 23 W., or about 6 miles from the shore of Lake Superior. The course was probably eastward from that point across the northern part of T. 46 N., R. 22 W., and thence southeastward into the Au Train-Whitefish lowland to the lake in the Lake Michigan basin. These lake features above the Lake Algonquin plane near Marquette seem to show that the ice was still occupying part of the south shore of Lake Superior farther east. Otherwise the Lake Algonquin water level would have extended to Marquette.

Below the shore line just noted near Marquette there is a slight wave-cut notch near the 940-foot level, but the first strong well-defined shore line in the Marquette quadrangle is 20 feet lower, or near 920 feet. This may be the highest Lake Algonquin beach.

To the east of the Au Train-Whitefish lowland, in the vicinity of Munising and Wetmore, lake features were noted at levels that seem to be higher than the Lake Algonquin plane. Accurate levels were run to these lake features north and south from Wetmore station by L. G. Hornby under the writer's direction. To the south, on the north slope of a table-land known as Scaffold Hill, there seems to have been wave action up to an altitude of 960 feet. This may, however, mark the storm beach, and the low-water level may be represented in a beach 10 or 12 feet lower, or 948 to 950 feet above sea level. North of Wetmore, in section 12, about a mile from the railroad station, a weak gravelly bar was found at 950 feet and another at 946 feet. Gravelly bars at 929 feet, at 903–904 feet, and at 879 feet were crossed in running northward from Wetmore station. The surface has a wave-washed appearance up to fully 950 feet in the district between Wetmore and the Lake Superior shore at Munising. In the southern part of Munising, less than a mile from the shore of Lake Superior, levels run by the Cleveland Cliffs Iron Co., showed that a ridge with an altitude of 966 feet is notched on its north slope about 5 or 6 feet lower, or about 960 feet above sea level. Morainic hills within 1 or 2 miles southwest of Munising rise to fully 1,000 feet and others east and southeast equally near the shore to about 1,000 feet. They are hummocky and irregular from the crests down to an altitude of about 950 or 960 feet, below which the surface is much smoother and seems to have been wave-washed.

The highest points on Grand Island, which stands in the bay north of Munising, are about 950 feet above sea level and consist of nearly bare limestone. The scarcity of drift seems likely to be due to removal by wave action, as the ledges are subject to attack from all directions. A beach of gravelly material is crossed by the Cleveland Cliffs driveway in the northern part of the west shore of the island at an altitude of 885 feet. This fits in well with the altitude of the highest Lake Algonquin beach farther east, whereas the higher beaches just noted seem to be above the Lake Algonquin water plane. A beach at 875 to 880 feet both north and south of Anna River at Wetmore may be the highest one of Lake Algonquin there.

In order to account for a water body being held up to the high level of 950 to 960 feet near Wetmore and Munising, it seems necessary to assume that the ice was still present in the great Manistique Swamp, to the east and southeast. It also seems probable, as already indicated, that the Scaffold Hill table-land stands in a recess in the ice border, the ice having been on the east as well as the north when this table-land was formed as an outwash plain. If the ice on the north disappeared earlier than that on the east the waters would have been ponded where these lake features occur. The most probable line of discharge would have been through the Au Train-Whitefish lowland. This lowland may thus have been a line of discharge for ponded waters over the whole interval from Marquette to Munising. The beach at 985 to 990 feet above sea level in the vicinity of Marquette may pertain to a lake that had a narrow line of discharge between the ice and the "Calciferous" escarpment in eastern Marquette County and western Alger County, with enough fall in this line of discharge to bring it down to the level of a lake at 950 to 960 feet around Munising. Or this lake near Marquette may have slightly antedated the melting of the ice from the Munising region.

GLACIAL LAKE ALGONQUIN

The name Lake Algonquin was first applied by J. W. Spencer [16] to a lake occupying the southern part of

[16] Am. Assoc. Adv. Sci. Proc., vol. 37, p. 199, 1889.

the basin of Lake Huron and the tributary Saginaw Basin. The lake, as shown in Plate 7, discharged southward past Port Huron through St. Clair River, Lake St. Clair, and Detroit River to Lake Erie. The northern part of the Lake Huron Basin and Georgian Bay were still occupied by the ice sheet, and the ice covered the northern part of the southern peninsula of Michigan between this lake and Lake Chicago, in the Lake Michigan Basin. With the melting away of this ice barrier the two water bodies came to the same level. At about the same time the ice front was melted back sufficiently in the Georgian Bay Basin to open an eastward outlet past Kirkfield, Ontario (pl. 7 and fig. 9), and down Trent River to the Lake Ontario Basin, which was somewhat lower than the outlet past Port Huron, but how much lower has not been determined. This change of outlet appears to have drawn down the waters of the Lake Michigan Basin as well as the Lake Huron Basin. The eastward outlet was maintained for a long time, perhaps until the ice had disappeared from the northern peninsula of Michigan and the waters of the western part of the Lake Superior Basin had been brought to the level of the lake in the Huron and Michigan Basins. An uplift that raised this eastward outlet and returned the discharge to the southward outlet appears to have occurred in the midst of the Lake Algonquin stage rather than near its beginning.

The highest shore line of Lake Algonquin to the south of the Kirkfield outlet and its isobase is not the one that opens into that outlet, for this shore became submerged when the tilting raised the water to the level of the Port Huron outlet. The waters to the north of the Kirkfield outlet probably dropped away from the highest shore of that region at the same time they were rising from the Kirkfield outlet to the Port Huron outlet. In the absence of definite data as to the amount of uplift that was necessary to raise the water from the Kirkfield to the Port Huron outlet it is not possible to determine which shore line to the north of the Kirkfield outlet is to be correlated with the beginning of the discharge through the Port Huron outlet.

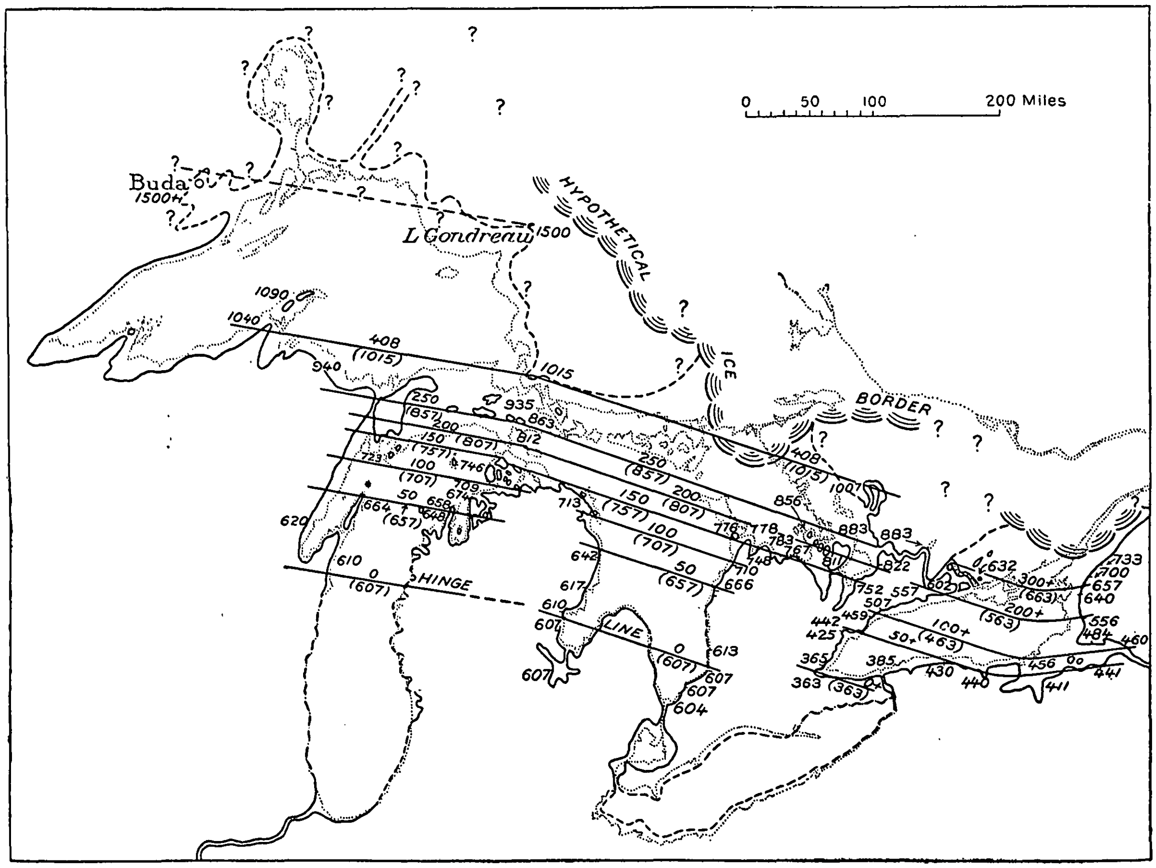


FIGURE 9.—Map showing isobases of glacial Lake Algonquin at its highest stage and isobases of glacial Lake Iroquois as represented by Goldthwait. The figures above the isobases indicate altitude above the horizontal or unaffected part of the beach south of the hinge line; the figures in parentheses below the isobases and the scattered figures elsewhere indicate altitude above sea level.

It is probable that when the waters were raised from the Kirkfield outlet to the level of the Port Huron outlet they were also raised sufficiently at the south end of the Lake Michigan Basin to cause some outflow through the Chicago outlet. The main discharge, however, seems to have been through the Port Huron outlet, and this became deepened to a level below that of the head of the Chicago outlet.

The part of Lake Algonquin in the Lake Huron and Lake Michigan Basins has been discussed in Monograph 53. Attention is therefore given here to the part that encroached upon the northern peninsula of Michigan and the border of the Lake Superior Basin in Michigan, Wisconsin, and Minnesota. There are so few data available on the Lake Algonquin shore lines in the Canadian part of the Lake Superior Basin that it can not be adequately treated at this time. It was shown in Monograph 53 that the Lake Algonquin beach is a single strong line in the Saginaw Basin, in the part of the Lake Huron Basin between the Saginaw Basin and Port Huron, and in the Lake Michigan Basin as far north as Manistee, Mich., and Two Rivers, Wis. North of the Saginaw Basin and the points named in the Lake Michigan Basin the shore features become more and more complex. Within a short distance three or four distinct ridges become traceable, which at first differ but little in altitude but which become more widely separated toward the north and also more numerous. In the northern part of the northern peninsula there are half a dozen or more distinct shore lines, all referable to Lake Algonquin.

At the top of the series are usually two or three ridges that are especially strong and continuous which are separated by intervals of but 5 to 10 feet. Below this strong series the ridges are more widely spaced and usually weaker and less continuous. They appear to have been formed while uplift was going on most rapidly, whereas the ridges at the top were developed before rapid uplift had set in, and their separation may be due in part to the cutting down of the outlet. The lowest member of this upper series may be the one that should be correlated with the single strong beach that leads to the Port Huron outlet and to the Chicago outlet. It seems probable, also, that the western part of the Lake Superior Basin had become connected with Lake Algonquin by the time this strong series was completed. On the whole, the Lake Algonquin beaches in the western part of the Lake Superior Basin are weak and widely spaced, as if they might have been formed during the time of rapid uplift. On the south border of this part of the basin there is a stiff clay on which sandy and gravelly material is very scanty, and the shores there are generally marked by slight notches in the clayey slope. On the north side of the Lake there was a large amount of gravel and cobble to be worked into beaches, and the beaches are more distinct than those on the south shore, yet even there they are in general widely spaced and appear to have been developed while rapid uplift was in progress.

From the west end of the Lake Superior Basin eastward to the Au Train-Whitefish outlet the limits of Lake Algonquin are found to lie only a short distance from the present Lake Superior shore. The lake extended into the Nemadji Basin only about to the Wisconsin-Minnesota State line, or scarcely 20 miles beyond the present head of Lake Superior. Its north shore throughout its course in Minnesota stood but 1 to 3 miles back from the present Lake Superior shore. From Superior, Wis., eastward around the Bayfield Peninsula to Ashland, Wis., the distance of Algonquin limits from the present lake shore ranges from a mile or less at Bayfield up to 6 or 7 miles. In the Bad River drainage basin, southeast of Ashland, the lake reached back in places 18 or 20 miles from Lake Superior. The limits were very close to the Superior shore from the Wisconsin-Michigan line eastward past the Porcupine Mountains. From these mountains northeastward to the Portage Canal the lake limits are 6 to 12 miles back, but from the canal eastward to the end of the peninsula they are closer. The lake covered the entire width of the peninsula at the Portage Channel and also at the Allouez Gap. On the east side of Keweenaw Peninsula the greatest extension was at the head of Keweenaw Bay, where it reached 20 miles to the southwest. From Keweenaw Bay eastward to the Au Train-Whitefish lowland the limits were from 1 to 6 miles back from the Lake Superior shore.

The limits of Lake Algonquin are less definitely known in the uninhabited districts of northeastern Delta County and adjacent parts of Alger and Schoolcraft Counties, Mich., but it is thought that an aggregate area of about 200 square miles in this region may have stood above the Algonquin level. From Munising eastward across eastern Alger County and northern Schoolcraft County into Luce County the amount of land standing above Lake Algonquin has not been determined. In this district there are extensive outwash plains which are slightly below 900 feet at their northern edge, and they may be not far from the Algonquin level.

In Schoocraft, Luce, Mackinac, and Chippewa Counties there was only a few square miles that stood above the level of Lake Algonquin. There were small islands south of McMillan, south of Newberry, between the Hendricks quarry and Rexton, and along the high escarpment in northern Mackinac County and east of Trout Lake in Chippewa County. At the highest stage of Lake Algonquin there may have been an island of considerable extent in the high area south of Whitefish Bay. There certainly was a large island there when the lake level had been lowered a few feet.

The shore lines of Lake Algonquin show a rapid rise northward in the area between the Huron and Michigan Basins and the Lake Superior Basin. Thus the upper limit of lake action on Mackinac Island is at 809 feet above sea level; on St. Joseph Island, at 934 feet, with a storm beach at 940 feet; and about 5 miles north of Sault Ste. Marie, Ontario, at 1,015 feet. This gives a rise of 206 feet in a distance of about 52 miles or practically 4 feet to the mile. The altitude is about 930 feet near Rexford station, or practically the same as on St. Joseph Island. An isobase drawn from Rexford to St. Joseph Island bears about 15° south of east, thus making the trend of the tilt line N. 15° E. This isobase is 32 miles from Mackinac Island, there being thus a rise of about 125 feet in that distance, or nearly 4 feet to the mile. In the district north of the isobase the rise is 85 feet in 20 miles to the shore lines north of Sault Ste. Marie. The rate of tilting is thus but little greater to the north of the Rexford-St. Joseph isobase than to the south. The line from Mackinac Island to the shore north of Sault Ste. Marie falls very close to the direction of maximum tilting, N. 15° E.

The tilt line appears to trend nearly north in the part of the northern peninsula of Michigan from Marquette eastward about to Whitefish Bay. There are, however, places in which the shore lines fail to come up to the general plane. For example, in the vicinity of Rexton there is definite shore work up to nearly 900 feet above sea level, but at McMillan, about 30 miles to the northwest, the highest shore work seems to be about 30 feet lower, or between 860 and 870 feet. To fit the plane it should be well above 900 feet. The shore work east of Trout Lake is also about 30 feet too low to fit the plane. This discrepancy might be accounted for if the ice covered the district around McMillan and Trout Lake to a later time than at Rexton, so that the highest beach at Rexton is not represented at these other places, but it is difficult to find anything to support this explanation unless the ice persisted as stagnant ice in the low areas immediately north of McMillan and along the Soo Line east from Trout Lake. A few miles farther northwest than McMillan on the road leading from Seney to Grand Marais shore features are found to come up about to the general plane, or to more than 900 feet.

The most remarkable rise in the upper shore line that has yet come to notice is found along the border of the Au Train-Whitefish Valley. From a point near the Delta-Alger county line northward to Chatham there is a rise of 93 feet in a distance of 13.5 miles, or about 7 feet to the mile. In the southern 8 miles of this line the rise is 65.5 feet, or slightly more than 8 feet to the mile, and in the northern 5.5 miles the rise is 27.5 feet, or 5 feet to the mile. This most rapid rate of tilting is in a narrow passage only 1 to 1½ miles wide. Farther north, where the rate is lower, the waters had greater width.

The rate is still lower in Delta County south of this narrow strip. The rate of rise from Brampton to the Delta-Alger county line is about 3 feet to the mile. It is possible that the highest shore action in this narrow strip and the district to the north occured at a transition stage in the course of the lowering of the waters from Lake Duluth to the Lake Algonquin level, for this lowland seems likely to have carried the discharge from such a transition lake southward to the Lake Michigan Basin. The passage may at first have been obstructed by drift deposits in southern Alger County, so that in cutting through this barrier there may have been considerable descent. In that case the uplift may turn out to be consistent with that shown to the north and to the south of this narrow part and to be between 3 and 5 feet to the mile.

The rise of the highest Algonquin shore along the west side of the Green Bay Basin increases in rate from south to north. In the 50 miles from Menominee to Ford River at Newhall the rise is 75 to 80 feet, or about 1½ feet to the mile. From Newhall to the north line of Delta County there is a rise of about 95 feet in 32 miles, or practically 3 feet to the mile. The trend of the shore is very nearly in the direction of the tilt line, as determined by drawing isobases from the highest Algonquin shore west of Green Bay to the highest shore on the peninsulas and islands east of the bay. The altitudes on the Wisconsin islands and peninsula were determined by J. W. Goldthwait by wye level, and those on the Michigan slope by W. H. Hobbs, but those on the west side of Green Bay, by the present writer, are chiefly from railroad surveys.

The altitudes of the Lake Algonquin shores are accurately determined in the Marquette, Houghton, and Calumet quadrangles. In the Marquette quadrangle Algonquin shore action and corresponding stream deltas are conspicuous at 920 feet, but shore action is more obscure at higher altitudes. There is, however, a shore at about 940 feet and one at about 990 feet, each traceable for several miles in the southwestern part of the quadrangle. The shore at 990 feet is evidently above the Algonquin plane, and the one at 940 feet may be also.

The highest Algonquin beach is between the 1,000 and 1,020 foot levels at the south edge of the Houghton quadrangle but rises to 1,042 feet at the Isle Royale mine, a mile south of Houghton, and to 1,080 feet directly west of Calumet. It is at 1,095 to 1,100 feet near Mohawk and at 1,110 feet at the north edge of the Calumet quadrangle, west of Cliff. Near the Central mine it is above 1,120 feet. Throughout its course in the Houghton and Calumet quadrangles it is an exceptionally strong beach. Where cut into steep slopes the bluff back of it is in places 15 to 20 feet high, but more commonly it is a gravelly ridge with a deposit several feet in depth. The highest Lake Duluth beach developed on this peninsula stands 200 to 220 feet above the highest Lake Algonquin beach. These beaches seem to run nearly parallel across these quadrangles, and the interval between them is no greater at the north than at the south edge. Each shows a rise of about 100 feet in 33 miles in a north-northeast direction.

There are but few accurate measurements of the highest Algonquin beach in the western part of the Lake Superior Basin. The Soo Line, running southeastward from Ashland, Wis., crosses it near North York at 860 feet above sea level. At Bayfield, Wis., a line of levels run by F. T. Thwaites crosses the beach at 915 feet and levels on Oak Island, also run by Thwaites, cross it at 926 feet. Oak Island is about 40 miles nearly due north of North York, and the northward component of uplift, 66 feet in 40 miles, is thus about 20 inches to the mile. The rate of rise is slightly higher across Lake Superior from Oak Island to Grand Marais, Minn., a distance of about 60 miles in a course slightly east of north. The measured altitude of the highest Algonquin beach at Grand Marais is 1,042 feet, and there is thus a rise of 116 feet in 60 miles, or a little less than 2 feet to the mile. Near the west end of the lake the altitude on the south shore is 850 to 855 feet. On the north shore it rises from about 860 feet near Fond du Lac to 880 feet in the main part of Duluth and 910 feet near Knife River. At Amnicon Falls, which is about 28 miles nearly south of Knife River, the altitude of the highest Algonquin shore is 855 feet, or 35 feet lower than near Knife River. The rate of tilting here is thus very similar to that between Oak Island and Grand Marais, or slightly less than 2 feet to the mile. The data are not sufficient to determine the precise direction of the tilt line, but such as are available suggest that it is but little east of north and about the same as that of the shores of Lake Duluth. (See figs. 7 and 8.)

TRANSITION FROM LAKE ALGONQUIN TO THE NIPISSING GREAT LAKES

BATTLEFIELD BEACH

The expansion of Lake Algonquin continued as the ice front was gradually melted back until it reached eastward beyond Georgian Bay as well as northward over much if not all of the Lake Superior Basin. From the east end of Georgian Bay a lowland extends past North Bay into the Ottawa Valley. It is 600 to 800 feet lower than the bordering uplands and several miles in width. On its north side are large tributary valleys, which may have served as passages for ice tongues extending southward from the main ice sheet after its border had receded a few miles on the uplands north of the Ottawa Valley. It has been suggested by F. B. Taylor [17] that the Ottawa Valley may have afforded an outlet eastward around the south ends of these ice tongues by which the waters of Lake Algonquin were drawn down below the level of the Port Huron outlet, and that the Battlefield and Fort Brady beaches, which stand a few feet above the level of the Nipissing beach, may have been formed while the discharge was eastward past these ice tongues. With the complete withdrawal of the ice from the Ottawa Valley the water was drawn down to the Nipissing level.

The name Battlefield was applied by F. B. Taylor to a beach on Mackinac Island that traverses an old battlefield. This beach stands 130 to 135 feet above Lake Huron, or 710 to 715 feet above sea level. It is about 70 feet above the Nipissing beach and 30 to 35 feet below the lowest Algonquin beach. When traced southward on the borders of the southern peninsula it is found to drop less rapidly than the Algonquin beaches as far south as Norwood, on the east side of Lake Michigan, and Ossineke, in the west side of Lake Huron. At Norwood it is about 650 feet above sea level, and at Ossineke 640 feet. The highest Algonquin beach at these points is only 22 to 24 feet above the Battlefield beach.

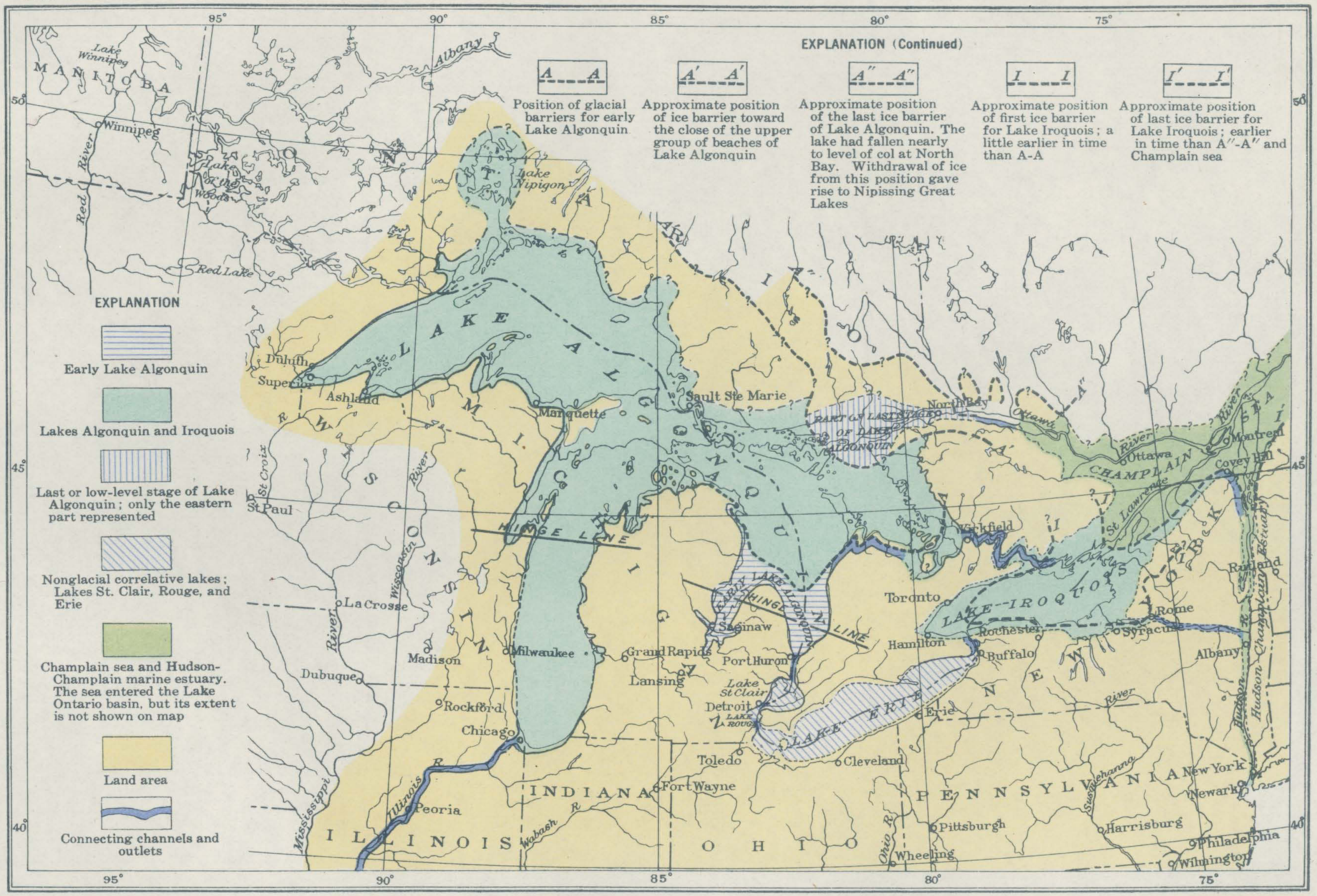
The Battlefield beach is well defined on the islands along St. Marys River from Drummond Island to Sugar Island and is present back of Sault Ste. Marie, where its altitude is 790 feet. This beach is also well defined on the borders of the Lake Superior Basin in Michigan, Wisconsin, and Minnesota. It becomes complex on the borders of this basin and is split into two or three members, whose altitude, as determined by hand level near Grand Marais Mich., is 785 feet, 760 feet, and 725 feet above sea level. Above these beaches at Grand Marais are five Lake Algonquin beaches, of which the highest is 895 feet and the lowest 820 feet above sea level. The highest beach here may not be the highest of the Algonquin series. Back of Sault Ste. Marie, Ontario, beaches that seem referable to the Battlefield series are found at intervals of 10 to 15 feet from 740 feet up to 790 feet above sea level. Nine Lake Algonquin beaches ranging in altitude from 820 feet to 1,015 feet are found in that locality. The Battlefield beach is especially well displayed on the Keweenaw Peninsula and the east face of the Bayfield Peninsula and at many places along the north side of Lake Superior in northeastern Minnesota. In all these places it is usually represented by two or more members separated by narrow spaces.

FORT BRADY BEACH

The Fort Brady beach stands between the Battlefield beach and the Nipissing beach. It seems to have been first brought to notice in the writer's studies in 1905. It is named from the fort at Sault Ste. Marie that stands on it. At the fort there is a cut bank, in front of which is a boulder-strewn terrace. The beach is relatively weak, being about like the weaker members of the Algonquin series. At Fort Brady the beach is slightly below 700 feet above sea level, but a few miles to the east, at the north end of Sugar Island, it reaches 704 feet. It declines to about 660 feet at St. Ignace and is exceptionally well developed in that vicinity. At Grand Marais and in the vicinity of Marquette it is 670 feet above sea level. It is well displayed on the Keweenaw and Bayfield Peninsulas and on the Apostle Islands, as well as along most of the north shore of Lake Superior in Minnesota.

The lake that formed this beach was probably merely a lower stage of the one that formed the Battle-

[17] U. S. Geol. Survey Mon. 53, p. 440, 1915.



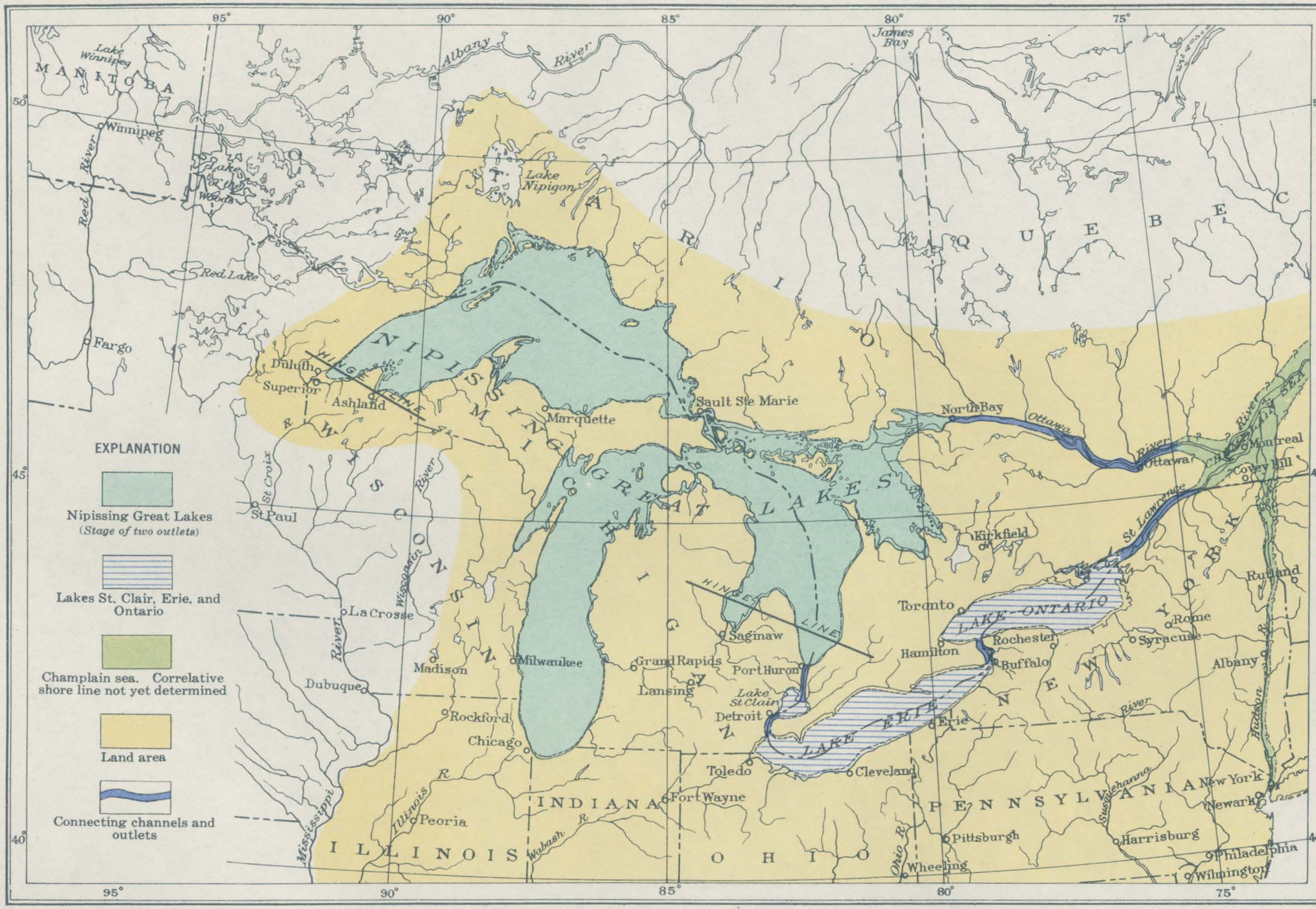
From Mon. LIII. Pl. XXI

MAP OF GLACIAL LAKE ALGONQUIN AND ITS CORRELATIVES

100 0 100 200 Miles

1929

By Frank B. Taylor and Frank Leverett



From Mon. LIII. Pl. XXVII

MAP OF NIPISSING GREAT LAKES AND THEIR CORRELATIVES

100 0 100 200 Miles

1929

By Frank B. Taylor and Frank Leverett

field beach and discharged eastward through the Ottawa Valley while it was still partly obstructed by the ice.

PASSAGES BETWEEN THE LAKE SUPERIOR AND LAKE MICHIGAN BASINS

Reference has already been made to the Au Train-Whitefish lowland, which runs southward from the Lake Superior coast at Au Train to the head of little Bay de Noc, an arm of Green Bay, at Rapid River. The divide on this lowland is in a swamp between Mud Lake and Trout Lake at 768 feet above sea level, or 166 feet above Lake Superior. This lowland has a rock floor exposed along much of its length, and Au Train River falls about 100 feet in less than a mile directly north of the crossing of the Munising, Marquette & Southeastern Railway. This lowland has been under consideration by Government officials and others interested in the development of navigation between the Lakes as a short cut between Lake Superior and Lake Michigan. But the expense of developing a waterway has been found to be so great that it overbalances the advantages in shipping. The amount of shipping between the ports on Lake Superior and Lake Michigan is relatively small when compared with the shipping toward the Atlantic seaboard.

Another passage between the Lake Superior and Lake Michigan drainage basins is found near Wetmore station on the Duluth, South Shore & Atlantic Railway. Here a swamp connects the head of Anna River with one of the tributaries of Manistique River. Its altitude is 838 feet. It is a relatively narrow passage, and the land close by on either side is nearly 900 feet above sea level.

A passage east of Sency connects headwaters of Taquamenaw River with one of the tributaries of Manistique River. This is the lowest passage into the Manistique drainage area from the Lake Superior Basin, being only 720 feet above sea level. It is about 2 miles in general width in its narrowest part, from a point near McMillan westward into the Manistique drainage basin, but there widens out into an extensive marsh through which several of the tributaries of the Manistique take their courses. East of McMillan in places the swamp is widened to 5 or 6 miles or more and is bordered by morainic ridges. A sandstone formation is crossed by Taquamenaw River at the northeast end of the swamp, and a descent is made in a short distance over the sandstone ledges to the level of Lake Superior. The effect of the northward differential uplift has been to increase the swampy conditions in the Taquamenaw by reducing the gradient of the stream. But in the Manistique drainage system, which leads southward, the gradient has been increased. As a result, the streams are cutting trenches and have narrow strips of dry land on their immediate borders.

The Manistique drainage basin is bordered on the north by extensive outwash plains next to the morainic belt that lies along the south edge of the Lake Superior Basin which are at a much higher level than the marshy plains to the south or the swampy passage connecting the Taquamenaw and Manistique drainage areas. There is generally an abrupt blufflike rise of 50 feet or more from the marshy sandy plains to these outwash plains. The higher plain consists usually of gravel and cobbles; the low plain and marshes are underlain by sand. It seems probable that the low plain was covered with lake waters to the height of the high plain at the time the high plain was built up as an outwash from the ice into this lake. If so, the abrupt border marks an old shore line or the place to which the outwash into the lake reached.

There are two table-lands of cobbly and gravelly outwash farther south in the Manistique drainage basin which stand somewhat higher than the bordering swamps and sandy plains. One of these is in the Hiawatha Settlement and is described on page 51 in connection with the moraine of which it is an outwash. It is fully 50 feet above the bordering sandy land and probably was built up at the edge of a lake, though it stands lower than the highest Algonquin shore. The other table-land lies about 6 miles southeast of Shingleton. It is covered with cobbles and gravel, but the surrounding lower land is sandy. It is about 60 feet higher than the sandy plain and covers about 4 square miles. It seems to be somewhat lower than the highest Algonquin level.

NIPISSING GREAT LAKES

The next stage in the geologic history of this region is represented by the Nipissing Great Lakes. These lakes occupied the basins of the upper three Great Lakes, Superior, Michigan, and Huron, and were almost as distinctly separated as those of to-day. (See pl. 8.) They were, however, all at a single level, for their waters covered the present rapids at Sault Ste. Marie to a depth of about 50 feet. The water also stood about 50 feet above the Strait of Mackinac, and there was a strait farther south leading from the head of Little Traverse Bay past Burt and Mullet Lakes to Cheboygan. On most of the borders of Lakes Superior, Michigan, and Huron the Nipissing shore line is less than a mile from the present water's edge. For a short distance near the west end of Lake Superior the present lake, as indicated in Figure 10, covers and extends beyond the Nipissing shore line. The water was about 2 miles in width at Sault Ste. Marie but expanded to a width of 10 to 12 miles a few miles to the southeast, in the vicinity of Mud Lake. The outlet of the Nipissing Great Lakes, as determined by F. B. Taylor in 1893, had its head at North Bay, Ontario, on the northeast shore of the present Lake Nipissing. The discharge passed down Mattawa River to the Ottawa and thence to an arm of the sea in the St. Lawrence Valley. (See pl. 8.) Later the differential uplift raised the outlet at North Bay so high that the lake waters were brought up to the St. Clair outlet at Port Huron. By this rise any shore work done by the Nipissing Great Lakes south of the isobase that runs through the North Bay outlet would have been submerged and to a large degree obliterated. The original Nipissing beach is to be seen, if anywhere, only in the extreme northeastern part of the Lake Superior Basin. The visible Nipissing beach is therefore, in the main, the product of the shore work after this rise, at a time when both the North Bay and the

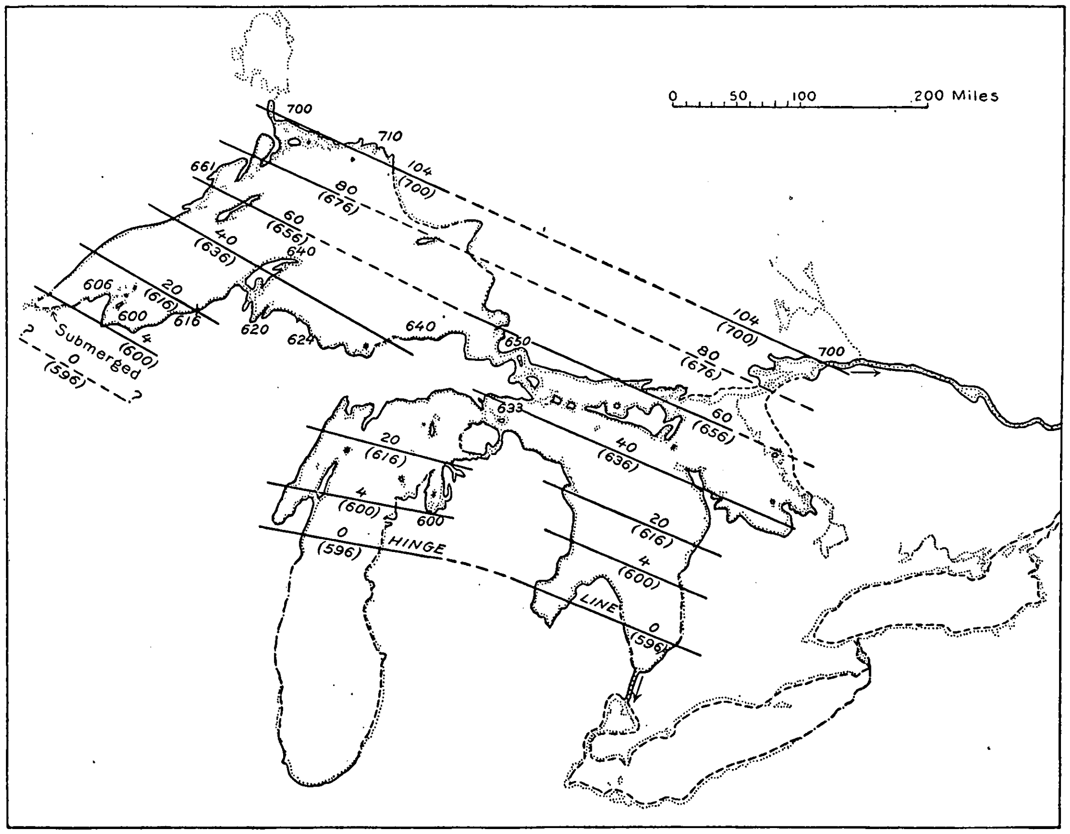


FIGURE 10.—Map showing isobases of the Nipissing Great Lakes at the two-outlet stage. The figures above the isobases indicate altitude above the horizontal or unaffected part of the beach south of the hinge line; the figures in parentheses below the isobases and the scattered figures elsewhere indicate altitude above sea level.

St. Clair outlet were in use. The Nipissing beach is a strong shore line throughout nearly all its course around the Nipissing Great Lakes. In places it is marked by a steep bluff 25 to 30 feet or more in height, and in others by strong gravel bars. To cut back far enough to give this height the lake probably encroached on the land a considerable part of a mile. The headlands or projections and exposed points on this old shore are generally marked by cut banks showing removal or encroachment, and the recesses along the shore are generally marked by ridges of sandy gravel which tend to fill them and thus straighten the shore.

On Whitefish Point a large number of ridges of sandy gravel were developed by the Nipissing Great Lakes, which extended the point several miles beyond its former limits. The area occupied by these sand ridges is indicated on Plate 1. At the city of Escanaba the currents of this lake stage and a slightly higher lake stage gathered up the sandy material laid down at the mouth of Escanaba River and strung it out in a long ridge that reaches from the mouth of the river beyond the city and has a width of about a mile and a length of 5 or 6 miles. The city thus stands on a sand bar, and the swamp back of the city represents a bay that separated it from the mainland. At Au Train there is a great accumulation of sandy and gravelly material filling in the space between Au Train Lake and the shore of Lake Superior. There are also very extensive sandy bars along the shore of Lake Michigan immediately west of the Strait of Mackinac, filling the space between Brevoort Lake and the Lake Michigan shore. They cover a space 1 to 2 miles in width and 8 to 10 miles in length. These several places afford some of the most striking examples of the development of sand ridges in connection with the Nipissing Great Lakes, but the wave-work along the shore is a conspicuous feature throughout almost the entire borders of Lakes Superior, Michigan, and Huron. Many of the land-survey plats made by the Government surveyors indicate the position of the Nipissing shore as the "former coast line," its features being so strikingly similar to that of the present shore and its separation so slight both in altitude and in distance as to leave no doubt concerning the interpretation.

The main Nipissing beach is at the level where the waters stood when the outlet past Port Huron came into use. In the course of the cutting down of the Port Huron outlet to the present level, a cut of about 15 feet, the waves have formed beaches below the main one. In the part of the shore where no uplift has occurred these lower beaches are less than 596 feet above sea level. This part embraces most of the Saginaw Basin, the part of the Lake Huron Basin east of the Thumb of Michigan, and the part of the Lake Michigan Basin south of Manistee, Mich., and Algoma, Wis. The northern parts of the Lake Huron and Lake Michigan Basins, including much of Georgian Bay and Green Bay, have suffered uplift, and so has the entire Lake Superior Basin. As a result of this uplift the main Nipissing beach has been carried up to about 700 feet above sea level in the vicinity of the North Bay outlet and in the northeastern part of the Lake Superior Basin. The lower beaches appear at several lower levels, but are relatively weak features, and indicate that uplift was going on at such a rate that the lowering waters had not time to build strong shores at any given level.

The altitudes and tilting of the highest Nipissing beach have been set forth in Monograph 53 for the Lake Superior Basin, as well as for the Lake Michigan and Lake Huron Basins. Plate 8 and Figure 10 are taken from that report. It was shown that on the east side of Lake Huron the beach rises from an altitude of 596 or 597 feet at the south end to 698 feet at North Bay. On the west side of Lake Huron it rises from 595 feet at Port Huron to 626 feet at Cheboygan and 631 feet on Mackinac Island. On the east side of Lake Michigan it is at 595 to 597 feet as far north as Herring Lake, a few miles south of Frankfort, Mich., and on the west side as far north as a point 4 miles north of Algoma, Wis. Between that point and Rapid River, at the head of Little Bay de Noc, it rises to 613 feet. It is also at 612 to 613 feet on the Garden Peninsula at Fayette Bay.

On the south side of Lake Superior the Nipissing beach declines from about 650 feet at Sault Ste. Marie to 635 feet at Grand Marais, Mich., 628 feet at Marquette, 620 feet at L'Anse, 616 feet at Ontonagon, and 606 feet near Bayfield, Wis.; west of the Bayfield Peninsula it is either combined with or falls below the present shore of Lake Superior. As the Keweenaw Peninsula is farther north than neighboring parts of the south shore of Lake Superior the Nipissing beach is somewhat higher there, being 640 feet above sea level at Eagle Harbor and Copper Harbor, 635 feet at Lac la Belle, and 630 feet at the north end of the Portage Canal. On the north shore of Lake Superior the Nipissing beach is combined with or below the present shore of the lake as far northeast as Beaver Bay. At Little Marais it is only 10 feet above Lake Superior, or 612 feet above sea level. It reaches 623 feet at Lutzen, 630 feet at Grand Marais, 638 feet at Chicago Bay, and 661 feet at Port Arthur. In the northeastern part of the Lake Superior coast, at Jackfish Bay and Peninsula Harbor, it is slightly above 700 feet. The accompanying map (fig. 10), taken from Monograph 53, sets forth the trend of isobases for each 20 feet of uplift in the three basins occupied by the Nipissing Great Lakes.

FEATURES OF THE PRESENT SHORES

The features of the present shores of the Great Lakes have on the whole a stronger expression than those of the glacial lakes, the lake cliffs reach greater heights, and the beaches and bars are more pronounced. The shores of the Nipissing Great Lakes come nearer than those of any of the glacial lakes in rivaling the strength of the present shores. From this it should not necessarily be inferred that the glacial lakes were of correspondingly shorter duration, for it seems not unlikely that shore work was hampered to a greater extent by a frozen condition in the glacial lakes than it is in the present lakes.

The present lakes have encroached on the land along the greater part of their shores, and in places cliffs over 100 feet in height rise abruptly from the water's edge. The islands especially show prominent cliffs. The building of barrier bars across bays is conspicuously illustrated in Minnesota Bar, at the head of Lake Superior, and in the bar across Chequamegon Bay opposite Ashland, Wis. At Gladstone, Escanaba, and Menominee, Mich., there has been a marked growth of sandy points lakeward. In the vicinity of Marquette, Mich., rocky islands have been joined to the mainland by the filling in of the channels that once separated them.

The northward differential uplift has caused a rise of water at the southwest end of the Lake Superior Basin, so that the Nipissing shore is submerged for a short distance from the head of the lake. There are features which suggest that this uplift may still be in progress. George R. Stuntz, [18] a land surveyor, found stumps in places beneath the water of St. Louis River near its mouth, which seem to indicate a relatively recent rise of the water on the land. G. L. Collie [19] in his studies of the Apostle Islands has found evidence of a rise of water that has caused the removal of the ends of spits that extend out from the islands

[18] On some recent geological changes in northeastern Wisconsin: Am. Assoc. Adv. Sci. Proc., vol. 18, pp. 205–210, 1870.

[19] The Wisconsin shore line of Lake Superior: Geol. Soc. America Bull. vol. 12, pp. 197–216, 1901.

into Chequamegon Bay. One at the south end of Madeline Island, "according to well-authenticated tradition," once extended 5,000 feet from the island. A shoal now marks its former position and shows that the extent is not exaggerated. It is a destructional feature, not constructional. Old residents of Madeline Island state that the spit has been cut away 2,000 feet in the last 50 years. It remains to be determined whether this recent rise is independent of the uplift that tilted the Nipissing and earlier beaches or is part of a movement that has continued to the present time. Its rate seems to be more rapid than is consistent with a continuous uplift dating back to the time of the Nipissing beach.

THE FAUNA OF THE MIDDLE BOONE NEAR BATESVILLE, ARKANSAS

By George H. Girty

INTRODUCTION

The geologic section at Batesville, Ark., so far as it is of present concern, comprises the Batesville sandstone, the Moorefield shale, and the Boone chert. The formations are cited in descending order, and the Boone is underlain at different places by rocks of different ages ranging from Ordovician to Devonian.

The faunas of the Batesville sandstone and Moorefield shale are already known. The Batesville fauna was first described by Weller [1] and somewhat later was reviewed by me [2] on collections more extensive inasmuch as they comprised material from Marshall as well as from Batesville. I also described the fauna of the Moorefield shale,[3] using the same two localities as sources for my collections. On the other hand, my contacts with the Boone fauna of that region have been few and more or less in the nature of afterthoughts. The faunas of the Moorefield and Batesville, then little known, were of chief interest, whereas the fauna of the Boone was naturally supposed to be the same as other Boone faunas, with which I was fairly familiar.

I had already observed, as I thought, that lithologically the Boone exposures near Batesville were somewhat different from the more typical exposures farther west. Near Batesville the formation seemed to consist of a darker, finer-grained, and more siliceous rock, lacking in beds of a crystalline or crinoidal nature, and conspicuously poor in fossil remains. It was divisible into a lower calcareous member and an upper cherty member. The cherty member, which was thought to be about 250 feet thick, even included near the middle some 20 feet of beds comprising calcareous shale, limestone, and calcareous sandstone, mostly black or dark gray. This feature is of course quite foreign to the Boone in its typical aspects. Finally, a small fauna collected in the upper part of the chert member [4] proved to be closely related to the fauna of the Moorefield shale and widely different from the typical Boone faunas. These facts, which were brought out in Bulletin 595, might provisionally be interpreted in three ways: (1) The Boone at Batesville is not the true Boone but a different formation and, if different, younger; (2) it is equivalent to the typical Boone but is more or less transformed in lithologic character and in fauna; (3) it is a more extensive formation, the lower part equivalent to the Boone but the upper part younger. The problem thus seemed to focus upon the lower part of the formation. If the fauna of the limestone member proved to be of the normal Boone type, and consequently different from the higher fauna, the inference would naturally follow that the limestone member represents the true Boone, and that the chert member is a later formation. If the fauna could be assigned to some definite part of the Boone, the inference would be modified to suit, but further progress along any but speculative paths seemed barred until something was known of the lower fauna.

Unfortunately, when I had an opportunity to examine the lower part of the Boone section near Batesville, I had little idea that the Boone of that region presented such a problem; my observations were hasty, and no collections were made. Under some circumstances one has recourse to one's friends, and as Mr. H. D. Miser was about to visit the Batesville region on an economic behest, I asked him to collect some fossils from the limestone member in the hope that its relations to the typical Boone might thus be determined. My request was graciously fulfilled, and Mr. Miser made the two collections upon which this report is based. This evidence, however, does not solve the problem but rather complicates it, for the fauna of the middle Boone, though conspicuously different from the upper fauna, is also conspicuously different from the faunas of the typical Boone. The purpose of the present paper, then, is to place these facts on record and to discuss certain relations which they suggest.

Mr. Miser has kindly furnished the following description of the stratigraphic relations and occurrence of the rocks from which these fossils came:

> The fossils described in the present report were obtained by me from a bed of limestone near the middle of the Boone chert at two localities on Spring Creek 5 miles northwest of Bates-

[1] Weller, Stuart, The Batesville sandstone of Arkansas: New York Acad. Sci. Trans., vol. 16, pp. 251–282, pls. 19–21, 1897.

[2] Girty, G. H., The fauna of the Batesville sandstone, northern Arkansas: U. S. Geol. Survey Bull. 593, 1915.

[3] Girty, G. H., The fauna of the Moorefield shale of Arkansas: U. S. Geol. Survey Bull. 439, 1911.

[4] Girty, G. H., Fauna of the so-called Boone chert near Batesville, Ark.: U. S. Geol. Survey Bull. 595, 1915.

ville, one in an abandoned limestone quarry on the east side of the Spring Creek valley about a quarter of a mile northeast of Denieville and the other on the east side of the valley about a mile southeast of Big Spring.

The limestone yielding the fossils is 22 feet thick in the quarry near Denieville and appears to be only a few feet thick at the locality a mile southeast of Big Spring. It is light gray, ranges from fine to coarse grained, occurs in layers attaining a thickness of 6 feet, and contains a few layers and nodules of flint. In addition to the brachiopods and the other fossils described by Mr. Girty, the limestone contains numerous crinoid stems, which are in fact abundant enough for the rock to be called a crinoidal limestone. Similar limestone of apparently the same age is exposed at other places in the Batesville region, though no fossils have been observed or obtained except at the two localities on Spring Creek. At Pfeiffer, 5 miles northeast of Batesville, there is an even-bedded fine-grained light-gray limestone 40 feet thick, which is being quarried, dressed, and marketed for use as a high-grade building stone. Similar though cross-bedded limestone has been quarried on the Blowing Cave road 2 miles north-northeast of Batesville.

The fossil-bearing limestone on Spring Creek and the limestone at the two localities just mentioned are near the middle of the Boone chert, a formation whose thickness is estimated to be between 300 and 400 feet. The full thickness of the Boone is revealed on Spring Creek. The base is exposed in a small area beginning at Big Spring and extending down the creek for almost half a mile. Here the Boone is underlain by the St. Clair limestone, of Silurian age. The topmost beds of the formation are exposed near Ruddells Mill, 2½ miles southeast of Denieville, where the Boone is overlain by the Moorefield shale.

The base of the limestone at the quarry near Denieville stands 50 feet above the bottom of Spring Creek, but no rock exposures were observed in the steep slope below the quarry. The chert underneath the limestone is thus not revealed there. It is, however, exposed farther upstream, especially along the Batesville-Cushman road, which follows Spring Creek past Big Spring. A large fresh exposure of the chert has been blasted recently in the construction of the highway three-quarters of a mile southeast of the spring. It shows the unweathered rock to consist of gray to blue flint in thin and thick layers, parts of which are limy. The flint on weathering loses its small quantity of calcium carbonate, becomes slightly porous, and breaks into hard, angular gray fragments that cover the steep slopes, with no admixture of clay. The flint as revealed in a fresh exposure on the highway and also in exposures to the north toward the outcrops of the St. Clair limestone has a southerly dip of a few degrees. On a hill half a mile southeast of Big Spring flinty chert that is below the fossil-bearing limestone of the Boone extends from the base to the top of the hill, which is 150 feet high. The chert below the limestone bed of the Boone is thus more than 150 feet thick but perhaps does not exceed 160 feet.

The upper chert member of the Boone along and near Spring Creek—the part of the formation lying above the fossil-bearing limestone—has been described by Mr. Girty in Bulletin 595 of the United States Geological Survey. He says that a fairly satisfactory estimate of the thickness is 200 to 250 feet. At the Denieville quarry the upper chert continues up the slope to the crest of the hill, 165 feet above the top of the limestone. The chert as revealed on the slopes occurs in part as soft, knotty, thin ledges but mostly as loose slabs and fragments of porous gray to brown vermicular chert, in some of which there are sparse casts of fossil remains.

The following beds are exposed along Spring Creek:

Section on Spring Creek between Big Spring and Ruddells Mill

	Feet
Moorefield shale, including at the base a limestone facies several feet thick that has been called "Spring Creek limestone."	
Boone chert:	
Chert weathering to porous vermicular slabs and fragments, sparsely fossiliferous; fauna described in Bulletin 595	200–250
Fossiliferous gray limestone; fauna described in present report	22
Flint weathering to hard angular fragments	150–160
St. Clair limestone; base not exposed	50+

For the purpose of recording a fauna the bare list of species is often highly unsatisfactory. It is not so always, because in a region where a fauna is well known certain undesirable features of a bare list are by that fact correspondingly minimized. Even then such a list makes somewhat trying demands upon the knowledge and imagination of the reader. If the fauna is new, however, or if, though not new, it comes from a new and remote area, the disadvantages inherent in a bare list become serious, and one feels the need of supplementing it by descriptions and figures. A list presents not facts but interpretations of facts, and it affords no opportunity for qualifying or discussing the interpretations which it presents—namely, the identifications of species.

In attempting to record the character of the middle Boone fauna of the Batesville region I have been prevented from giving discussions and illustrations of the different species, such as I would like, by the unsatisfactory character of the fossils. They are, to be sure, abundant, but at the same time they are rather poorly preserved. The matrix seems to consist of thin irregular plates of granular or crinoidal limestone alternating with fine-grained impure calcareous material that has been more or less converted into chert. The same process of alteration which gave a cherty character to the rock has perhaps caused it to adhere tightly to the shells. At all events, most of the shells are seriously exfoliated and, where they are partly concealed by matrix, sometimes very hard to uncover. Of many species only the larger features could be determined, and specimens that were suitable for illustration, that exhibited at one time all the significant characters shown singly by the others, were indeed few. Under these circumstances it has not been found practicable to illustrate all the species or to describe some of them in any but a large way. Nevertheless, the general aspect of the fauna, I believe, will be presented to others almost as well as the collections themselves presented it to me.

The subjoined table shows the representation of the middle Boone fauna of the Batesville region in the two collections by which it is at present known. The species marked with an asterisk are to be compared with species in the meager fauna of the upper Boone, which as here considered is that obtained from the cherty beds, to the exclusion of the richer fauna obtained from the overlying "Spring Creek limestone." Species are thus marked that may prove to be the same, though they are not now known to be so, as *Triplophyllum?* sp. or *Rhombopora?* sp. It is rather doubtful whether subsequent knowledge will show these forms to be identical; on the other hand, some of the Producti that are not marked as identical may prove to be so. On the whole, although but six species are marked as common to the two faunas, this probably overstates the relationship indicated by the facts at hand. As at present known (and it would be useless to speculate what future discoveries will reveal) the middle fauna is very different from the upper, and the difference is even more impressive in the collections than in the lists, because of the numerical representation of the species. Regarding the fauna of the "Spring Creek limestone," as that fauna is more extensive than the upper fauna of the Boone, by so much the more does it differ from the present one.

Distribution of the middle Boone fauna from localities 3203 and 3204 [a]

	3203	3204
Cladochonus beecheri	×	------
Cladochonus aff. C. longi	×	------
Cyathaxonia? n. sp	------	×
*Triplophyllum? sp	------	×
*Rhombopora? sp	×	------
Cystodictya pustulosa?	×	×
Rhipidomella aff. R. jerseyensis	×	------
Schizophoria compacta	×	×
*Orthotetes? sp	×	------
Chonetes miseri	×	×
Chonetes miseri var	×	------
Chonetes aff. C. shumardianus	×	×
Chonetes batesvillensis	×	×
*Productella hirsutiformis?	------	×
Productus magnus	×	------
Productus crawfordsvillensis?	------	×
Productus mesialis?	------	×
Productus burlingtonensis	×	------
Productus aff. P. gallatinensis	×	------
*Productus ovatus var. minor	×	------
Avonia arkansana var. multilirata?	×	------
Pustula aff. P. gradata	------	------
Pustula incrassata	------	------
Rhynchopora palmeri?	------	×
Rhynchopora sp	------	×
Spirifer floydensis?	×	×
Spirifer incertiformis	×	×
Spirifer washingtonensis var. incomptus	×	------
*Spirifer martiniiformis	×	×
Spirifer sp	------	×
Syringothyris subcuspidatus	×	×
Pseudosyrinx gigas	×	×
Brachythyris suborbicularis	×	×
Reticularia setigera var. internascens	×	×
Spiriferina subelliptica var. fayettevillensis	×	×
Spiriferina sp	×	×
Hustedia circularis	×	------
Bembexia magna?	------	×
Orthonychia ungula	×	×
Orthonychia undata	×	×
Orthonychia sp	×	------
Platyceras oxynotum	×	×
Platyceras latum	×	×
Proetus sp. aff. P. roundyi var. alternatus	×	------
Cytherella sp	------	×

[a] For a description of these localities see p. 97.

As at present known, the fauna of the middle beds of the Boone comprises 45 species or varieties. It is essentially a fauna of brachiopods, and among these the Spirifers are by all means the most abundant. Measured in variety the Producti are essentially their equals, but in numbers they are far inferior. *Spirifer incertiformis* and *S. floydensis* are especially abundant, and shells of *Syringothyris* and *Reticularia* are also numerous. Of the Producti, *P. burlingtonensis* is the best represented, though it is much less abundant than the Spirifers just mentioned.

In considering the relations of this fauna it must be borne in mind that the specific identifications are more or less provisional. As regards the specific identifications the disfigurement of the specimens—that is, the loss of characters which they have suffered through exfoliation or other accidents—is more likely to cause them to be identified with kindred species when they are really distinct than to cause them to appear distinct when they are really identical. Be this as it may, it is obviously impossible to discuss the relations of the fauna except upon the evidence as it now stands. With the undetermined species and with a few that appear to be new (*Chonetes miseri*, *C. batesvillensis*, *Pustula incrassata*, and *Spirifer incertiformis*) we have in such discussion no concern.

In a few points the fauna of the middle Boone shows affinities with that of the upper Boone from the same area and with that of the "Spring Creek limestone," which are closely related to one another and for present purposes may be treated as a unit. As evidence in this direction one might cite *Productella hirsutiformis*, *Avonia arkansana* var. *multilirata*, *Spirifer martiniiformis*, *Reticularia setigera* var. *internascens*, and some others. This evidence is weak, however, in comparison with that which is opposite in character. The greater number of species, especially the more abundant and more characteristic species of either fauna are conspicuously absent from the other. To pass over the *Producti*, *Spirifer floydensis*, *S. incertiformis*, *Syringothyris subcuspidatus*, and *Pseudosyrinx gigas* are found in the fauna of the middle Boone but not in that of the upper Boone and "Spring Creek limestone," whereas *Spirifer arkansana* and a great rhynchonelloid development (*Camarotoechia*, *Leiorhynchus*, and *Moorefieldella*) are found in the faunas of the upper Boone and "Spring Creek limestone" but not in that of the middle Boone. These comparisons might be pursued much further, but they would lead to the same conclusion that the middle fauna, though allied to the upper ones in a few articles, is overwhelmingly different.

To reach any substantial conclusion as to the precise relations of this fauna to the typical Mississippian faunas of Iowa and Missouri is at present out of the question. Its relations seem to lie distinctly with the lower Mississippian faunas rather than with the middle

Mississippian, and little, if at all, with the upper Mississippian. The relative abundance of *Platyceras* types, unless it is interpreted in terms of environment rather than of time, is suggestive of the Burlington fauna. *Productus burlingtonensis* to some extent confirms the evidence of the Platycerata, though similar Producti occur in higher and in lower faunas. *Rhipidomella jerseyensis* and *Hustedia circularis* might be regarded as still further confirmation, for they occur in the Fern Glen and Chouteau faunas, which appear to be closely allied to the lower Burlington fauna. *Pustula gradata,* if it is the same as *P. alternata,* and also *Brachythyris suborbicularis* span Burlington and Keokuk time and might be cited for either geologic epoch.

As suggesting Keokuk rather than Burlington time, we have *Cladochonus beecheri, Productus magnus, P. crawfordsvillensis, P. mesialis, Spirifer floydensis, Pseudosyrinx gigas,* and *Syringothyris subcuspidatus,* a somewhat more weighty assemblage. Obviously, however, this is far from being a characteristic Burlington fauna or a characteristic Keokuk fauna. The flashes of resemblance are neither very numerous nor very illuminating.

As might be expected, the fauna that we have here shows greater affinity with the typical Boone fauna than with the typical faunas of the Mississippian, which are more remote, but its Boone affinities are surprisingly tenuous in view of its geographic proximity. A discussion of this relation is embarrassed by the fact that the Boone faunas as compared with those of the typical Mississippian are but little known. I have myself, it is true, devoted considerable study to them, but the study has been unequal—much to certain groups, to others little. In a general way the species found in the Boone are the same as those of the typical Mississippian rocks, but they are somewhat differently assembled and comprise as well some types that are absent or have not yet been found in the typical Mississippian. The typical Boone, aside from the St. Joe limestone member, which has a fauna of its own, contains at least two distinguishable faunas—an upper one supposed to be of Warsaw age and a lower one, which seems to represent the Burlington and Keokuk faunas undifferentiated. I do not wish to convey the impression that a more intimate knowledge of these faunas will not afford means for dividing them more finely, but those two divisions are the most obvious ones.

Neither of the two faunal facies found in the typical Boone is represented with full integrity by the fauna of the middle Boone near Batesville. The later one is, indeed, somewhat pointedly suggested by such forms as *Productus magnus, Rhynchopora palmeri,* and *Spirifer washingtonensis* var. *incomptus,* even though the identification with those species is not final. Nevertheless, most of the significant members of that fauna are lacking in this one—for instance, *Spirifer lateralis, S. washingtonensis,* and many other species, including some that are undescribed. On the whole this fauna from Batesville contains more species that are close to or actually identical with species of the Burlington and Keokuk part of the Boone than species that are similarly related to species of the Warsaw part, and the general aspect of the fauna seems to be older than Warsaw, in spite of the few forms that suggest that epoch. A more specific treatment of this phase of the subject must be deferred until my detailed study of the Boone faunas is brought to completion. The only safe statement at present seems to be that this fauna from Batesville does not faithfully represent any of the faunas known from the the typical Boone but appears to be more solidly related to the earlier faunas, which are of Burlington and Keokuk age, although possessing a few features that suggest the later epoch.

If one were to forget for the moment the paleontologic evidence and were to consider that of lithology, geography, stratigraphic succession, and such tracing as has been done, he would probably conclude that the Boone of the Batesville region was the same as the Boone farther west—for instance, the same as the Boone in its typical outcrop in Boone County, though somewhat altered in its extension to the east. He might even be inclined to believe that the middle part of the Batesville Boone, which furnished the present fauna and which to me seemed a distinguishable part of the formation, was the St. Joe member. This hypothesis the character of the fauna collected by Mr. Miser seems to put beyond the pale of serious consideration. On the other hand, the alternative extreme, that these beds represent the whole of the Boone, seems also improbable, though by no means to be dismissed without consideration. For example, the pronounced change in the faunas that appears to have occurred between middle and upper Boone time in the Batesville region might be cited in favor of this interpretation, which, if adopted, would make much of the Batesville Boone post-Boone in age. Furthermore, if, as is now believed, the upper part of the typical Boone is of Warsaw age, the upper part of the Batesville Boone would needs be post-Warsaw—possibly Spergen, possibly St. Louis in age. That the upper Boone fauna of the Batesville region is neither a Spergen nor a St. Louis fauna is beside the mark, for it almost necessarily has to correspond with some one of the typical Mississippian faunas, and it is equally unlike any of them.

If what seems to be the more conservative hypothesis were adopted, the middle part of the Boone in the Batesville region would correspond to the Burlington and Keokuk part of the typical Boone, and the upper part of the Boone near Batesville to the Warsaw part of the typical Boone. Where in the largely unexplored Boone section near Batesville the boundary between Keokuk and Warsaw occurs can not now be designated. Possibly there is no good stratigraphic boundary; possibly even no good paleontologic boundary, for although the faunas at present known are wide apart in facies, they are also rather wide apart in their occurrence within the formation.

It will be seen that of the three hypotheses which presented themselves in the forepart of this discussion, the one which at the end of it seems the most probable is that the Boone of the Batesville region is an eastward extension of the typical Boone, somewhat transformed in its lithologic and still more in its faunal characters, the upper fauna becoming more completely transformed than the middle fauna but both having undergone vital changes. Although this hypothesis is adopted, it is adopted provisionally and without wholly dismissing the alternative one that the upper part of the Boone in the Batesville region is younger than the upper beds of the typical Boone.

As connected with the adoption of a hypothesis involving pronounced changes in the lithologic character of the Boone and even more pronounced changes in its fauna, we may scan the character of our early Mississippian sediments in a very broad way. Our Burlington and Keokuk rocks appear to be part of a limestone lens of almost continental proportions. It can hardly be doubted that the Madison limestone and its correlates come within the same general period of time, and it seems probable that these western limestones were originally, even if they are not now, continuous with those so well known in the Mississippi Valley. All the direct evidence on this head is, one might say, buried beneath the deposits of the Great Plains region. These Mississippian rocks have, we know, been removed in places during Carboniferous time. To what extent they are now continuous under cover and to what extent they were originally continuous, though in part removed by erosion, is, for the reason given, largely speculative. My own belief is that the Burlington and Keokuk rocks formed one lobe of a widespread limestone lens, chiefly developed in western seas. To the south and east, on the other hand, this limestone lens surely gave way to clastic deposits, for one can scarcely doubt that the "Knobstone group" of Indiana and Kentucky, the Waverly group of Ohio, the Marshall formation and Coldwater shale of Michigan, and in part the "Siliceous group" of Tennessee were in a broad way contemporaneous. Although these formations, which comprise sands, both fine and coarse, and shales of various colors including black, with but small proportions of intermingled calcareous matter, are so strikingly different from the Burlington and Keokuk in lithologic character, they differ even more strikingly in their faunal content. If these faunal and lithologic transitions took place, it seems likely from all the evidence that the sediments and faunas of the Batesville region now known as Boone were in the transition zone where the calcareous lens was merging with its clastic equivalent.

The discussion must turn next to a fauna recently described [5] that came from some limestones supposed to represent an attenuated extension of the Boone in an opposite direction—that to the southwest, this to the east. The region in which these limestones occur—San Saba County, Tex.—is remote from Batesville, and the two faunas are widely unlike. This was to be expected not only from geographic considerations but because the fauna from Texas is peculiar in consisting of diminutive types, as well as in other ways. Nevertheless, if both represent the Boone, they may be essentially contemporaneous and their differences may answer to differences in environment. The fauna from Texas, however, has a facies that impresses one as primitive, so that if the rocks containing it represent some particular part of the Boone, instead of being the thin end of a Boone wedge, they would apparently represent the lower part. On the other hand, the fauna from Arkansas, if the rocks near Batesville represent the modified Boone, belongs by stratigraphic position in the middle part.

It seems desirable before concluding this discussion to bring together and set down the facts regarding the other Mississippian faunas of the Batesville region that are related to the one here described, even though the same ground has already been traversed in other reports. Those reports covered collections made at Marshall as well as at Batesville, and although they offer ready means for separating the two faunas, I shall repeat the record for this region alone, with an eye to discussing the classification of the Batesville section. The following list, which is taken from Bulletin 595, shows the species that have been identified in the upper part of the Boone near Batesville. In the list of species from the middle Boone (see p. 75) I have marked with an asterisk those that occur in the upper Boone; so in the list of species from the upper Boone I am marking those that occur in the fauna of the Moorefield shale.

[5] Girty, G. H., Mississippian formations of San Saba County, Tex.: U. S. Geol. Survey Prof. Paper 146, pp. 25 et seq., 1926.

Species from the upper part of the Boone chert near Batesville, Ark.

[Based on lots 387, 387a, 388, 389, 390, 1237B, 1248W. For description of these localities see pages 96-97, and for further details see United States Geological Survey Bulletin 595, 1915]

*Triplophyllum sp. a.
Triplophyllum? sp.
*Batostomella sp.
Stenopora sp.
Rhombopora? sp.
*Lingula albapinensis.
*Orbiculoidea newberryi var. moorefieldana.
Derbya? sp.
*Productella hirsutiformis.
*Productella hirsutiformis var. batesvillensis?
*Productus coloradoensis?
*Productus ovatus.
Productus sp. a.
Productus sp. b.
*Rhipidomella arkansana.
*Leiorhynchus carboniferum.
*Leiorhynchus carboniferum var. polypleurum?
*Camarotoechia purduei var. agrestis?
*Moorefieldella eurekensis.
*Spirifer martiniiformis.
*Spirifer arkansanus.
*Reticularia setigera var. internascens.
*Martinia? pilosa.
Conocardium meekanum var. magnum.
Conocardium sp. a.
Conocardium sp. b.
*Parallelodon multiliratum.
*Bembexia nodimarginata.
Bembexia sp.
Pleurotomaria aff. P. carbonaria.
Pleurotomaria sp.
Euomphalus planidorsatus.
Sphaerodoma? sp.
*Primitia moorefieldana?
Bairdia aff. B. cestriensis.

At this point I find it necessary to digress and for the sake of clarity to repeat what has already been set down in another place. When the Moorefield shale was described it was made to contain at its base beds which had previously been named "Spring Creek limestone," consisting of about 18 feet of earthy black limestone and dark or black shale more or less mixed with sand. In fact, the "Spring Creek limestone" furnished most of the fossils that were later described as constituting the fauna of the Moorefield shale. Though in color similar to the black Moorefield shale above it, the "Spring Creek limestone" is different in its rock materials, and though in both features, perhaps, conspicuously different from the typical Boone, it is not so very different from the modified Boone of the Batesville region. Furthermore, as already described, when the fauna of the upper Boone came to be known, it proved to be essentially identical with that of the "Spring Creek limestone," while the residual Moorefield fauna, deprived of its "Spring Creek limestone" species, was conspicuously different from both. The following list shows the species identified in the "Spring Creek limestone" near Batesville; the only ones found in the overlying shaly beds at the same locality are marked by an asterisk.

Fauna of the "Spring Creek limestone" of the Batesville region, Arkansas

[Based on lots 1248A, 1248R, 1248T, 1248V, 1248Y, 1248Z, 2048, 2049, 2049a, 2049b, 2049c, 2049d, 2049f, and 2053. For a description of these localities see pages 96-97, and for further details see United States Geological Survey Bulletin 439, 1911]

Triplophyllum sp.
Enchostoma bicarinatum.
Batostomella dubia.
Batostomella parvula.
Stenopora sp.
Fenestella aff. F. rudis?
Fenestella aff. F. multispinosa?
Lingula batesvillae.
Lingula albapinensis.
Orbiculoidea newberryi var. moorefieldana.
Orbiculoidea newberryi var. marshallensis?
Orbiculoidea newberryi var. ovata.
Orbiculoidea newberryi var. caneyana.
Chonetes sp.
Productella hirsutiformis.
Productella hirsutiformis var. batesvillensis.
Productus coloradoensis?
Productus ovatus.
Avonia arkansana var. multilirata.
Pustula biseriata.
Pustula subsulcata.
Pustula subsulcata var janus.
Pustula moorefieldana.
Pustula moorefieldana var. pusilla.
Rhipidomella arkansana.
*Leiorhynchus carboniferum.
Leiorhynchus carboniferum var. polypleurum.
Camarotoechia purduei.
Camarotoechia purduei var. agrestis.
Moorefieldella eurekensis.
Moorefieldella eurekensis var. subcuboides.
Girtyella brevilobata.
Girtyella turgida var. elongata.
Spirifer arkansanus.
Spirifer moorefieldanus.
Spirifer increbescens.
Reticularia setigera var. internascens.
Spirifer martiniiformis.
Martinia? pilosa.
Ambocoelia laevicula?
Spiriferina subelliptica var. fayettevillensis.
Composita subquadrata var. lateralis.
Composita madisonensis var. pusilla.
Composita humilis.
Eumetria verneuiliana.
Solenomya? sp.
Sphenotus? meslerianus?
Sphenotus? sp.
Solenopsis nitida?
Edmondia crassa.
Edmondia crassa var. suborbiculata.
Nucula rectangula.
Leda vaseyana (fide McChesney).
Leda nasuta.
Parallelodon multiliratum.
Cypricardinia moorefieldana.
Schizodus batesvillensis.
*Deltopecten batesvillensis.
Deltopecten? sp.

Allerisma walkeri var. abbreviatum.
Bembexia nodimarginata.
Bucanopsis cancellata?
Bellerophon sp.
*Strophostylus aff. S. carleyanus.
Orthoceras aff. S. crebriliratum.
Bactrites? smithianus?
*Goniatites choctawensis?
Griffithides sp.
Paraparchites nicklesi.
Primitia moorefieldana.
Bairdia attenuata.

To round out the subject as I would wish, it has seemed desirable to add a list of the Moorefield fauna proper, that obtained from the formation exclusive of the "Spring Creek limestone." This list is given below. The facts as here set forth suggest a regrouping of the Mississippian rocks near Batesville, such that the "Spring Creek limestone" shall be considered part of the Boone instead of part of the Moorefield. This thesis has, however, another aspect. The paleontology of these rocks in the region of Moorefield, east of Batesville, is very inadequately known, but there is reason to believe that they will afford much that is new. It is from there, in fact, that most of the fauna which I am about to list was obtained, especially the goniatites, which form its most distinctive element. The "Spring Creek limestone" has not been definitely recognized in the section at Moorefield, but some beds that on lithologic, stratigraphic, and paleontologic grounds I thought to represent that horizon were so closely associated with some goniatite-bearing ledges that it seemed almost out of reason to refer them to separate formations. The Moorefield shale, in this its typical region, contains more beds of limestone and affords a better prospect of obtaining fossils than the exposures near Batesville, which in fact I found exceptionally poor in both respects. The "Spring Creek limestone" and the overlying beds of the Moorefield shale, then, may prove to be more completely merged lithologically and especially paleontologically at Moorefield than they were found to be at Batesville.

Fauna of the Moorefield shale exclusive of the "Spring Creek limestone" as known from Batesville and Moorefield, Ark.

[Based on collections from stations 2051, 2051b, 2051c, 1245A, 1245B, and 1248x. From United States Geological Survey Bulletin 595, page 14. The localities mentioned are described on pages 96-97 of the present report]

Orbiculoidea newberryi var. caneyana.
Leiorhynchus carboniferum.
Caneyella vaughani.
Caneyella percostata.
Deltopecten batesvillensis.
Pleurotomaria? sp.
Strophostylus aff. S. carleyanus.
Orthoceras sp. a.
Orthoceras sp. b.
Endolobus ornatus.
Bactrites? carbonarius.
Goniatites choctawensis.
Goniatites crenistria.
Goniatites subcircularis.
Goniatites newsomi.
Gastrioceras richardsonianum?
Gastrioceras caneyanum.
Eumorphoceras bisulcatum.
Girtyoceras meslerianum.

The absence of synonymic lists from the description of species next following will probably be noted. Such lists form an important, one might almost say an essential, part of formal works in the field of descriptive paleontology. Material like this, however, which comes from but two localities and is but indifferently preserved, is unsuited to formal treatment, and to combine long lists of citations with sketchy descriptions might be thought inappropriate if not pretentious. In fact, this account of the middle Boone fauna at Batesville may be regarded as an annotated faunal list on a somewhat extensive scale. It seemed adequate, therefore, to cite only a few works such as would properly present one side of a picture of which the descriptions and figures presented the other.

Another item, essential in many reports but here not specifically given, is that of horizon and locality. The reasons for this omission are the same as for the foregoing. Only two collections are involved, both from beds at the same horizon and at localities not far apart. The localities are described on pages 73–74 and 96–97, and the species which each of them yielded are shown inthe table on page 75.

DESCRIPTION OF SPECIES

Cladochonus beecheri (Grabau)

1899. *Monilopora beecheri* Grabau, Boston Soc. Nat. Hist. Proc., vol. 28, No. 16, p. 411, pl. 1, figs. 2, 3, pl. 2, figs 1–5. Keokuk group: Crawfordsville, Ind.

This species seems to be fairly common, though only seven specimens are in the collection, and those are ill preserved. They consist mostly of single corallites, are mostly internal molds, and are mostly imperfect at one end or at both. They are chiefly distinguished by their large size, some being as much as 8 millimeters in diameter, which would probably mean 10 millimeters if the epitheca were still present. As to length, not even a reasonable estimate can be made, because the corallites, now imperfect, did not taper to a point but were truncated at the proximal end. The longest fragment measures 13 millimeters, and I can not doubt that a length of 15 millimeters was attained or exceeded by many. The corallum apparently branched freely, for several of the corallites have two lateral scars where they were connected with others.

In its large size this form suggests *C. beecheri*, and, indeed, it suggests no other American species.

Cladochonus aff. C. longi (Rowley)

1901. *Aulopora longi* Rowley, Am. Geologist, vol. 27, p. 352, pl. 28, fig. 57. Upper and lower parts of Burlington limestone: Louisiana, Mo.

This is a much more delicate type than the foregoing, distinguished not only by its small size but by the long, slender stem or stolonal part of the epitheca. The general appearance suggests *C. longi*, and the proportions are not far different. The species is poorly represented.

Cyathaxonia? n. sp.

This unusual coral is represented by a few fragmentary specimens. Only a partial description can be given, and even in that some points are open to verification or correction. The shape appears to have been subcylindrical or very gradually tapering, and the size (for the genus to which it is provisionally assigned) very large. The diameter is at least 13 millimeters. The structure consists of three rather distinct zones, an axial zone occupied by the columella, a peripheral zone or epitheca, and an intermediate zone traversed by the septa.

The columella is very massive. In transverse section it is surrounded by a few concentric lamellae, and longitudinal sections also show a few plates running up and down the sides but at the same time cemented to one another and to the columella.

The septa occur in pairs and possibly should be classed as primary and secondary. Such they may be, but they do not everywhere conspicuously alternate in size, and the effect of pairing is produced by their union, two at a time, at their inner ends. The thick plates thus produced then continue inward and are amalgamated with the columella. Each of the septa is made up of two plates, and they become thicker peripherally until their sides are in contact, thus forming a solid and very thick epitheca. I am unable to give the precise number of septa, but there are probably at least 60 (apparently from 60 to 70). The interseptal loculi are not very long radially and are narrower than the septa. They are apparently unoccupied, tabulae or dissepiments being absent.

In some respects this coral has the characters of *Cyathaxonia*, yet in others it is more or less anomalous. As compared with other Mississippian Cyathaxonias, this species is exceptionally large. The way the septa unite in pairs before their inner ends consolidate with the columella is also unusual, as well as the structure of the columella of concentric plates, in the outer parts at least. The columella is far less complex than in the characteristic types of *Lonsdaleia*, and that genus is quite out of the question on other grounds. The coral is somewhat more closely related to *Lithostrotion*, but it lacks the outer vesicular zone of that genus, which is, in fact, almost as little to be considered as *Lonsdaleia*. The species is doubtfully a *Cyathaxonia*, but if not of that genus, it appears, so far as the facts are now known, to represent an undescribed one.

Triplophyllum? sp.

This type is represented by a single rather small specimen which appears to be constructed more after the plan of *Triplophyllum* than after that of *Cyathaxonia?* sp., with which it is associated. Besides its small size it is characterized by its very rapid, very irregular expansion. Approximately it has a length of 25 millimeters and a diameter, where it is widest, of about the same.

Rhombopora? sp.

This species is represented by a single small fragmentary specimen, of which it did not seem advisable to make thin sections. The following notes were accordingly made under unfavorable conditions, and some of them may need correction.

The branches are about 3 millimeters in diameter and have a strongly and abruptly thickened mature zone comprising about half the radius on each side. The surface is divided into rather regular hexagons by low, relatively broad ridges. The hexagonal areas are, of course, depressed, but the aperture in the center, which is rather small and circular, is surrounded by a raised peristome. Apparently the zooecial tubes are without diaphragms. The tops of the ridges appear to be granular, but no well-defined acanthopores have been observed.

The generic position of this striking form remains in doubt so long as some of the structural characters are in doubt. The very sharply defined mature zone, the evenly thickened walls, the open zooecial tubes, without diaphragms, and the vestibulate configuration of the hexagonal areas defined by the walls are all suggestive of *Rhombopora*. The peculiar and striking appearance of the outer surface, due to the regular hexagonal areas with their small apertures and elevated peristomes, reminds one of the genus *Stenopora* when specimens are broken just so as to show the centrally perforated diaphragms. In this bryozoan, however, all the cells have this appearance simultaneously instead of sporadically, and the suggested relationship to *Stenopora* is also contradicted by the fact that diaphragms are apparently nowhere present.

Cystodictya pustulosa Ulrich?

1890. *Cystodictya pustulosa* Ulrich, Illinois Geol. Survey, vol. 8, p. 495, pl. 76, figs. 2, 2a. Keokuk group: Kings Mountain tunnel, Ky.; Keokuk, Iowa; Warsaw and Nauvoo, Ill.

To this species are referred several small fragments, chiefly interesting because of the rarity of Bryozoa of any sort at these localities. The zooecia open from distinct prominences or low pustules, but at the same time the pustules occur in longitudinal rows and are connected by obscure ridges. This is also true of typical *C. pustulosa*.

Rhipidomella aff. R. jerseyensis Weller

1914. *Rhipidomella jerseyensis* Weller, Illinois Geol. Survey Mon. 1, p. 157, pl. 20, figs. 36–43. Fern Glen formation: Elsah, Ill.; Kimmswick, Mo.

The single small pedicle valve included here is associated with *Schizophoria compacta* and may be a misleading specimen of that species, but it apparently belongs to the related genus *Rhipidomella* and has the general appearance of *R. jerseyensis*. Its characters are too imperfectly known for a trustworthy identification.

Schizophoria compacta Girty, n. sp., MS.

This species is represented by three brachial valves and one pedicle valve from station 3203 and by a mere fragment from station 3204. The shape is subcircular, somewhat wider than long; the length of the largest specimen is about 23 millimeters. The brachial valve is rather strongly gibbous but develops a narrow and obscure sinus. The pedicle valve is shallow, deepest in the posterior part; toward the front it also is apparently depressed into a faint sinus. The beak is moderately incurved.

The surface is marked by fine radial lirae, some of which are more prominent than others. At least on the exfoliated surface (such being the condition of all my specimens) some of the lirae are defined by much deeper striae than others. They may thus be actually rather depressed than prominent, but they are rendered in this way especially conspicuous.

This form much resembles a manuscript species found in the Boone limestone and is probably identical with it. The critical characters necessary to a good identification are, however, not well shown, and it may prove more nearly related to such species as *S. chouteauensis* and *S. sedaliensis*.

Orthotetes? sp.

Strophomenoid shells are rare in the Boone fauna near Batesville, and the scanty material does not permit a decision as between the two probable genera *Orthotetes* and *Schuchertella*. Such importance as the material possesses is negative and is derived from the fact that the species is not large and not abundant, so far as the evidence can be trusted.

Chonetes miseri Girty, n. sp.

Plate 9, Figures 1–3

Shell small, subquadrate or deeply semicircular, very long for its width. The dimensions of the typical specimen are, width 8 millimeters, length 6 millimeters. The cardinal line slightly exceeds the width in front, the outlines contracting gradually forward and being broadly rounded about the anterior margin.

The convexity of the pedicle valve is high and symmetrical, the most prominent point being about midway, in a side view, with diminished curvature toward the posterior and the anterior margins. Corresponding to this the posterior part of the valve has a conspicuously flattened appearance and the umbonal parts are depressed. A sinus is not developed.

The brachial valve is not known.

The surface is marked by rather fine faint radial lirae crossed by rather strong coarse crenulations, which are most conspicuous upon the crests of the lirae.

C. miseri is in a measure intermediate between *C. logani* and *C. planumbonus*, approximating the one in sculpture, the other in configuration. The surface markings are comparable to those of *C. logani* except that they are appreciably finer and a little fainter. In shape the shell is relatively narrower and less extended at the hinge line. It is somewhat more convex and differs greatly in the flattened posterior region, which in *C. logani* is arched with a prominent umbo.

On the other hand, *C. miseri* resembles *C. planumbonus* in the flattened posterior region and obscure umbo but differs in the greater convexity, in the smaller size, and in the less transverse shape. The sculpture, though similar, shows decided differences. It is finer and far more regular. In *C. planumbonus* the concentric markings are the dominant superficial features, the lirae being so faint as to be sometimes scarcely appreciable. Often they can be recognized only as radial rows of scalelike crenulations. The crenulations may be connected laterally to form lamellose concentric lines which are sharp and sometimes have a wavy irregular course. Nothing comparable to this has been observed in the present form, which is regular in its sculpture and has the radial lirae quite as distinct as the concentric crenulations. On other specimens than the typical one, however, the crenulations make continuous lamellose lines that are close and regular in their distribution, like delicate fluted frills. Much, however, depends upon the light in which the specimens are viewed. If they are held at one angle the concentric lines are conspicuous, or even the only ones visible; if they are held at another the radial lirae come into prominence. Similar considerations must be taken into account in connection with exfoliation, which I suspect sometimes affects the relative strength of these markings. The specimens of *C. planumbonus* which I have used for comparison, though numerous, may be weathered or exfoliated to such an extent that their sculpture has been appreciably modified.

Chonetes miseri Girty, var.

This specimen, the only one of its kind, is a pedicle valve having a peculiar shape and possibly a peculiar sculpture. The posterior region is flattened, as in the typical specimen, but over the anterior half the curvature is subangular from side to side with somewhat obliquely flattened slopes. This tends to give the outline more of a triangular shape.

The shell is in large part exfoliated, but where the sculpture is shown (approximately) it consists of strong lamellose concentric lines with very faint or obsolete radial lirae. This occurs far around at one side, however, where the radial lirae are regularly weak and the concentric markings, if not exceptionally strong, at least exceptionally conspicuous in consequence.

Except for the flattened umbo the configuration of this shell recalls *C. geniculatus*, but obviously the sculpture is entirely different. The sculpture is more like that of *C. planumbonus*, but the resemblance is probably exaggerated by the part of the shell where the surface markings are shown and by the exfoliation which they have suffered. The specimen may be only an abnormal form of *C. miseri*, but it is too abnormal to be passed over without special mention.

Chonetes aff. C. shumardianus DeKoninck

1847. *Chonetes shumardiana* De Koninck, Monographie des genres *Productus* et *Chonetes*, p. 192, pl. 20, figs. 1a–d. Carboniferous: Knobs of Jefferson County, Ky.

1914. *Chonetes shumardanus* De Koninck. Weller, Illinois Geol. Survey Mon. 1, p. 89, pl. 8, figs. 1–7. New Providence shale: Kentucky.

The form identified as above is of moderate size, some specimens probably measuring as much as 20 millimeters in width, of quadrate shape, distinctly wider than long, and of rather high convexity. The pedicle valve bears a faint sinus, and the brachial valve doubtless a corresponding fold. The pedicle valve is rather strongly convex. Of the brachial valve only one fragmentary specimen has been examined, and it is but gently arched.

The most characteristic feature of this form is its fine sharp liration. The shell is thick, and most of the specimens are deeply exfoliated. One of them retains part of the surface intact, and there the lirae are fine, sharp, and rigid; five to seven of them occur in a space of 1 millimeter, and they are crossed by fine, sharp crenulations.

This form approaches *C. shumardianus* very closely but shows, or appears to show, a few minor differences. None of the specimens from Batesville is as large as many of those from Kentucky, and their convexity is perhaps a little higher. Weller describes the median sinus in *C. shumardianus* as being entirely obsolete. This appears to be only true in part, as some of my specimens from Kentucky have an appreciable sinus, though others appear to be regularly arched. It is the larger specimens, generally, that have a sinus. The Kentucky specimens occur in shale and have been more or less flattened, a process which would tend to lower the convexity and obliterate the sinus. To some extent the not very material differences between them and the Batesville specimens can be accounted for in this way.

This form might be identified with *C. illinoisensis* almost as well as with *C. shumardianus*. The scale of liration can be matched almost equally well in both. The convexity is stronger than it is in *C. illinoisensis*, but on the other hand that species, like this one, has a median sinus. Weller, it is true, says that the lirae in *C. illinoisensis* are not crenulated; nevertheless, many of my specimens from Burlington and points adjacent clearly show the presence of fine crenulations, and I suspect that Weller's specimens, like some of mine, had lost this feature, which, I believe, is characteristic not only of *C. illinoisensis* but of a large group of *Chonetes* to which *C. illinoisensis* belongs.

Chonetes batesvillensis Girty, n. sp.

Plate 9, Figures 4–6

Shell rather small, none of the specimens observed being wider than 15 millimeters. Shape semicircular or subquadrate. Cardinal angles quadrate or slightly acute. Hinge line equaling the width in front.

Pedicle valve rather convex; beak and region adjacent, more or less depressed. The type specimen bears toward the front a faint mesial depression, but other pedicle valves are regularly rounded.

The only brachial valve seen is nearly flat.

The surface is marked by moderately coarse, sharply defined radial lirae, of which three or four occur in 1 millimeter. The lirae are crossed concentrically by fine, sharp elevated lines that generally are conspicuous only upon their crests but locally are continued across the interspaces. The lirae are all but interrupted at intervals by the development of large "spines," of which only the openings now remain. The sculpture has a certain irregular appearance, due to a slightly unequal development of the lirae and their partial interruption by the "spines" as well as to the locally stronger and more continuous development of the concentric lines.

In the general character of its sculpture this form is intermediate between *C. illinoisenis* and *C. ornatus*, having much coarser lirae than the one and much finer lirae than the other. The specimens of *C. illinoisensis* studied by Weller evidently did not show that the lirae were crenulated, but specimens in my collection have this character quite distinct. Consequently in this feature also the present form is intermediate. I might refer it to *C. burlingtonensis* provisionally (not having specimens by me for comparison) but for Weller's description of the concentric lines, "which are more strongly developed across the intercostal furrows than upon the costae themselves and are often or nearly quite obsolete." This is far from true of the form from Batesville. The concentric lines are always present and always a conspicuous feature. They commonly appear as crenulations, and only here and there (where the lirae are locally weak) are they noticeably continuous. The large "spines," their tendency to interrupt the lirae, and the generally somewhat irregular character of the sculpture would also seem to distinguish this form from *C. burlingtonensis* and indeed from most of the species of *Chonetes* occurring in the typical Mississippian section. To some extent such characters may be made appreciable by the accidents of preservation or partly obscured in the same way, so that the value of this difference can not at this time be accurately estimated.

Productella hirsutiformis (Walcott)?

Plate 9, Figure 10

1884. *Productus hirsutiforme* Walcott, U. S. Geol. Survey Mon. 8, p. 133, pl. 2, fig. 10. Upper Devonian: Eureka and White Pine districts, Nev.

1909. *Productella hirsutiformis* (Walcott). Girty, U. S. Geol. Survey Bull. 377, p. 24, pl. 2, figs. 4–6. Caney shale: Ardmore, Atoka, and Tishomingo quadrangles, Okla.

1911. *Productella hirsutiformis* (Walcott). Girty, U. S. Geol. Survey Bull. 439, p. 50, pl. 3, figs. 1–4. Moorefield shale: Batesville and Moorefield, Ark.

To this species is referred a single specimen, a pedicle valve which is about 30 millimeters in length and about 50 millimeters in width. The convexity is very low and on the whole very regular. The shell is deeply exfoliated, but nowhere affords any evidence of having had radial costae. It is true that over a small area irregular, interrupted radial markings can be seen, but at that point the specimen is more deeply exfoliated than anywhere else—essentially an internal mold, in fact—and these markings are to be regarded as belonging to the inner surface. Extremely faint concentric undulations are about the only other markings visible. The evidence is fairly conclusive that the shell bore small scattered spines, but it is not conclusive as to their number and arrangement. Clearly, however, a row of spines protruded from it close to the hinge line, so close and so regularly arranged as to suggest the genus *Chonetes*, though of course an assignment to that genus can not be considered.

The characters noted above seem to ally this form with *Productella hirsutiformis* and *P. patula*, but no trustworthy identification can be made with such evidence as is available.

Productus magnus Meek and Worthen

Plate 9, Figures 11, 12

1861. *Productus magnus* Meek and Worthen, Acad. Nat. Sci. Philadelphia Proc., p. 142. Keokuk limestone: Monroe County, Ill.; Ste. Genevieve County, Mo.

1914. *Productus magnus* Meek and Worthen. Weller, Illinois Geol. Survey Mon. 1, p. 117, pl. 15, figs. 1–8. Upper part of Keokuk limestone: Monroe County, Ill.; St. Louis County, Mo.

This species is represented only by brachial valves, and a satisfactory identification is not possible without the pedicle valve. Nevertheless, the resemblance between the brachial valve of the Boone form and that of *P. magnus* is striking.

The specimens are preserved as external molds and show a large shell distinctly wider at the hinge than at any point in front and having slight sinuses in the outline just below the auricles. The largest specimens have a width at the hinge of 65 or 70 millimeters; the length of such specimens is about 45 millimeters. The visceral disk is large and in a general way flat or slightly convex (the mold is here being described), and the trail is rather narrow and somewhat abruptly and strongly deflected. Pieces of the shell show that a deposit was laid down around the upper part of the trail, thinning downward so that the inner surface of the valve was much more abruptly and strongly deflected than the outer surface.

The surface markings are not clearly shown. Radial costae are present, but they are rather fine and rather weak. Concentric wrinkles are also to be seen, chiefly toward the cardinal angles and on the trail (where, however, the markings are more like fascicles of growth lines), but these also are rather feeble, rather fine, and it would appear rather irregularly distributed. No evidence of spines has been observed.

The shells here considered differ a good deal in size, and if size is an index the larger ones belong to *P. magnus* rather than to *P. crawfordsvillensis*, two species which are related to each other and are not readily distinguishable if represented only by brachial valves. Some of the smaller shells, on the other hand, may belong to *P. crawfordsvillensis*—one especially which is about 50 millimeters in width and 40 millimeters in length. Apparently, however, the brachial valve of *P. crawfordsvillensis* has a much longer trail than that of *P. magnus*, and if so, this small shell is in better agreement with *P. magnus*.

Productus crawfordsvillensis Weller?

Plate 9, Figures 13, 14

1914. *Productus crawfordsvillensis* Weller, Illinois Geol. Survey Mon. 1, p. 116, pl. 12, figs. 4–7. Beds of Keokuk age: Crawfordsville, Ind.

This identification rests almost wholly upon a brachial valve preserved as an external mold, but it is also used for two pedicle valves and several other brachial valves of inferior character. These pedicle valves are so poor that although no satisfactory identification of *P. crawfordsvillensis* is possible without a knowledge of the pedicle valve, they have been disregarded as evidence. The brachial valve which thus has mainly determined the identification is transversely subquadrate in outline, slightly extended at the ears and slightly emarginate below them. The visceral disk is very large and the trail short. These two parts make with one another an angle that is slightly obtuse, joining in a strong curve without any distinct boundary. The visceral disk is almost flat or in the mold gently convex, divided in the anterior part by a faint median sinus. The width at the hinge is 45 millimeters; the length 35 millimeters.

The surface is marked by radial costae that are sharply defined upon the trail and upon part of the visceral disk but are fainter as they approach the beak. They are rather fine, about six in 5 millimeters. The visceral disk is crossed by concentric wrinkles, which are rather fine, irregular, and mostly rather weak. Fine, sharp, regular incremental lines are also shown, especially upon the trail. If this valve bore spines, the evidence for them has been obscured.

The general character of this brachial valve recalls especially *P. magnus* and *P. crawfordsvillensis*. *P. magnus*, determined like this species upon the brachial valve, has been identified in the other collection, and a marked similarity between the two brachial valves is at once seen. This one, however, is much smaller, and the outline is more quadrate, with subparallel sides. It differs still more conspicuously in the radial costae, which are much more sharply developed. In the presentation of *P. crawfordsvillensis* and *P. magnus* offered us by Weller, this specimen is in most respects nearer *P. crawfordsvillensis*. The brachial valve of *P. crawfordsvillensis*, however, has a rather uncommonly long trail, a fact that is brought out more clearly in Weller's description than in his figures, and in this respect the two valves differ rather strongly. Furthermore, the identification here adopted lacks the evidence, confirmatory or otherwise, of the pedicle valve with its more or less characteristic curvature and profuse development of spines upon the prolonged trail.

To other described species this form seems less comparable than to these two, unless it were entered with the catholic *Productus semireticulatus*. There is, however, an undescribed species, *P. crassilabrum* of my manuscript, to which it may belong. I refer to the form which in the Moorefield fauna of Arkansas I identified as *Productus semireticulatus* var. *coloradoensis* and which from the same horizon, but from northeastern Oklahoma, Snider cited as *P. coloradoensis*. Brachial valves of that species resemble this brachial valve very closely. Many have the trail somewhat more prolonged, and some have a stronger development of the concentric wrinkles, but these differences are not constant. In *P. crawfordsvillensis* the spines on the trail of the pedicle valve should be indicated by dimples upon the trail of the brachial valve. In *P. crassilabrum* the trail of the pedicle valve is not so prolonged, and it is not furnished with numerous spines. Consequently the present form, from our incomplete data, seems really in better accord with *P. crassilabrum* than with *P. crawfordsvillensis*.

Productus mesialis Hall?

Plate 9, Figures 15–19

1858. *Productus mesialis* Hall, Iowa Geol. Survey Rept., vol. 1, pt. 2, p. 636, pl. 19, figs. 2a–c. Keokuk limestone: Nauvoo, Ill.

1914. *Productus mesialis* Hall. Weller, Illinois Geol. Survey Mon. 1, p. 112, pl. 10, figs. 7–13; pl. 83, figs. 14–17. Keokuk limestone: Pierce City, Mo.; Nauvoo, Ill.

The specimens referred here seem to be possessed of essentially the same characters, but their preservation is such that these characters have been to some extent obscured and to some extent perhaps transformed. The form thus presented may be described as a small or medium-sized member of the *semireticulatus* group, distinguished in the way of configuration by having the pedicle valve more or less flattened over the visceral disk and strongly deflected about its margin. This character, though shared by all the specimens, may have been exaggerated or even entirely produced by compression. It is conspicuous in the specimen which chiefly suggested the identification adopted and which on that account might be mistaken for a brachial valve. This specimen is about 45 millimeters in width and 30 millimeters in length, measured from the beak to the anterior margin. It is marked by rather fine costae, which are rather feebly expressed and tend to become even feebler on the anterior slope. The visceral disk is crossed by fine, rather regular and strong concentric corrugations. The trail, which is shorter than the visceral disk, bears a few very large spines, each of which covers several of the costae and gives rise to low plications that extend forward to the margin. To what extent spines were developed on the visceral disk is uncertain, as the shell is exfoliated there. The other pedicle valves agree with this one so far as their characters are preserved, the chief difference being that some are more closely striated.

The brachial valve from the same locality that shows corresponding characters is somewhat smaller than the pedicle valve described, about 33 millimeters in width and 27 millimeters in length. The visceral disk is nearly flat, and the marginal parts are so strongly curved that the short trail forms with it an angle distinctly acute. The radial costae are of about the same character as those of the pedicle valve, but they are more sharply defined. The costae are crossed by concentric wrinkles, which are moderately fine, strong, and regular. This valve developed at least a few spines of its own, but it affords no evidence in the way of nodes as to how the pedicle valve may have been equipped.

These shells resemble *P. mesialis* in their size, in their somewhat geniculate pedicle valve, and in the large spines that developed from it. On the other hand, it is not certain how far the geniculate shape may have been accidental or due to compression. The spines, though large, are far less numerous, and the mesial sinus, though distinct enough, is much less pronounced than those of *P. mesialis*. This form appears from the evidence to be more nearly related to that species than to any other, but the affirmative evidence is not wholly to be trusted, and the negative evidence, if constantly maintained, discredits the identification. At all events the material is not sufficiently good to form the basis for a new species even if a new species were clearly indicated.

Productus burlingtonensis Hall

Plate 9, Figures 20–24

1858. *Productus flemingi* var. *burlingtonensis* Hall, Iowa Geol. Survey Rept., vol. 1, pt. 2, p. 598, pl. 12, figs. 3a–g. Burlington limestone: Burlington, Iowa; Quincy, Ill.
1914. *Productus burlingtonensis* Hall. Weller, Illinois Geol. Survey Mon. 1, p. 104, pl. 9, figs. 1–10. Burlington limestone: Burlington, Iowa; Springfield, Mo.; Quincy, Ill.

The shells referred here belong to the *semireticulatus* group and have little to distinguish them, save that they are of medium size, highly arched, and rather finely striated. The most perfect pedicle valve has a width at the hinge of nearly 40 millimeters and a length of 35 millimeters from the umbonal prominence to the front margin. Some specimens are slightly larger, others smaller. The shell is strongly arched, with the anterior slope considerably produced so that the umbonal parts project far beyond the hinge line and have a squarish shape. Transversely the vault is flattened across the top and indented into a narrow, inconspicuous sinus. The sides descend steeply but near the hinge suffer an abrupt outward deflection so as to form rather small oblique arched auricles.

The surface is marked with fine, even, radial costae and over the visceral disk by rather fine, rather strong, and rather regular concentric wrinkles. Small but numerous spines once projected from the surface, as is now indicated by obscure nodes, which are visible chiefly on the anterior half of the shell.

The best brachial valve observed has characters corresponding to the pedicle valve just described. It is gently concave over the visceral disk and strongly though not abruptly curved about its margin to form a trail that is nearly straight radially and distinctly shorter than the disk itself. Low radial undulations cross the visceral disk. Three of these are elevated, one forming the mesial fold, the others situated one on each side a little below the hinge line. It is not certain that the brachial valve bore spines, but the spines of the pedicle valve are reflected upon it in the shape of rounded depressions—low nodes on the specimen itself, which is an external mold.

Though somewhat larger than the generality of shells found at Burlington, these specimens agree with *P. burlingtonensis* very closely. In fact, I am unable to name any characters of importance in which they show material difference. On the other hand, it is not clear to what extent they differ from those here identified as *P. mesialis?*, and the line between the two groups is more or less arbitrary, though this fact may signify not so much that the two forms can not be distinguished as that the doubtful specimens no longer show the distinctive characters. It seems more probable that some of the specimens placed with *P. mesialis?* may really belong here than that any of the specimens referred here really belong under *P. mesialis?*. Between characteristic representatives of the two forms which I have sought to discriminate, marked differences appear. One difference is that of configuration, the prolonged anterior slope and the gibbous umbonal region of the present form contrasting strongly with the flattened umbonal region and the irregular curvature of the other species. The other species also has a few large spines; this a larger number of much smaller ones.

Productus aff. P. gallatinensis Girty

1899. *Productus gallatinensis* Girty, U. S. Geol. Survey Mon. 32, pt. 2, p. 533, pl. 68, figs. 11*a*–11*d*, 7*a*–7*c*. Madison limestone: Yellowstone National Park.

This form is represented by a single pedicle valve, some of whose characters are not well shown. It resembles several of the small semireticulate Producti, notably *P. gallatinensis* and *P. parvus*. *P. parvus* generally forms a broad shell which is divided by a more or less distinct sinus. This specimen is more elongate and slender, and it lacks a sinus. *P. parvus* is rather copiously supplied with spines. The facts with regard to this specimen are not clear, but apparently the spines were much less numerous. The most conspicuous difference is found in the transverse wrinkles, which in this shell are uncommonly large and strong for its size, much more so than on any of my specimens of *P. parvus* from Pella, Iowa, which have been used for comparison. The same difference, though it is less pronounced, distinguishes this specimen from the type specimen of *P. gallatinensis*, with which, however, it appears to agree closely in other respects. Both specimens are exfoliated and are possibly misleading in the matter of spinose equipment. They may have had many more spines than are indicated in their present condition.

Productus ovatus var. minor Snider

1915. *Productus ovatus* var. *minor* Snider, Oklahoma Geol. Survey Bull. 24, p. 79, pl. 3, figs. 19–21. Fayetteville shale: Northeastern Oklahoma.

This name, as used here, covers several specimens of the *ovatus* group distinguished by their small size and fine striation. The specimens, which are probably mature, measure only about 13 millimeters in width, though but few of them can be measured accurately. In such characters as are shown they agree very closely with *P. ovatus* var. *minor*, but they may be only a dwarfed variety of *P. ovatus*, which is possibly all that the typical variety *minor* is also.

Avonia arkansana var. multilirata Girty?

Plate 9, Figure 25

1910. *Productus arkansanus* var. *multiliratus* Girty, New York Acad. Sci. Annals, vol. 20, No. 3, pt. 2, p. 217. Basal part of Fayetteville shale: Fayetteville quadrangle, Ark.

1911. *Productus arkansanus* var. *multiliratus* Girty, U. S. Geol. Survey Bull. 439, p. 43, pl. 2, figs. 10, 11. Moorefield shale: Batesville quadrangle, Ark.

Under this title is included a single pedicle valve which appears to be in a half-grown stage. The outline is more or less quadrate, though the sides conspicuously converge forward. The cardinal angles are rounded, probably through breakage. The convexity is low and rather regular. The beak is small and projects but little beyond the hinge line. The vault is flattened across the top and depressed into a rather weak and narrow sinus; it descends very gradually to the ill-defined auricles.

The surface markings comprise radial costae, concentric wrinkles, and spines. The costæ are fine and sharp, but somewhat irregular and intermittent. The concentric wrinkles, which are weak and irregular across the vault, become stronger as they approach the sides and considerably disturb the radial costae, which consequently take on more or less the character of elongated, disconnected spine bases. The spines are apparently small and numerous. Their development renders the costae somewhat nodose and discontinuous.

This specimen in many respects closely resembles *A. arkansana* var. *multilirata*. That variety is, of course, much more elongated and convex, but it shows little disparity in a proportional part of the posterior end. The lirae on the Boone specimen also appear to be less continuous, more distinctly interrupted or at least semidiscontinuous. Another species which deserves consideration in this connection is *Productus setiger*, but if the Boone specimen is mature, obvious differences in shape aside from differences in sculpture would show that it can not be classed with that species. If, on the other hand, it is not mature, it would, when fully grown—if one may predict its characters—have been rather large for *P. setiger*, just as it now has radial lirae that are too irregular and concentric wrinkles that are too weak and inconspicuous in the auricular region. It seems to have less in common with *P. setiger* than with *A. arkansana* var. *multilirata*, and, all things considered, it is less likely to belong to the latter than to some species at present undescribed.

Pustula aff. P. gradata Swallow

1863. *Productus gradatus* Swallow, St. Louis Acad. Sci. Trans., vol. 2, p. 93. Keokuk limestone: Keokuk, Iowa; Lewis and St. Louis Counties, Mo.

The single specimen referred here is an imperfect brachial valve which shows the inner surface but is more or less deeply exfoliated in places. The characters shown are therefore in large part not the real surface characters, which must be inferred. Unquestionably the outer surface was crossed by strong concentric corrugations, which were more or less imbricated. The bands that were defined in this way differ greatly in width, though most of them are rather narrow. The surface was also clearly beset with numerous small spines, which appear to have arranged themselves in several rows on each band, to have been oblique, and to have been attached to elongated bases.

These characters indicate rather clearly that this shell is a member of the *punctata* group of *Pustula* of which *P. alternata*, *P. genevievensis*, and *P. biseriata* are representative Mississippian species. The size of this specimen, which must be nearly 40 millimeters in length, indicates a relationship with the larger species rather than with *P. biseriata*. As between *P. alternata* and *P. genevievensis*, the characters actually observed offer no grounds for choice, but the probabilities undoubtedly favor *P. alternata*. Now under *P. alternata* Weller places as synonyms *P. vittata* Hall and *P. gradata* Swallow, and perhaps he is right in doing so. Shells of this group, however, do vary a great deal in their surface markings, and typical *P. alternata* can readily be distinguished among them. The same is probably true, though not equally, of *P. vittata* and *P. gradata*. All three names I believe stand for real differences in the shells themselves, the chief question being to what extent the three types are merged into one by intergradation. At present I am inclined to believe that careful discrimination will lead to the recognition of all three species, and the evidence—very unsubstantial, it is true—suggests *P. gradata* as the better identification for the Boone specimen. Even with ample allowances for differences between the markings of the pedicle and brachial valves of such shells, it scarcely seems possible that this specimen can be the brachial valve and the associated specimen identified as *A. arkansana* var. *multilirata?* the pedicle valve of the same species.

Pustula incrassata Girty, n. sp.

Plate 9, Figures 7–9

Although this species is represented in the collection by seven specimens, they are all apparently pedicle valves, and one of them is so much more perfect than the rest that the following description is for the most part drawn from it alone.

Shell small; outline subcircular, widest at the hinge, strongly rounded across the front, the sides becoming nearly straight above and diverging posteriorly. Convexity moderate; curvature rather regular, though longitudinally it is a little stronger in the posterior part and transversely a little stronger in the median part. Umbo rather depressed, spreading at a wide angle. Ears small, ill defined. The surface lacks both concentric wrinkles and radial costae. Spines are fairly numerous but small, and they project from inconspicuous roundish bases. The shell is very thick and lamellose, and the surface of the type specimen is marked by sharply defined imbricating layers, an appearance which is probably due in part to exfoliation. Other specimens suggest that the original markings consisted of fine irregular striae of growth, some of which here and there were distinctly stronger than the rest.

The other specimens are more deeply exfoliated than the typical one, in places reduced to the condition of internal molds. They show that upon the inside, there was a solid elevation or platform which extended from a point near the beak distinctly less than half the length of the shell. It rises rather sharply at the sides but declines gradually at the front and perhaps at the back as well. In shape it is distinctly elongated, widening somewhat toward the anterior end. The shell seems to be excavated somewhat on each side of the platform about midway, so that internal molds show a rather broad, deep channel down the middle of the umbonal region, with a distinct moundlike elevation on each side. Many Producti show the same feature, all perhaps in some measure, and in certain ones it is developed to an astonishing degree.

In some respects this species recalls *Pustula moorefieldana* var. *pusilla*, but comparisons between them are somewhat hampered by the fact that the typical specimens of that form are brachial valves and of this pedicle valves. The brachial valves of *P. moorefieldana* var. *pusilla* all show a few angular ridges which divide the surface into concentric bands. Some corresponding feature would be expected on the pedicle valve also, but nothing of the sort is shown by the pedicle valves of *P. incrassata*. The pedicle valve of *P. moorefieldana* var. *pusilla* is, in fact, imperfectly known. The best specimen available for comparison is more inflated than *P. incrassata;* its spines produce distinct elongated bases, and it has, moreover, an uncommonly thin instead of an uncommonly thick shell. *P. incrassata* might perhaps be regarded as a dwarfed form of *Productella hirsutiformis* var. *batesvillensis*, so reduced in size that it was only 9 millimeters wide instead of 30 millimeters. So to interpret the relationship would be at present a mere assumption, with some evidence unfavorable to it. Another related species is one described in manuscript as *Productella planiconvexa*. Pedicle valves of that species are relatively much broader. They are less convex, and they show certain superficial differences, for the spines are apparently larger and less numerous, and the surface is crossed by concentric corrugations, which though not strong are distinct, regular, and fine.

Rhynchopora palmeri Girty, n. sp., MS.?

Rhynchopora palmeri is a manuscript name proposed for a series of specimens in my collection which appear to belong to a species that was identified and figured by Weller in his invaluable monograph as *R. beecheri*, but that is probably not true *R. beecheri*, especially if that species be restricted to the more common of the varied forms covered by the original description. The present collection contains but two specimens, both very fragmentary, which resemble *R. palmeri* so far as their characters are shown.

Rhynchopora sp.

This species is almost certainly different from that referred to *R. palmeri*, though both are represented by mere fragments. It has more slender and more numerous plications, of which five occur in the sinus, so that six must occur on the fold. The number of lateral plications can not be given.

Spirifer floydensis Weller?

Plate 10, Figures 1–5

1914. *Spirifer floydensis* Weller, Illinois Geol. Survey Mon. 1, p. 351, pl. 49, figs. 15–19. "Knobstone" group: Floyd County, Ind.

This species is extremely abundant, but the specimens examined are crushed, broken or exfoliated, so that in spite of their number the characters that belong to them, especially the more minute characters, are not well shown.

In a general way, this form markedly resembles *S. arkansanus* (of which I was at first inclined to regard it as a variety) and *S. floydensis*. It is on the average distinctly smaller than *S. arkansanus*, no specimens of this form being as large as the typical specimens of that. The plications are generally stronger; few specimens, if any, have the broad, flat costae that are rather characteristic of *S. arkansanus*. The plications bifurcate more rarely, and so far as observed they never have the appearance, so common in *S. arkansanus*, of being double or in pairs. However, the plications of both the fold and the sinus increase by the subdivision of others, and furthermore the first plication on each side of the fold of the brachial valve is as a rule bifurcated. Presumably a corresponding condition exists on the pedicle valve, but it is less conspicuous. The plications of the sinus are sometimes noticeably finer than those of the lateral areas, and, in addition, they are sometimes noticeably fainter. As to the size of the plications, a coarsely ribbed and a finely ribbed variety can be distinguished, but the extremes are not far apart, and most of the intermediate stages can be found.

Of the fine surface markings nothing definite can be said. Most of the specimens show no sculpture whatever. A very few have what appear to be traces of fine radial striae. These specimens are exfoliated, and to this fact they probably owe the appearance mentioned, for some of the specimens referred to *S. martiniiformis*, which should be entirely smooth if correctly identified, show, in places, fine striae comparable to these. Two or three specimens that seem to retain the outer layers of the shell more intact than the rest, on the other hand, present to view only obscure growth lines without trace or with only the faintest trace of radial markings. Fine, regular radial lirae are a well-recognized and presumably constant character of *S. arkansanus*, and thus, again, another difference is suggested.

Although one might wish to identify this species with *S. arkansanus*, which occurs at essentially the same locality but at a higher horizon, it manifests a closer agreement, so far as one may judge at this time, with *S. floydensis*. Many specimens agree closely with Weller's description and figures; others have a somewhat deeper and more angular sinus in the pedicle valve. In neither species are the fine details of sculpture at present definitely known.

Some of these shells might be mistaken for a large variety of *S. keokuk*. In that species the median rib in the sinus of the pedicle valve is commonly larger than the other ribs of the sinus; in this, the median rib tends to be small rather than large, and in consequence the sinus in such specimens has a somewhat deep, angular shape, while that of *S. keokuk* is shallow and rounded. The plications of *S. keokuk* are as a rule more elevated, but in this character and in the shape of the sinus the two species overlap to some extent.

Weller compares *S. floydensis* with *S. keokuk*, and in a general way it appears to bear the same relation to *S. keokuk* that this species does. On the other hand, the median sinus in some of these specimens is deeper and more angular than in the figured specimens of *S. floydensis*, and the plications seem more generally to be simple. Some specimens from Indiana which I have tentatively identified as *S. floydensis* (they have rather strongly rounded plications) show fine radial lirae crossed by rather stronger growth lines. Something of the sort is suggested by these specimens, but the facts are so uncertain that they may show difference instead of agreement.

The present species differs rather conspicuously from the associated one cited as *S. incertiformis* in its coarser costae and more gibbous and prominent umbo. The finely ribbed variety of this species, above referred to, differs only in the configuration of the umbo, and many specimens (owing probably to their numerous imperfections) occupy a doubtful place.

Spirifer incertiformis Girty, n. sp.

Plate 10, Figures 6–17

This form occurs with the one cited as *S. floydensis?* and in nearly equal abundance. From that species it is distinguished by its finer costae and by its wider umbonal angle, the umbonal region appearing somewhat flattened and the beak incurved and not very conspicuous. The sinus of the pedicle valve is broad toward the front, more or less angular, and rather deep. It is not, however, well defined but joins the lateral areas in a regular curve without any definite boundary. The fold of the brachial valve has corresponding characters, but it is more sharply bounded. In a number of specimens the costae on the lateral areas are arranged in groups of two or three, and this arrangement may have been rather general, for doubtless exfoliation has tended to obscure it. It is not conspicuous, but it can be clearly seen if looked for, especially over the posterior half of the shell. The costae are grouped by their spacing, not by their prominence, without the least suggestion of the bundling or fasciculation that is so conspicuous a feature of *Spirifer triplicatus*.

The cardinal area of the pedicle valve is moderately high, about 6 or 7 millimeters in most specimens, and somewhat variable in direction. It may be almost erect—that is, almost complanate with the shell margins—but is commonly much less inclined backward from the hinge. It is curved in the upper part, rather strongly in some specimens, but almost flat below. The delthyrium is wider than it is high, measuring 10 or 11 millimeters at the hinge line.

All the specimens collected are more or less exfoliated and are almost smooth, for the most part without a trace of such fine surface markings as may have been originally present. This fact would indicate that the markings were rather fine, and from the evidence available, including some external molds, they almost certainly consisted of fine radial lirae, cancellated by fine lamellose concentric lines.

In most of the characters observed this species appears to agree closely with *S. incertus* as described and figured by Weller, and the relation between them hangs more upon possible differences in sculpture than upon observed differences in configuration. *S. incertus* is marked by fine regular concentric lamellae or imbrications, and it is doubtful whether the present form has anything at all comparable. Imbrications as strong as those of *S. incertus* would leave traces, one would expect, even on the exfoliated surface, but the exfoliated specimens from Batesville are essentially smooth. Indeed, from the best evidence available I am fairly satisfied that this species is marked by fine radial striae, which *S. incertus* lacks, and that it lacks coarse imbrications, which *S. incertus* possesses. If this difference exists, the present species can not be *S. incertus*. It is in fact, more nearly related to *S. subequalis*, which has a similar configuration, especially in the flattened, spreading shape of the umbo of the pedicle valve, and also similar finely cancellated surface markings. *S. subequalis* is, however, much more coarsely costate, besides differing in other ways—it is more extended transversely, its brachial valve is more gibbous, and it shows other differences.

Though similar in a general way, characteristic specimens of this species are readily distinguished from characteristic specimens of the associated form identified as *S. floydensis?* Without taking into account possible differences in sculpture, *S. floydensis?* is more coarsely costate and has a more prominent and jutting umbo. Specimens occur, however, that seem to be intermediate, having finer costae than *S. floydensis?* and a more prominent beak than *S. incertiformis*. I have regarded such specimens as constituting a mutation of *S. floydensis?*, and they can be recognized by the configuration of the umbo, if that is adequately shown. Were many characters of these specimens not in doubt, however, such questions probably would not arise.

A few specimens included under this caption, one especially, shows a peculiar phase that possibly should be given recognition as a distinct variety. This specimen is a pedicle valve, and the costae in the sinus, instead of becoming numerous by subdivision, increase gradually in size so that toward the front they are conspicuously larger than the plications on the lateral areas.

Spirifer washingtonensis var. incomptus Girty, n. var., MS.

Plate 10, Figures 18–21

This identification rests primarily upon a large but imperfect pedicle valve, on which the following descriptive sketch is based, and secondarily upon two small and probably immature pedicle valves that apparently belong to the same species.

The cardinal angles appear to have been a little extended and acute, thus constituting the greatest width, which was about 37 millimeters; the length was 22 millimeters. The convexity is rather high, and the median sinus broad, deep, and fairly well defined. The plications are rather large and strong. Three occur in the sinus, the median one the largest, and ten on each of the lateral slopes. The sculpture, observed close to the cardinal line, consists of fine radial lirae crossed by fine lamellose concentric lirae.

The two smaller specimens show characters similar to those of the large one, with such modifications as might be expected in young shells of the same species. It is a noteworthy fact, as bearing upon the original sculpture of the specimens identified as *S. floydensis*, few of which show any surface markings at all, that all three of the present specimens are clearly marked by fine superficial radiating lirae.

This form is distinguished from the associated Spirifers especially by its coarse and strongly expressed costae. The costae are finer than those of the specimens referred to *Brachythyris suborbicularis*, and they are also stronger; the specimens so referred are further distinguished by their shape and their lack of fine sculptural markings. This species is of the general character of *S. keokuk*, but it is larger and especially has much coarser plications. It is, in fact, rather more like *S. increbescens*. In its general shape it differs conspicuously from typical *S. washingtonensis*, being more compact and less alate. In the Joplin district, however, a short-hinged variety of *S. washingtonensis* is associated with the typical form, and this the Batesville shell greatly resembles. In fact, it would at present be difficult to name any important difference between them. Nevertheless, comparisons have been possible only between pedicle valves, and between these only in certain characters, so that although negative evidence is wanting (apart from that of geologic age and faunal association) the affirmative evidence for the identification is inconclusive.

Spirifer martiniiformis Girty

Plate 12, Figures 18–20

1911. *Martinia glabra?* Girty, U. S. Geol. Survey Bull. 439, p. 70, pl. 9, figs. 9–11. Moorefield shale: Batesville, Ark.

1915. *Spirifer martiniiformis* Girty, U. S. Geol. Survey Bull. 595, p. 30, pl. 1, figs. 2–4. Boone chert: Batesville, Ark.

Of more than a score of specimens referred to *S. martiniiformis* in lot 3204, all, with possibly one exception, are pedicle valves. They show a rather large species (though a length of 35 millimeters is the maximum observed) having the general appearance of *Martinia* and *Reticularia*. The width is greater than the length, the convexity high, the beak prominent and incurved, and the cardinal angles strongly rounded. The cardinal area is high, rather well arched in the upper part, defined by pronounced angles, and divided by a rather narrow delthyrium. The pedicle valve is depressed along the median line into a conspicuous sinus, which is broad and subangular toward the front but in the umbonal region is only a narrow, shallow though distinct groove.

The shell in these specimens is exfoliated and presents a smooth, shining, finely fibrous appearance, and such external molds as could be found show it to be practically devoid of surface markings. On the inside the valve possesses dental plates of considerable height and length, placed rather close together and diverging but slightly toward the front.

If only its external characters were considered, this form would be referred to *Martinia*, but the presence of strongly developed dental plates makes such a reference impossible. Though having the configuration of *Reticularia* and like it possessing dental plates, the complete absence of a median septum would remove that genus also from consideration, even aside from the fact, which is well assured, that the surface lacks the concentric bands and rows of spines so characteristic of *Reticularia*. From *R. setigera* var. *internascens*, with which they are associated, these shells are readily distinguished by a number of characters, several of which are useful even in the imperfect condition in which all these specimens are found. Besides marked differences of structure, this form has a conspicuous median sinus, and it has a perfectly smooth surface, whereas the *Reticularia* shows the characteristic concentric banding, even if exfoliated, and also either indications of the rows of spines or, if the exfoliation goes deeper, the intricate network of fine lines. That these shells belong to the same species as those obtained somewhat higher in the formation and described as *Spirifer martiniiformis*, I can not doubt, for an essential agreement was found in every character shown.

Spirifer sp.

This specimen, which is a pedicle valve, does not perhaps deserve individual notice except for its appearance of combining the external expression of *Brachythyris* with the internal characters of *Spirifer*. It has at first sight a broadly ovate shape with a short hinge line and a surface marked by large depressed radial plications. The sinus is well developed though ill defined, and it tends to be somewhat angular or sharply rounded. The beak is prominent and suberect.

The general aspect, therefore, is highly suggestive of shells of the *Brachythyris* group, and the specimen might pass without challenge if identified as *B. suborbicularis*, were it not so broken as to show the presence of two powerful dental lamellae. The specimen is obviously imperfect and probably owes its shortness of hinge to that fact. Certainly the cardinal extremities are broken, but the portions also missing around the rest of the margin may be sufficient to compensate for this loss and still make the shell a short-hinged species. The best interpretation, however, seems to be that this is an aberrant specimen of the form referred to *S. floydensis*, distinguished especially by unusually large depressed costae.

Syringothyris subcuspidata (Hall)

Plate 11, Figures 4–9

1858. *Spirifer subcuspidatus* Hall, Iowa Geol. Survey, vol. 1, pt. 2, p. 646, pl. 20, figs. 61*a*, *b*. Keokuk limestone: Keokuk, Iowa; Nauvoo and Warsaw, Ill.

1914. *Syringothyris subcuspidatus* (Hall). Weller, Illinois Geol. Survey Mon. 1, p. 401, pl. 71, figs. 3–7. Keokuk limestone: Warsaw, Ill.

Though this form is in a general way similar to *Pseudosyrinx gigas* and occurs in the same fauna, the two species are readily distinguished unless the specimens have lost many of their original characters. In those shells the cardinal area is so much better developed than the opposite side that the area slopes forward from the hinge line, making an acute angle with the plane of the valve. In these, the relations are just the reverse; the cardinal area is not so long as the opposite side, the area slopes backward instead of forward, and the angle is obtuse instead of acute. Furthermore, those shells are highly punctate, while these are apparently impunctate; and lastly those are without the inner tube or syrinx which these possess. This last character, though fundamentally the most significant, is under the existing conditions the least available for discriminating the two forms because it is in so few specimens shown definitely or even at all. The presence of a syrinx is, of course, most readily determined if the fossils are preserved as internal molds; those from the Boone, however, are preserved in a limestone matrix without enough differentiation in color to render the facts at all clear. A syrinx has been identified in at least some of the specimens referred to *S. subcuspidata*, whereas it has not been identified in any of those referred to *P. gigas*. In view of the poor preservation of even the best of these specimens my observations do not prove the absence of this structure.

The punctate character of the shell in *P. gigas* is in most specimens very conspicuous, but in some it is not so readily ascertained. Nearly all the species of *Syringothyris* are described by Weller as having a punctate shell, but in my experience the punctate structure can rarely be seen, and still more rarely is it developed in a degree comparable with that of *P. gigas*. The shells under consideration seem to be without punctae, though this may mean only that they are finely punctate. At all events they offer a marked contrast to those cited under *P. gigas* and at the same time demonstrate a point in common with *S. subcuspidata*, the punctate structure of which Weller was unable to observe, though he did not doubt that it was originally present.

The cardinal area is essentially flat in some specimens but gently concave in others. Its direction can be determined definitely only in specimens that are perfect about the margin, and those are few. It sometimes appears to make more of a right angle with the plane of the valve than an obtuse angle, though this can not be stated positively and is stated at all only to suggest that a certain variation does occur, but in any event a marked contrast is shown in this regard with *P. gigas*.

Of the numerous species of *Syringothyris* recognized by Weller in the Mississippian faunas of the Mississippi Valley, none has so many characters in common with the present form as *S. subcuspidata*. In fact, at this time I am unable to name any differences of importance. Though probably not to be classed as important, one difference may exist in the plications of the pedicle valve, which, in my shell, are very subdued, much less distinct than they are represented in Weller's figures.

Pseudosyrinx gigas Weller

Plate 11, Figures 10–15

1914. *Pseudosyrinx gigas* Weller, Illinois Geol. Survey Mon. 1, p. 410, pl. 66, figs. 1–5. Keokuk (?): Kentucky. Keokuk limestone: Warsaw, Ill. Beds of Keokuk age: Crawfordsville, Ind.

This species is abundant at both stations, but the largest and best specimens were obtained at station 3203. Some of these shells are of large size, one measuring no less than 65 millimeters at the hinge line. The width, however, is conditioned by the angle included between the sides of the cardinal area, together with the height of the area. The height naturally varies with age, but the angle made by the sides, though constant for each specimen, varies from one specimen to another. In the large specimen just mentioned, which is uncommonly broad, this angle is about 105°, while in a narrow specimen it is only 80°. The height of the area in the narrow specimen is about 40 millimeters and in the broad one about 55 millimeters. Few of my specimens have the area as high as 40 millimeters, however.

Besides their size, one of the noteworthy features of these shells is the height of the cardinal area, which in comparison with the length of the side opposite to it is very great. The greater height of the area causes it to have a strong forward inclination from the cardinal line. In most specimens the area is nearly flat, but it may be appreciably curved, especially in the upper part, and the growth of the valve as a whole may be somewhat twisted.

A third conspicuous feature of these shells is their highly punctate structure, which is especially conspicuous in the specimens from station 3204 but is readily seen in all of them.

Several other features possibly deserve mention. The sinus of the pedicle valve widens rapidly and may be very broad at the anterior margin. It is ill-defined, but the fold corresponding to it in the brachial valve has very definite boundaries. The lateral plications of the pedicle valve are commonly depressed and, though, distinctly defined, far from conspicuous. They are as a rule distinctly stronger than the lateral plications of the brachial valve.

In none of the specimens observed has a syrinx been discovered, and in one specimen which was ground down across the apex the structure was apparently absent. If the syrinx was undeveloped, as it appears to be, this form belongs under *Pseudosyrinx* instead of *Syringothyris*, and it appears to agree very closely with *P. gigas*.

Brachythyris suborbicularis (Hall)

Plate 11, Figures 1–3

1858. *Spirifer suborbicularis* Hall, Iowa Geol. Survey Rept., vol. 1, pt. 2, p. 644. Keokuk limestone: Keokuk, Iowa; Warsaw, Ill.

1914. *Brachythyris suborbicularis* (Hall). Weller, Illinois Geol. Survey Mon. 1, p. 374, pl. 61, figs. 1–8, pl. 62, figs. 1–2. Burlington limestone: Springfield, Mo.; Sulphur Springs, Mo. Keokuk limestone: Keokuk, Iowa; Springfield, Mo. Beds of Keokuk age: Crawfordsville, Ind.

Some of the forms assumed by *Spirifer floydensis?* simulate species of the *Brachythyris* group very closely, so that one is sometimes in doubt where certain specimens belong, though only, of course, if they are in an imperfect condition. A few specimens in my collections, however, can safely be referred to *Brachythyris* because of their configuration, of their lack of superficial sculpture, and, where the facts have been determined, of their lack of internal structures in the pedicle valve.

The most characteristic of the specimens here referred have a rather elongate shape and contract above to a somewhat short hinge line. The surface is covered by rather large, weak plications, which are distributed somewhat in the following manner: The sinus begins as a narrow, deep groove inclosed between two bounding costae. Shortly the groove becomes shallow or flat and defined by incised lines which form the inner outlines of two costae, one on each side, given off by the bounding costae of the sinus. Thus in the anterior part the sinus is ill-defined, though its boundaries can be determined by tracing forward the plications that bound it in the umbonal region. It has one plication on each side and a flat, narrow bottom defined by grooves, like a sort of depressed plication, which traces back into the simple sulcus or sinus of the umbonal region. The lateral plications number eight or more, the exact number being difficult to determine because they grow finer and fainter toward the sides and gradually lose definition entirely. The surface is apparently quite without fine superficial markings except those of the nature of growth lines.

Besides specimens having the characters just recited, I am including in this species others whose shape is broader and still others whose plications are almost obsolete.

Although comparison can not be made in every detail, this form agrees very closely with *B. suborbicularis*, so that with the facts at hand it can not be distinguished specifically.

Reticularia setigera var. internascens Girty, n. var., MS.

Plate 12, Figures 1–12

In ordinary states of preservation shells of this type retain few characters that are useful for the differentiation and identification of species. The range of variation in shape is slight, and the very nature of the sculpture renders exfoliation inevitable if specimens are obtained in the usual way by being broken from hard rock. When the details of the sculpture are, though somewhat rarely, ascertained, they can generally not be ascertained in enough specimens to give much assurance as to the range of variation. Possibly on this account Weller was led to supplement such characters as are customarily used by the striated markings of the inside of the shell and the amount of surface covered by them.

The present form, which is represented by numerous though ill-preserved specimens, is of fairly large size, a width of 30 millimeters, however, being very rarely exceeded. The brachial valve is much wider than long and has a rather regular transversely elliptical shape. The pedicle valve, because of the projection of the umbonal parts, has the two dimensions more nearly equal, though here also the width is almost invariably greater. The proportions, however, vary.

The pedicle valve is highly convex. The beak tapers rapidly to a point and is not strongly incurved. The cardinal area is rather high and slopes backward but slightly from the cardinal line, but the curvature, chiefly localized in the upper part, brings the point of the beak to an angle of about 45° from the perpendicular. Many pedicle valves lack an appreciable sinus, but others show a faint depression down the median line, which becomes distinct only as it approaches the anterior border.

The brachial valve is less convex than the pedicle valve but is a little inflated in the umbonal region.

The surface markings are of the usual type, but they appear rather widely different in different specimens, largely, I believe, as a result of varying preservation. As a rule the surface is crossed by rather conspicuous, fine, regular corrugations, which gradually increase in size toward the front. It is also more or less covered by fine inosculating lines that have a generally radial direction. They form a sort of irregular network of crêpelike wrinkles, and the finely roughened surface which they produce is distinctly different from that made by the straight, continuous radial lines on the interior of *R. pseudolineata*, such as are shown by some of Weller's figures and by some of my specimens from the Keokuk limestone at Keokuk. I am not quite satisfied, however, that this character is uniformly present in *R. pseudolineata*, as I have specimens presumably of that species from the chert beds of the Joplin region that have a hachured surface much like that which I have just attempted to describe, only coarser. In apparent association with such specimens others having rectilinear markings also occur. Have we two distinct or one variable species?

Returning to the specimens from Batesville, the surface where it is not so deeply exfoliated sometimes shows small elongated excavations or nicks (really the loci of spines) which are very regularly arranged and, though they are not connected, produce an appearance as of slender, widely spaced radiating grooves. One may suspect that both sorts of markings had their origin in the spinose character of the outer surface, or rather that all three are an expression of changes in the mantle by which the entire shelly structure was created. Presumably as deposits were laid more and more thickly over the older parts of the shell, the individual scars made by the spines became transformed into the fine reticulation above described. The details of the transformation are, however, hard to understand, for the reticulation is far too fine to correspond directly to the relatively large and widely spaced spines.

On the inside the pedicle valve possesses a median septum and dental plates. The septum is rather low and thick and is confined to about one-third of the shell in the posterior part. Incredible as it may seem, the dental plates are fairly strong in some specimens and quite undeveloped in others. Where present they are somewhat less than half as long as the septum; they are situated rather close to it and are distinctly but not strongly divergent.

In the brachial valve a median septum may fairly be described as absent, though internal molds show an incised line which represents a linear elevation of inconsiderable height. Much more obvious are two rather narrow, elongated muscle scars, somewhat enlarged in the lower part and rounded at the end, that are situated not far apart close to the median line. These appear as excavations on the shell itself, where they are separated by a narrow ridge down the center and are bounded on the outer side by a rather thick elevated margin. In some aspects of preservation these three ridges might be misinterpreted as a median septum and, possibly, two socket plates.

Although no structure that could appropriately be called a septum has been observed in any brachial valve, a septum may sporadically be developed, for in *R. pseudolineata* also it is not invariably present. Weller, indeed, describes it as a character of that species, but his figure of a specimen from Callaway County, Mo. (fig. 11), fails to show a septum, and the only brachial valve in my collection from the same locality also fails to show one. Of other chert specimens (and no type of preservation would more faithfully disclose the facts than internal molds in chert) some have a well-developed septum, but others have not. This statement should be qualified to some extent, inasmuch as most of them have at least a faint groove along the median line, somewhat more pronounced than the other radial grooves that cover the inner surface. This groove could hardly be identified as the impression of a septum, however; but if the structure here is a septum, it is not hard to find specimens which though they must be referred to *Spirifer*, have a much better septum in the pedicle valve, for on internal molds the mound of matrix that filled the space between the dental plates bears not uncommonly a distinct groove. One other concession must also be made. The faint groove on the brachial valve of the specimens under discussion might be all that remained of an appreciable septum nearly buried in a secondary deposit, or callus. As against this we should bear in mind that the specimens still showing the impression of a high or at least a distinct septum were presumably thickened in a corresponding manner.

This species is clearly not *R. pseudolineata*. It resembles that species in the almost complete obsolescence of fold and sinus but differs in almost every other important character. It agrees rather better with *R. cooperensis*, though it is hard to compare the two on equal terms. The very different faunal association and geologic age in which the present form occurs establishes a strong presumption against its belonging to the species named. It is a larger shell, and besides this and one or two minor differences, the dental plates of the pedicle valve are relatively shorter, more nearly parallel, and placed more closely to the median septum. *R. setigera* must also be dismissed after a brief consideration. Like the other, it occurs with a markedly different fauna. It is commonly flexed into a much more pronounced fold and sinus, and the concentric rows of spines are generally much farther apart, though enough variation is shown in this regard to lay the statement open to exception. Possibly too, the absence of a median septum in the brachial valve of the present species and the presence of the two elongated muscle scars may be reckoned a distinguishing character not only from *R. setigera* but from other species. A much closer agreement is found with a form which occurs at the same general locality but at a somewhat higher horizon, which I propose to call *R. setigera* var. *internascens*. I can not yet say that the two forms agree in every essential point, though they agree in many, but at least I am unable to mention any essential point in which they differ.

Spiriferina subelliptica var. fayettevillensis Girty

1910. *Spiriferina subelliptica* var. *fayettevillensis* Girty, New York Acad. Sci. Annals, vol. 20, No. 3, pt. 2, p. 221. Basal part of Fayetteville shale: Fayetteville, Ark.

1911. *Spiriferina subelliptica* var. *fayettevillensis* Girty, U. S. Geol. Survey Bull. 439, p. 74, pl. 8, fig. 5. Moorefield shale: Batesville, Ark.

This species is inadequately represented by specimens which are both few in number and imperfect in preservation. The width of the larger specimens must have been as much as 20 millimeters. The fold and sinus are simple and are similar to the lateral plications except that they are conspicuously larger and stronger. Each of the lateral slopes bears six or possibly seven simple costae. The surface is marked by regular concentric lamellae, which are rather closely arranged. The shell substance is strongly and coarsely punctate.

So far as the characters are shown this form is in complete agreement with the one from the "Spring Creek limestone" identified as *S. subelliptica* var. *fayettevillensis*, and with one, much better represented, from the "Mayes formation" of Oklahoma, which apparently belongs to the same species. The general probabilities also favor this identification and add materially to the not wholly conclusive evidence of the specimens themselves.

Spiriferina sp.

Plate 12, Figures 13–17

The shells included here differ from one another sufficiently to suggest that they might be referred to different species if their characters were adequately known. Probably, therefore, it will be better to describe in a few words two or three specimens individually rather than to embrace all in a general description.

One pedicle valve from station 3203 is of uncommon size—at least 40 millimeters in width—very transverse, and with acute cardinal angles. Each of the lateral areas bears seven or eight costae separated by subangular furrows. The sinus, which is simple, is relatively large and shallow. The surface is crossed by rather coarse, regular concentric lamellae, and the shell is traversed by a few small tubules. A median septum is apparently present.

Another pedicle valve (from station 3204) is still larger, possibly 50 millimeters in width, and apparently not so transverse. The plications are larger and weaker, the median sinus being especially broad. The shell appears to be feebly punctate, and a median septum appears to be present.

The other specimens are mostly smaller and presumably younger, but they have essentially the same characters, especially the punctate structure and the lamellose surface.

The two most diagnostic characters ascribed to these shells, the median septum and the punctate structure, are more or less dubious. They are, in fact, so obscure that I at first referred these fossils to *Spirifer moorefieldanus*. More careful study directed to these critical characters led me to believe that a median septum was present in the pedicle valve. Consequently I was inclined to refer the species under the genus *Delthyris*. The shell substance appears fibrous and impunctate even to a careful inspection, and it was almost by accident that I discovered that one of the smaller specimens when wet showed punctae. This led me to reexamine the larger specimens, and these also proved to be punctate, but the punctae are so few and so irregular, in so far as one can see, that they might almost be due to some boring organism. The larger specimens share with the small ones the character of lamellose surface markings and probably of a median septum, for it is the larger ones that show these best. It would seem unwise, therefore, when they have such significant characters in common, to attempt to distinguish between the small specimens and the large ones that are so feebly and so erratically punctate. I have considered whether this form might not be the same as, or a variant of, the one identified as *Spiriferina subelliptica* var. *fayettevillensis*. They do not, to be sure, differ greatly in configuration, though they do in size, the larger specimens in this group being very much larger than any known specimens of the other. The shell structure in the specimens referred to *S. subelliptica* var. *fayettevillensis* is conspicuously punctate, so that that feature was recognized from the first. The punctae are finer as well as more obvious, and the concentric lamellae are finer and more closely arranged. There would thus appear to be two distinct species, but the distribution between them of the specimens contained in the collection is not free from doubt.

Hustedia circularis (Miller)

1892. *Retzia circularis* Miller, Indiana Geol. Survey Eighteenth Ann. Rept., adv. sheets, p. 72, pl. 9, figs. 32–34. Chouteau limestone: Sedalia, Mo.

1914. *Hustedia circularis* (Miller). Weller, Illinois Geol. Survey Mon. 1, p. 451, pl. 76, figs. 47–52. Chouteau limestone: Sedalia, Mo.; Pettis County, Mo.

The only specimen referred here is probably a pedicle valve. It is a small oval shell about 6.5 millimeters long and 5.5 millimeters broad, rather strongly arched, and marked by slender but well-defined rounded costae to the number of 16 or 18. The surface near the anterior margin appears to be slightly depressed across the middle, and the median stria is apparently a little deeper than the other striae that separate the costae. There are eight or possibly nine costae on each side of the median stria. The shell substance is distinctly punctate.

This specimen seems to agree perfectly with *H. circularis* in all its ascertained characters, but this agreement is not enough, in the group of shells to which it belongs, to establish its identification. The generic position of neither *H. circularis* nor the present form is certainly known, nor can it be determined from the exterior alone.

Bembexia magna Girty, n. sp., MS.?

This is a fine large species, but it is represented by a specimen so fragmentary that its characters can be given only in part. The final volution may have been as much as 35 millimeters in diameter. The whorls were probably well rounded, so that the suture was deeply depressed, and the spire was probably moderately high. The slit band is a conspicuous feature and was probably situated on the periphery or a little above. It is a shallow groove, about 2 millimeters wide, guarded by sharp ridges and crossed by fairly regular, closely arranged lamellose lines. The character of the surface above the slit band is not well shown, but it clearly was marked by rather strong, regular transverse lirae, coarser and more widely spaced than those on the band. The lower surface also is marked only by strong, regular transverse lirae, flattened or broadly rounded on top and rising abruptly from somewhat wider interspaces.

The simple character of this species, its regularly rounded volutions, marked only by transverse lirae which are interrupted by a broad, prominent slit band, make this a striking form and one easily to be recognized if it had been already described from our Mississippian faunas. Nothing like it, however, appears in the literature, except possibly two large forms named by Worthen but too imperfectly known for recognition. I have, however, a species described in manuscript as *Bembexia magna*, whose characters are almost exactly like those of the present specimen, though the two forms are of a markedly different geologic age and are associated with markedly different faunas. In the characters shown, the only differences noted are that the present form may be a little more strongly and coarsely striated on the surface below the slit band and a little less sharply striated on the surface above it.

Orthonychia ungula Weller

Plate 12, Figures 21, 22

1906. *Orthonychia ungula* Weller, St. Louis Acad. Sci. Trans., vol. 16, p. 461, pl. 7 figs. 36–37. Glen Park limestone: Glen Park, Mo.

Three specimens are included here, none of which is in exact agreement with the species cited. One from station 3203 closely resembles Weller's figure of *O. jeffersonensis*, but the figure represents a perfect shell, while my specimen is broken at the apex in such a manner as to indicate that that part was originally slightly hook-shaped. Of the two specimens figured by Weller to represent *O. ungula*, my specimen is less curved than one and less slender than the other. A second specimen from station 3203 and another much like it from station 3204 are even more imperfect, but their present appearance is suggestive of the smaller and more curved specimen of *O. ungula*.

Orthonychia undata (Winchell)

Plate 12, Figures 23, 24

1865. *Metoptoma undata* Winchell, Acad. Nat. Sci. Philadelphia Proc., p. 31. [Kinderhook group], bed No. 5: Burlington, Iowa.

1901. *Igoceras undata* (Winchell). Weller, St. Louis Acad. Sci. Trans., vol. 11, No. 9, p. 202, pl. 20, fig. 16. Kinderhook group, bed No. 7: Burlington, Iowa.

This identification is primarily concerned with a single specimen from station 3203 which has a rather rapidly expanding shape and is erect, straight, and almost symmetrical, although it is slightly compressed so that one axis is a little longer than the other in transverse section. The rate of expansion and other characters are very suggestive of *O. undata* as figured by Weller, but the size is less than half that of the typical specimen. The straight axis and absence of longitudinal folds distinguish this form from *Capulus fissurella* and similar species, while the more rapid expansion and the absence of folds distinguish it from the broad variety of "*Platyceras infundibulum*" figured by Meek and Worthen. A very similar though even smaller and less perfect specimen was collected at station 3204.

Orthonychia sp.

The single specimen included here resembles the one from the same locality referred to *O. undata*, but it is decidedly more slender. It resembles the form or forms described by Meek and Worthen under the name of *Platyceras infundibulum*, but has only half the height of any of those specimens and lacks the plications of some of them. Its rate of expansion is intermediate between the slender specimen for which the provisional name *extinctor* was suggested and the more spreading one shown by Meek and Worthen's Figures 3b and 3c.[6]

Platyceras oxynotum Girty, n. sp.

Plate 12, Figures 28, 29

Shells of the *Platyceras* type are rather abundant in the middle Boone fauna near Batesville, but almost all the specimens collected are fragmentary—a fact which renders a satisfactory identification, in a genus where even good specimens are identified with difficulty, almost impossible. The typical specimen cited under this title is a large and nearly complete shell having the shape of a rapidly expanded cone which is bent into a hook at the apex but is more gently curved toward the aperture. Even the apex does not form a closed coil, and the whole shell makes only about one complete volution. The expansion is rapid, but only in the anterior-posterior dimension; the transverse expansion is much more gradual, with the result that the shell has a strongly compressed appearance, and the anterior side is even somewhat angulate or keeled, consequently also the aperture is much longer than it is wide, measuring about 28 by about 21 millimeters. The entire shell has a maximum length of about 48 millimeters. It is only slightly unsymmetrical with reference to a plane passing through the long axis of the aperture but displays a backward inclination so that in side view the apex projects very appreciably beyond the posterior outline of the parts below. A few large obscure folds are introduced toward the aperture, which is sinuous in two directions—that is, the sides of the shell are plicated, and its margin is scalloped.

In side view this specimen much resembles Keyes's figure of *P. latum*, although it is even more loosely coiled, and the apex rises higher above the plane of the aperture. The outline of the aperture, however, is here laterally compressed, much longer than wide, while there it is rounded and wider than long. The same may be said of *P. capax*, which is little more than a small form of *P. latum*.

Platyceras latum Keyes

Plate 12, Figures 25–27

1888. *Platyceras latum* Keyes, Am. Philos. Soc. Proc., vol. 25, p. 242, pl., figs. 10, 11. Burlington limestone: Burlington, Iowa.

1894. *Capulus latus* Keyes, Missouri Geol. Survey, vol. 5, p. 176, pl. 53, figs. 13*a*, *b*. Burlington limestone: Burlington, Iowa, Hannibal, Mo.

I am covering under this title a number of specimens, mostly somewhat fragmentary, that vary considerably among themselves. In general they have a conical shape, gently arched so as to make a more or less complete turn, rather less than more, and inclined so that the apex considerably overhangs the posterior end of the aperture. The aperture itself is rounded, about as wide as it is long, and somewhat campanulate, the shell tending to flare appreciably in the lower part. Seemingly the inclination is mainly backward, little if at all to one side, and the growth is fairly symmetrical with reference to a plane passing through the anterior-posterior axis.

One noteworthy deviation from this generally symmetrical shape is shown by several specimens and consists in a strong expansion toward the left posterior segment with a straightening of the outline so that the aperture to that extent is somewhat triangular instead of circular, and the greater development of the shell is on the left-hand side. Seemingly also some specimens have a stronger backward inclination than others, but unless specimens are rather perfect about the aperture, which few of mine are, this may be more of an appearance than a reality.

My specimens are mostly or wholly exfoliated, so that their surface characters can no longer be seen. One which is crushed and fragmentary and therefore especially uncertain as to its relations shows very fine longitudinal costae of several sizes. These are superficial, and consequently the othes specimens may originally have been ornamented in like manner. If so, they can scarcely be cited as *P. latum*, and of course this particular specimen is, for the same reason, more than under suspicion.

The characters just enumerated bring these shells into close relationship with *P. latum*, at least in point of configuration. Those with the unsymmetrical aperture of course are in that respect not like *P. latum*, although they seem to be a mere modification of those

[6] Meek, F. B., and Worthen, A. H., Illinois Geol. Survey, vol. 5, pl. 17, 1873.

that are. None of my specimens is as large as the one originally figured, and the smaller ones are more like *P. capax*, which seems little more than a small variety of *P. latum*, distinguished in addition, by its possibly less oblique shape.

Proetus sp. aff. P. roundyi var. alternatus Girty

1926. *Proetus roundyi* var. *alternatus* Girty, U. S. Geol. Survey Prof. Paper 146, p. 40, pl. 6, figs. 13a–15b. Limestone of Boone age: San Saba County, Tex.

Of this form the collection contains only a single specimen, a small pygidium of semicircular outline about 6 millimeters wide and 4 millimeters long. It is rather strongly arched from side to side, the axial lobes rising considerably from the pleural lobes. The pleural lobes are not strongly arched themselves but descend with considerably obliquity. The axial lobe is broad at the anterior end, though not so broad as the pleural lobes. The segmentation is fairly sharp over the anterior half of the pygidium but obscure or incomplete over the posterior half, so that the number of segments can not be counted with any certainty. Besides this the axial lobe is largely exfoliated. Nevertheless, it has four distinguishable segments toward the anterior end, with space for three or possibly four indistinct ones posterior to them. The segments of the pleural lobes seem to correspond exactly with those of the axial lobe, so that there are four distinct pleural segments in the anterior part with several others suggested or incompletely defined in the posterior part. The pleural segments thus appear as an outward prolongation of the axial segments; the pleural segments, however, are subdivided, with the anterior semisegment of each pair narrower than the other and slightly depressed below it. In the general obsolescence of the segmentation posteriorly the subdivision of the segments is first obscured and then the definition of the segments themselves. The marginal parts of the pygidium are unsegmented, forming a distinct but undefined border. The surface throughout appears to be uniformly and finely granulose.

I have been unable to locate this pygidium under any of our Mississippian species of *Proetus*. It appears to belong to an undescribed species or else, as its small size suggests, to be a young specimen of some known form. Of the described species some have more numerous segments; some that have about the same number of lateral segments have more numerous axial segments. Even in this specimen the correspondence between the segments of the axial and pleural lobes may not be as complete as I suppose, though discordance must be limited to the posterior half. *Proetus swallowi* has a like number of segments on the pleural lobes (seven), but it has eleven on the axial lobe, and it is also much larger. *Proetus tennesseensis* comes nearest perhaps to the Boone form. It is described as having eight or nine segments on both the axial and pleural lobes, but nothing is said about the pleural segments being subdivided. Winchell remarks that the length of the pygidium is nearly twice the breadth, proportions very different from those of my specimen, but Winchell evidently meant to say just the opposite, as he gives measurements "length 3/8 inch and breadth 5/8 inch." In some respects this pygidium much resembles that of *P. roundyi*, especially the variety *alternatus*. That species, however, has 11 axial segments; this apparently only 7 or 8.

Cytherella sp.

This, the only ostracode in the collection, consists of a single valve which is poorly preserved but which clearly belongs to the genus *Cytherella*. It occurs on a chip of rather siliceous limestone, and the character of the inner or contact margin can not be determined. The outline is a little more strongly curved along the dorsal than along the ventral side and more strongly curved at the anterior than at the posterior end. A faint indentation occurs near the middle of the valve—probably the external expression of a muscle scar. The specimen, which is probably a left valve, does not closely resemble any described species. The measurements are, length 0.96 millimeter, height 0.60 millimeter.

REGISTER OF LOCALITIES CITED

387. Batesville quadrangle, Ark. Loose pieces of chert in the bed of Spring Creek, a mile or two above Ruddell's mill. Upper chert member of the Boone.

387*a*. Same as 387. Another loose piece found near by. Upper chert member of the Boone.

388. Batesville quadrangle, Ark. Spring Creek, 1 mile above the trestle near Ruddell's mill. Loose pieces of chert from the top of the hill, probably about in place. Upper chert member of the Boone.

389. Batesville quadrangle, Ark. Loose blocks of chert, probably in place on hillside just south of station 390 but about 150 feet higher in section. Upper chert member of the Boone.

390. Batesville quadrangle, Ark. Hillside along Spring Creek, half a mile north of Ruddell's mill, near Batesville, Ark. Lower part of black calcareous shale near the middle of the upper chert member of the Boone.

1237B. Batesville quadrangle, Ark. Probably in NW. 1/4 NE. 1/4 sec. 21, T. 13 N., R. 7 W. The point thus designated is 6 or 7 miles southwest of Batesville. Upper chert member of the Boone.

1245A. Batesville quadrangle, Ark., Howards Wells, in SE. 1/4 sec. 28, T. 14 N., R. 5 W. Moorefield shale.

1245B. Batesville quadrangle, Howards Wells, Ark. Specimen thrown out in digging well. Given by the proprietor, Mr. Howard. Moorefield shale.

1284A. Batesville quadrangle, Spring Creek, Ark. In railroad cut east of trestle over wagon road. Moorefield shale ("Spring Creek limestone").

1248R. Batesville quadrangle, Spring Creek, Ark. Moorefield shale ("Spring Creek limestone").

1284T. Batesville quadrangle, Spring Creek, Ark. Loose material on railroad embankment. Moorefield shale ("Spring Creek limestone").

1248V. Batesville quadrangle, Spring Creek, Ark. Loose material on railroad embankment. Moorefield shale ("Spring Creek limestone").

1248W. Batesville quadrangle, Ark. Found loose on the railroad embankment along Spring Creek near Batesville. Upper chert member of the Boone.

1248X. Batesville quadrangle, Ark. NE. ¼ SW. ¼ sec. 34, T. 14 N., R. 5 W. Moorefield shale ("Spring Creek limestone").

1248Y. Batesville quadrangle, Spring Creek, Ark. Railroad embankment. Moorefield shale ("Spring Creek limestone").

1248Z. Batesville quadrangle, Spring Creek, Ark. Débris along railroad bank. Moorefield shale.

2048. Batesville quadrangle, Ruddell's mill on Spring Creek, 2½ miles west of Batesville, Ark. Moorefield shale ("Spring Creek limestone").

2049. Batesville quadrangle, 2½ miles west of Batesville, Ark., cut on railroad above Ruddell's mill; about same as 2048. Moorefield shale ("Spring Creek limestone").

2049a. Batesville quadrangle, Ruddell's mill, 2½ miles west of Batesville, Ark. A single loose block of "Spring Creek limestone."

2049b. Same as 2049a. Another loose block. Moorefield shale ("Spring Creek limestone").

2049c. Same as 2049a. Another loose block. Moorefield shale ("Spring Creek limestone").

2049d. Batesville quadrangle, Ark. Railroad ballast adjacent to cut at Ruddell's mill. Evidently from the "Spring Creek limestone."

2049f. Batesville quadrangle, Ark. Loose material from Moorefield shale ("Spring Creek limestone"); Spring Creek, Ark., same locality as 2049a.

2051. Batesville quadrangle, Moorefield, Ark.; hill opposite Godfrey's house. Moorefield shale.

2051b. Batesville quadrangle, Moorefield, Ark.; hill near Godfrey's house. Moorefield shale.

2051c. Batesville quadrangle, Moorefield, Ark. Moorefield shale.

2053. Batesville quadrangle, cut on railroad about half a mile west of White River Junction, Ark. Moorefield shale ("Spring Creek limestone").

3203. Batesville quadrangle, 1 mile southeast of James, Ark. Limestone in Boone chert, 150–160 feet above base of Boone.

3204. Batesville quadrangle, limestone quarry at Denieville, Ark. Limestone in Boone chert, about same horizon as 3203.

PLATES 9–12

PLATE 9

Chonetes miseri Girty, n. sp. (p. 81).

Figures 1–3. A pedicle valve seen from above, ×4 and natural size; side view in outline.

Boone chert, James, Ark. (station 3203).

Chonetes batesvillensis Girty, n. sp. (p. 82).

Figures 4, 5. A pedicle valve taken as the type. Seen from above, ×2 and natural size.

Boone chert, Denieville, Ark. (station 3204).

Figure 6. Another pedicle valve, seen from above, ×2.

Boone chert, James, Ark. (station 3203).

Pustula incrassata Girty, n. sp. (p. 86).

Figures 7–9. A pedicle valve seen from above, ×3 and natural size; side view in outline.

Boone chert, Denieville, Ark. (station 3204).

Productella hirsutiformis (Walcott)? (p. 83).

Figure 10. A fragment of a pedicle valve, deeply exfoliated. Its general relations appear to be with *P. hirsutiformis* as identified in the Moorefield shale.

Boone chert, Denieville, Ark. (station 3204).

Productus magnus Meek and Worthen (p. 83).

Figures 11, 12. A brachial valve preserved as an external mold with fragments of shell adhering to it. Seen from above and side view in outline.

Boone chert, James, Ark. (station 3203).

Productus crawfordsvillensis Weller ? (p. 83).

Figures 13, 14. A brachial valve preserved as an external mold. Seen from above and side view in outline.

Boone chert, Denieville, Ark. (station 3204).

Productus mesialis Hall? (p. 84).

Figures 15, 16. External mold of a brachial valve that has been somewhat deformed by pressure. Seen from above and side view in outline.

Figures 17–19. A pedicle valve that has been somewhat deformed by pressure and has lost some of its surface characters through exfoliation. Anterior view, posterior view, and side view in outline. The brachial valve shown by Figures 15 and 16 may belong with the species identified with *Productus burlingtonensis;* this is hardly true of the pedicle valve, by reason of its large spines.

Boone chert, Denieville, Ark. (station 3204).

Productus burlingtonensis Hall (p. 85).

Figures 20, 21. External mold of a brachial valve. Visceral disk and side view.

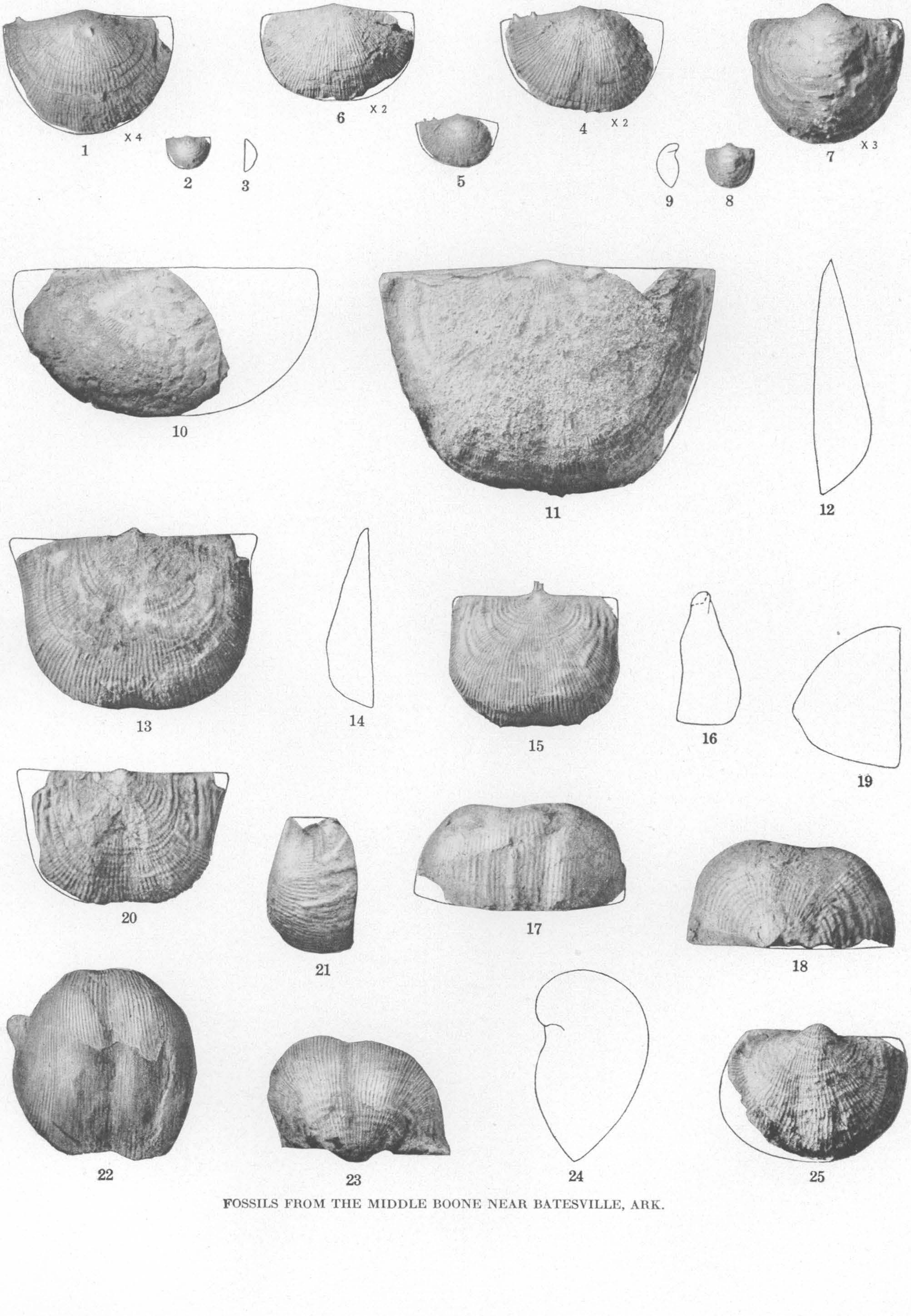
Figures 22–24. Three views of a pedicle valve that has been obliquely compressed

Boone chert, James, Ark. (station 3203).

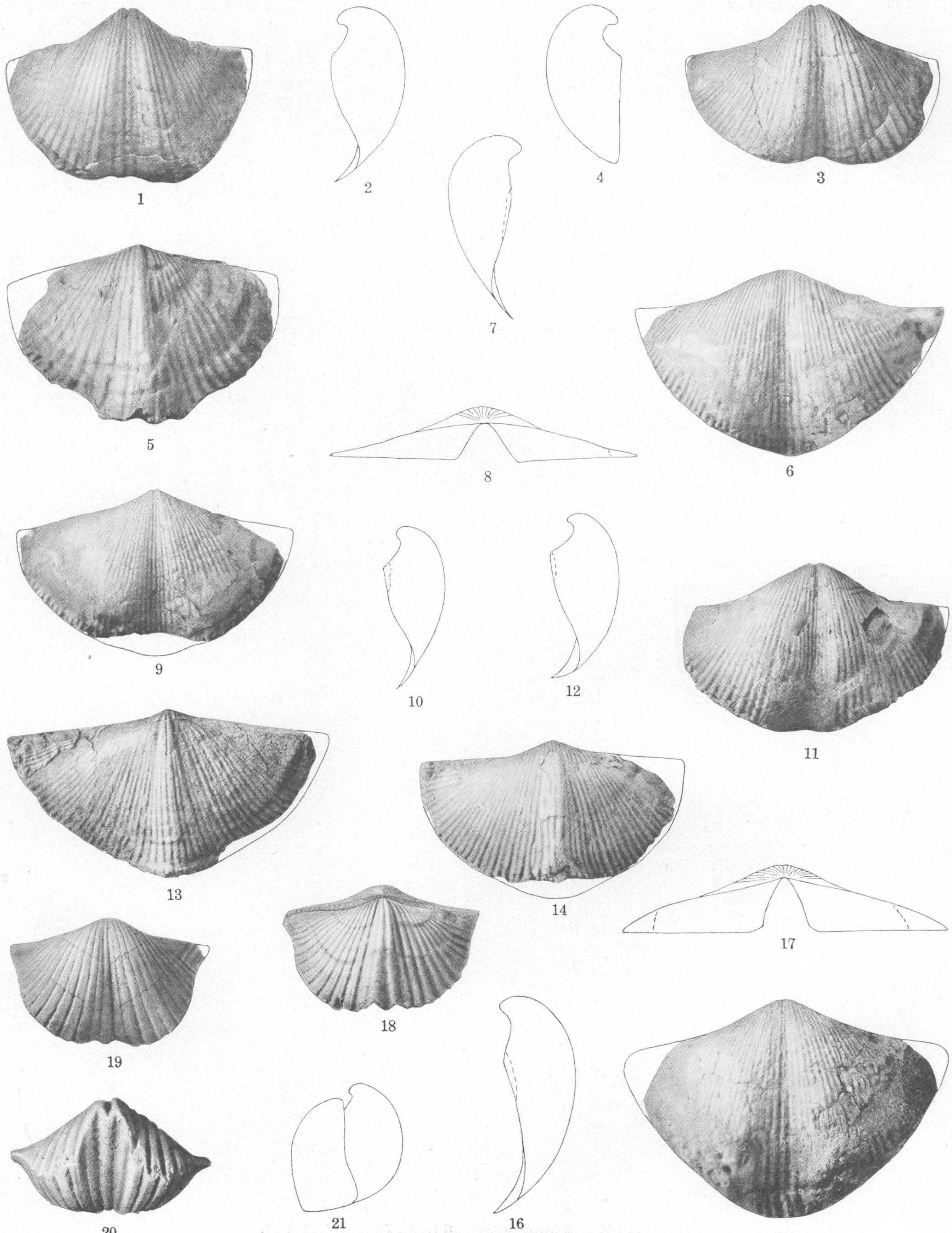
Avonia arkansana var. *multilirata* Girty? (p. 86).

Figure 25. An imperfect pedicle valve of doubtful affinities.

Boone chert, James, Ark. (station 3203).



FOSSILS FROM THE MIDDLE BOONE NEAR BATESVILLE, ARK.



FOSSILS FROM THE MIDDLE BOONE NEAR BATESVILLE, ARK.

PLATE 10

Spirifer floydensis Weller? (p. 87).

Figures 1, 2. A pedicle valve, seen from above and side view in outline.

Figures 3, 4. Similar views of another pedicle valve.

Figure 5. An exfoliated brachial valve.

Boone chert, James, Ark. (station 3203).

Spirifer incertiformis Girty, n. sp. (p. 88).

Figures 6–8. Three views of a pedicle valve of more than average length.

Figures 9, 10. A small transverse pedicle valve.

Figures 11, 12. Two views of a strongly arched specimen which probably owes this peculiarity to compression.

Figure 13. A brachial valve which is scarcely more than an internal mold.

Figure 14. A brachial valve, similarly preserved, of somewhat different type.

Boone chert, James, Ark. (station 3203).

Spirifer incertiformis Girty var. (p. 89).

Figures 15–17. Three views of a pedicle valve distinguished by large costae in the sinus.

Boone chert, James, Ark. (station 3203).

Spirifer washingtonensis Weller var. *incomptus* Girty, n. var. (p. 89).

Figures 18–21. Four views of a characteristic specimen. The same species apparently occurs in the fauna under consideration, but the specimens are too poor for illustration.

Boone chert, mine dump, Prosperity, Mo.

PLATE 11

Brachythyris suborbicularis (Hall) (p. 91).

Figure 1. A large fragmentary pedicle valve.

Boone chert, Denieville, Ark. (station 3204)

Figures 2, 3. Two views of a small pedicle valve.

Boone chert, James, Ark. (station 3203).

Syringothyris subcuspidata (Hall) (p. 90).

Figures 4–6. A rather broad pedicle valve, seen from above, side view in outline, and view of the cardinal area.

Figures 7–9. Three similar views of a narrower and somewhat twisted pedicle valve.

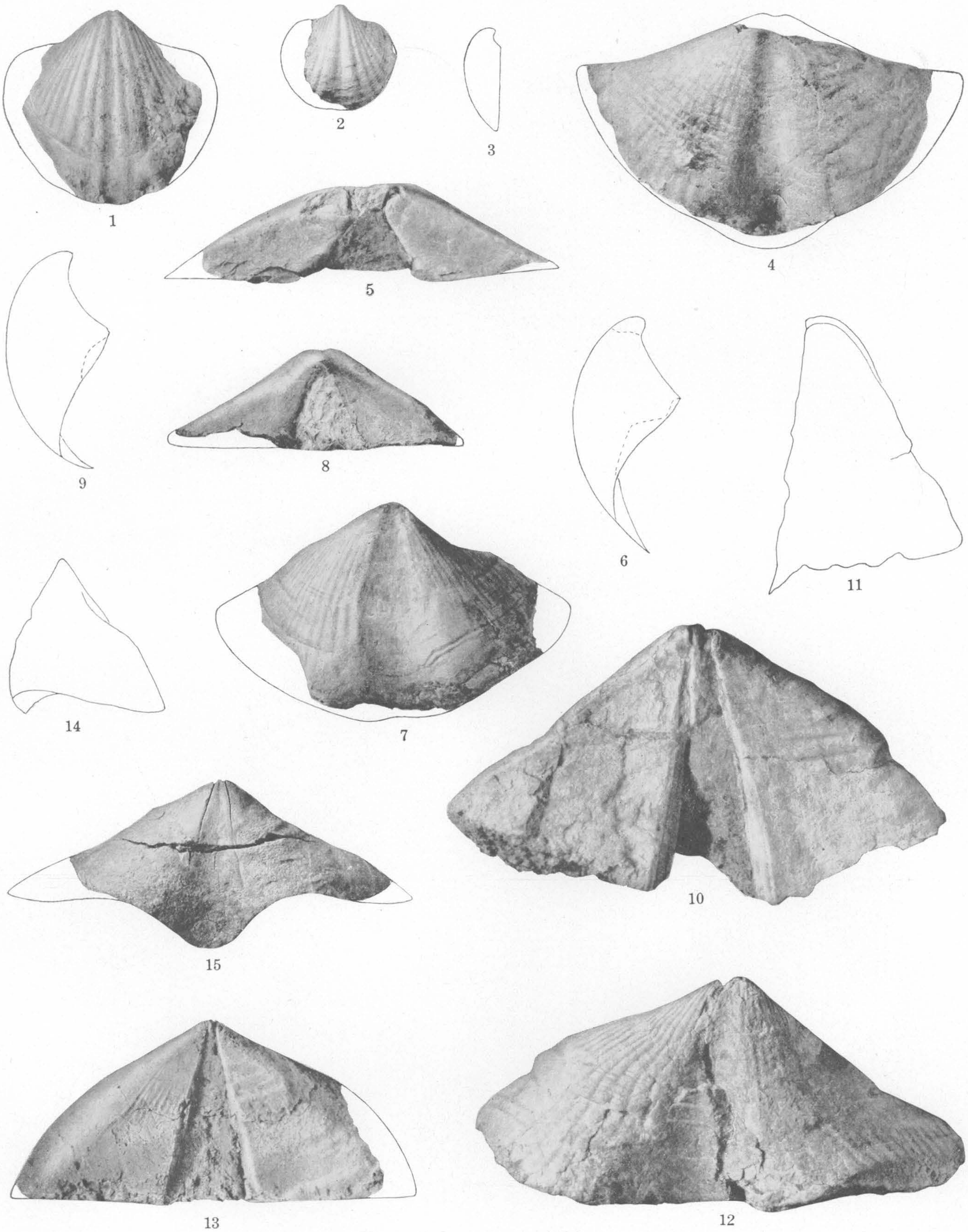
Boone chert, Denieville, Ark. (station 3204).

Pseudosyrinx gigas Weller. (p. 91).

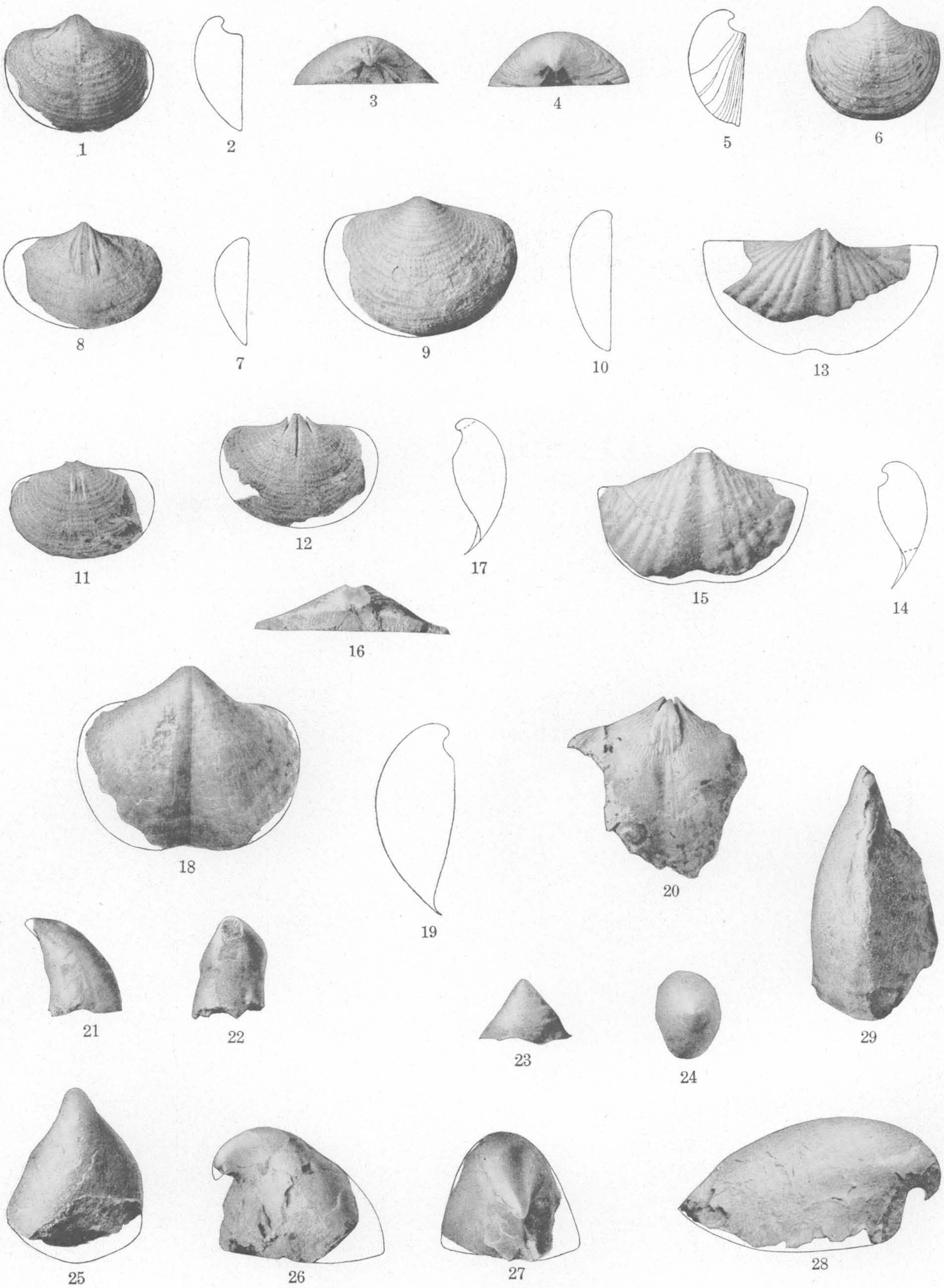
Figures 10–12. Cardinal area, anterior surface, and side view of a twisted pedicle valve.

Figures 13–15. Three similar views of a small pedicle valve.

Boone chert, James, Ark. (station 3203).



FOSSILS FROM THE MIDDLE BOONE NEAR BATESVILLE, ARK.



FOSSILS FROM THE MIDDLE BOONE NEAR BATESVILLE, ARK.

PLATE 12

Reticularia setigera Hall var. *internascens* Girty, n. var. (p. 91).

Figures 1–3. Three views of an exfoliated pedicle valve.

Figures 4–6. Three views of a pedicle valve that is not so deeply exfoliated.

Figures 7, 8. A brachial valve which is practically an internal mold and shows the muscular imprints.

Figures 9, 10. A brachial valve that retains most of the shell but has been somewhat flattened by pressure.

Boone chert, James, Ark. (station 3203).

Figure 11. Internal mold of a pedicle valve in chert.

Figure 12. Internal mold of a pedicle valve in chert. The specimen shows well the median septum, the dental lamellae, and the finely hachured surface.

Boone chert, Denieville, Ark. (station 3204).

Spiriferina sp. (p. 93).

Figures 13, 14. Fragment of an exfoliated pedicle valve which retains traces of coarse concentric lamellae and is pierced by rather large and very scarce punctae. Seen from above and side view in outline.

Boone chert, James, Ark. (station 3203).

Figures 15–17. An exfoliated and somewhat broken pedicle valve. The section across the beak shows the presence of a median septum. The surface retains traces of strong concentric lamellae, and scattered punctae can be seen here and there. Seen from above, side view in outline, and cardinal area.

Boone chert, Denieville, Ark. (station 3204).

Spirifer martiniiformis Girty (p. 89).

Figures 18, 19. Two views of a pedicle valve showing the *Martinia*-like shape.

Figure 20. Internal mold of a pedicle valve showing the imprints of well-developed dental plates. The differences in shape and convexity between the specimens, shown by a comparison of Figures 18 and 20, is due to the thickness of the shell which is present in the one and absent in the other.

Boone chert, Denieville, Ark. (station 3204).

Orthonychia ungula Weller (p. 94).

Figures 21, 22. Side view and posterior view of an imperfect specimen preserved as an internal mold.

Boone chert, James, Ark. (station 3203).

Orthonychia undata (Winchell) (p. 94).

Figures 23, 24. Two views of a specimen doubtfully referred to this species.

Boone chert, James, Ark. (station 3203).

Platyceras latum Keyes (p. 95).

Figures 25–27. An imperfect specimen which is an internal mold but for small pieces of shell that still adhere to it. It is represented as seen from above, from the side, and from the posterior end.

Boone chert, James, Ark. (station 3203).

Platyceras oxynotum Girty, n. sp. (p. 95).

Figures 28, 29. The typical specimen, which is in large part an internal mold. The apex is restored from a fragment of the same shell left in the matrix. The specimen is represented as seen from the side and from above.

Boone chert, James, Ark. (station 3203).

SALINITY OF THE WATER OF CHESAPEAKE BAY

By Roger C. Wells, Reginald K. Bailey, and Edward P. Henderson

INTRODUCTION

It is well known that the water of Chesapeake Bay is more or less salty. This characteristic has a bearing on navigation, engineering, the fish and oyster industries, sanitation, sedimentation, and many other matters. The saltiness, or salinity, of the water is far from uniform throughout the bay, however, and the data presented in this contribution show the distribution, range, and variation of the salinity in so far as about 2,500 determinations made at intervals during 1920, 1921, and 1922 could reveal the nature of the phenomena involved. The results show that definite physical factors are at work which, in spite of occasional seasonal fluctuations, tend to reproduce definite conditions from year to year. Briefly, it may be said that the salinity of the water increases from the head of the bay to its mouth in a fairly regular way at any given time and that the salinity also generally increases with depth at any given location. The final adjustments reached are the result of a complex interplay of several different factors, whose separate influences are in this paper considered in connection with the individual determinations.

Determinations of the salinity of the water of Chesapeake Bay were made in the chemical laboratory of the United States Geological Survey at the request of the United States Bureau of Fisheries, cooperating in a general biologic survey of the bay made under the direction of Dr. R. P. Cowles, of Johns Hopkins University. The results are published by the Geological Survey on account of the bearing they have on problems of geology, especially sedimentation, in Coastal Plain areas, the relation to biologic and other questions being left for consideration elsewhere. Doctor Cowles has kindly consented to release for publication the data on the temperature, depth, location, and other features of the samples collected under his direction, which are essential to establish the records of the samples.

The samples were collected from the Bureau of Fisheries boat *Fish Hawk*, by means of the usual water bottle and with the precautions generally observed in collecting samples of sea water. They were preserved in "magnesium citrate" bottles. At the end of the cruise one set of samples was shipped to Washington for determination of the salinity. The thermometers used to determine the temperature of the water at the different depths at the time of collection were standardized by the Bureau of Standards.

The word "salinity" as used in this report, means the total number of parts, by weight, of chemical compounds of the same composition as those found in sea water, dissolved in 1,000 parts, by weight, of the sample. More specifically, the salinity, S, is defined, according to Knudsen,[1] as a definite function of the chloride content, Cl, thus:

$$S = 0.030 + 1.8050Cl$$

PREVIOUS WORK

A considerable number of determinations of the salinity of the water of Chesapeake Bay were published in 1916 by the United States Public Health Service in connection with a study of the pollution of the tidal waters of Maryland and Virginia.[2] Most of these, however, were made on samples from rivers and inlets along the borders of the bay. Some further determinations were published in 1917 by Sale and Skinner.[3] but the localities are too scattering to establish any general relations concerning the distribution of the salinity over the bay as a whole.

The determinations in these two papers fit in very well with those found in the present investigation. Some of the salinities found by Cumming in 1914 in the sounds along the eastern shore of the bay are higher than those found by the writers at corresponding stations in the bay—a fact, however, which may be in harmony with the tendency outlined on page 109.

METHOD OF DETERMINATION

The salinity of each sample was calculated from the chlorine content, as determined by titration by silver nitrate, potassium chromate being used as indicator. Titrations on Bureau of Fisheries samples Nos. 8707 to 8737 were made by R. C. Wells, on Nos. 8738 to 8769 by R. K. Bailey, and on Nos. 8770 to 9019 by E. P. Henderson. Mr. Wells supervised the methods used. Each author calculated the densities of the samples he analyzed from the data in Knudsen's tables.[4]

[1] Knudsen, Martin, Hydrographische Tabellen, p. iii, Copenhagen, 1901.

[2] Cumming, H. S., Investigation of the pollution of the tidal waters of Maryland and Virginia with special reference to shellfish-bearing areas: Public Health Bull. 74, 199 pp., with maps, 1916.

[3] Sale, J. W., and Skinner, W W., The vertical distribution of dissolved oxygen and the precipitation by salt water in certain tidal areas: Franklin Inst. Jour., December, 1917, pp. 837-848.

[4] Knudsen, Martin, op. cit.

The titrations were made essentially as recommended by the Conseil permanent international de la mer, except that an ordinary 50 cubic centimeter burette and a 15 cubic centimeter pipette were used. The silver nitrate solution was of such strength that about 41 cubic centimeters was required for a 15 cubic centimeter portion of normal sea water. This procedure necessitates a little more calculation to reduce the results to standard form, but is believed to be fully as accurate as that with the special apparatus and silver nitrate solution. The usual precautions to maintain a uniform temperature and clean apparatus were observed.

The silver nitrate solution was standardized with a sample of sea water sent out from Copenhagen, marked "Cl = 19.379 ‰," which was checked and found to be correct on the basis of weighings in air and counting the bromine as an equivalent amount of chlorine. A pipette full of standard sea water is titrated against the silver nitrate solution after the addition of 5 drops of 10 per cent potassium chromate solution, until a definite pink color persists for about three minutes while the solution is stirred vigorously with a stirring rod. Suppose it is found that 42.58 cubic centimeters of silver nitrate is required. Knudsen's table on page 19 shows that sea water having 19.38 parts of chlorine per thousand has a salinity of 35.01 parts per thousand and a density at 0° of 1.02814. Knudsen's table on page 41 shows that the density of this water at 20° would be 1.02463—that is, 1 liter at 20° would weigh 1,024.6 grams—and 1,024.6 grams of the water would contain 35.87 grams of salts, as 1,000 grams contain 35.01 grams of salts by definition of the word salinity.

If now an unknown sample is titrated and requires b cubic centimeters, of silver nitrate the salt content in grams per liter at 20° C. will be $\frac{b}{42.58}\times 35.87$. The fraction $\frac{35.87}{42.58}$ will be a constant factor, and the product indicated gives the salt content in grams per liter at 20° for each sample titrated. The results are reduced to salinity, or parts per thousand, by means of the accompanying Table 1. It is not necessary that the titration should be made at exactly 20°, but it is essential that the silver solution and the sample being titrated should be at approximately the same temperature. It is obvious that the factor used $\left(\text{for example, } \frac{35.87}{42.58}\right)$ should refer to the same temperature as the table of corrections (Table 1), and that this factor must be determined for each lot of silver nitrate solution made up. A large quantity of silver nitrate solution prepared at one time saves repeated standardizations, but has the disadvantage of changing in temperature more slowly than the small bottles of sea water being titrated. When many titrations are to be made it is convenient to have the silver nitrate solution kept in a dark bottle placed on a shelf above the burette but connected by a siphon so that the burette may be quickly filled merely by opening a pinchcock.

TABLE 1.—*Correction for reducing salt content expressed as grams per liter at 20° C. to salinity, or parts per thousand*

Grams per liter at 20° C.	Correction	Grams per liter at 20° C.	Correction
10	−0. 06	26	−0. 44
11	−. 07	27	−. 48
12	−. 09	28	−. 52
13	−. 11	29	−. 56
14	−. 13	30	−. 60
15	−. 15	31	−. 64
16	−. 17	32	−. 68
17	−. 19	33	−. 72
18	−. 21	34	−. 77
19	−. 23	35	−. 82
20	−. 26	36	−. 87
21	−. 29	37	−. 92
22	−. 32	38	−. 97
23	−. 35	39	−1. 03
24	−. 38	40	−1. 09
25	−. 41		

The density at 0° is read from the salinity by means of Knudsen's tables, pages 1–22, and the density at the temperature the sample had when collected is calculated by means of the tables on pages 39–42.

It is believed by the writers that the salinities and densities calculated as described above are but slightly if at all inaccurate, even for the more dilute waters, as can be readily shown. The tables are based on the assumption that sea water is diluted with practically pure water, whereas in Chesapeake Bay it is actually diluted with river water of somewhat different composition from sea water. For example, Susquehanna River water, according to Dole,[5] has the following mean composition, in parts per million of dissolved matter: SiO_2, 8.7; Fe, 0.09; Ca, 21; Mg, 4.6; Na+K, 8.9; HCO_3, 54; SO_4, 31; NO_3, 3.4; Cl, 8.1; total, 112. Here the ratio of total dissolved matter to chlorine is 13.8, whereas in sea water it is 1.806. But sea water is so much more salty than Susquehanna River water that the admixture of river water in such quantities as occur in Chesapeake Bay does not alter the ratio between the chlorine and total salts appreciably.

As an illustration it is calculated that a mixture of 6 kilograms of Susquehanna River water with 1 kilogram of sea water would have a chlorine content of 2.62 grams per kilogram, from which the calculated salinity, according to Knudsen's table, would be 4.76 and the density at 0° C. 1.00377. The true salinity of this mixture, determined by analysis, would be 4.81, and its density at 0° approximately 1.00382. The difference is of the order of the experimental error.

[5] Dole, R. B., U. S. Geol. Survey Water-Supply Paper 236, p. 104, 1909.

Slight variations in composition of the salts doubtless occur with the season, but it would be impossible to make a complete analysis of every sample.[6] It has not seemed worth the time required to make any correction on this account. The method used has permitted a large number of determinations to be made, giving results which permit comparisons of the different waters on a common basis, and so far as known no comparisons will have any significant error on account of the slight departure of the waters from average ocean water.

LOCATION OF STATIONS

In accordance with the custom of the Bureau of Fisheries each station where samples were collected was designated by a consecutive number, and consequently the same stations, or points as near as the navigator of the *Fish Hawk* could get to them, appear repeatedly with new numbers. For the sake of simplicity these stations have been reduced to a single series of numbers, 1 to 34, and stations differing by only very short distances are grouped together, provided the differences in location are not essential. The location of these stations by chart bearings and by latitude and longitude is given in Table 2. (See also pl. 13.)

TABLE 2.—*Location of stations in Chesapeake Bay*

Station No.	Bureau of Fisheries Nos.		Bearings, latitude, and longitude
1	8738 8799 8800 8866 8867	8928 8959 8960 9019 9078	7 Foot Knoll Light W. by N. ¼ N.; Craig Channel Light NW. Lat. 39° 08′ 49″ N. Long. 76° 19′ 42″ W.
2	8739		Sandy Point Light SW.; Baltimore Light W. Lat. 39° 03′ 52″ N. Long. 76° 20′ 04″ W.
3	8736 8740 8797 8802 8864 8869	8926 8957 8962 9017 9076	Off Sandy Point. Sandy Point Light SW. by S. ½ S.; Baltimore Light NW. ¾ N. Lat. 39° 02′ 16″ N. Long. 76° 22′ 27″ W.
4	8737 8798 8801 8865 8868	8927 8958 8961 9018 9077	Love Point. Sandy Point Light SW. by W. ½ W.; Baltimore Light NW. by W. ⅜ W. Lat. 39° 02′ 23″ N. Long. 76° 20′ 30″ W.
5	8741 8796 8803 8861 8872 8925	8954 8963 9014 9045 9073	Thomas Point Light N. by E. ½ E.; Bloody Point Light E. ⅞ S Lat. 38° 50′ 10″ N. Long. 76° 27′ 02″ N.
6	8735 8742 8804 8862 8871 8924	8955 8964 9015 9046 9074	Bloody Point Light E. by S. about 1¾ miles. Lat. 38° 50′ 09″ N. Long. 76° 25′ 44″ W.

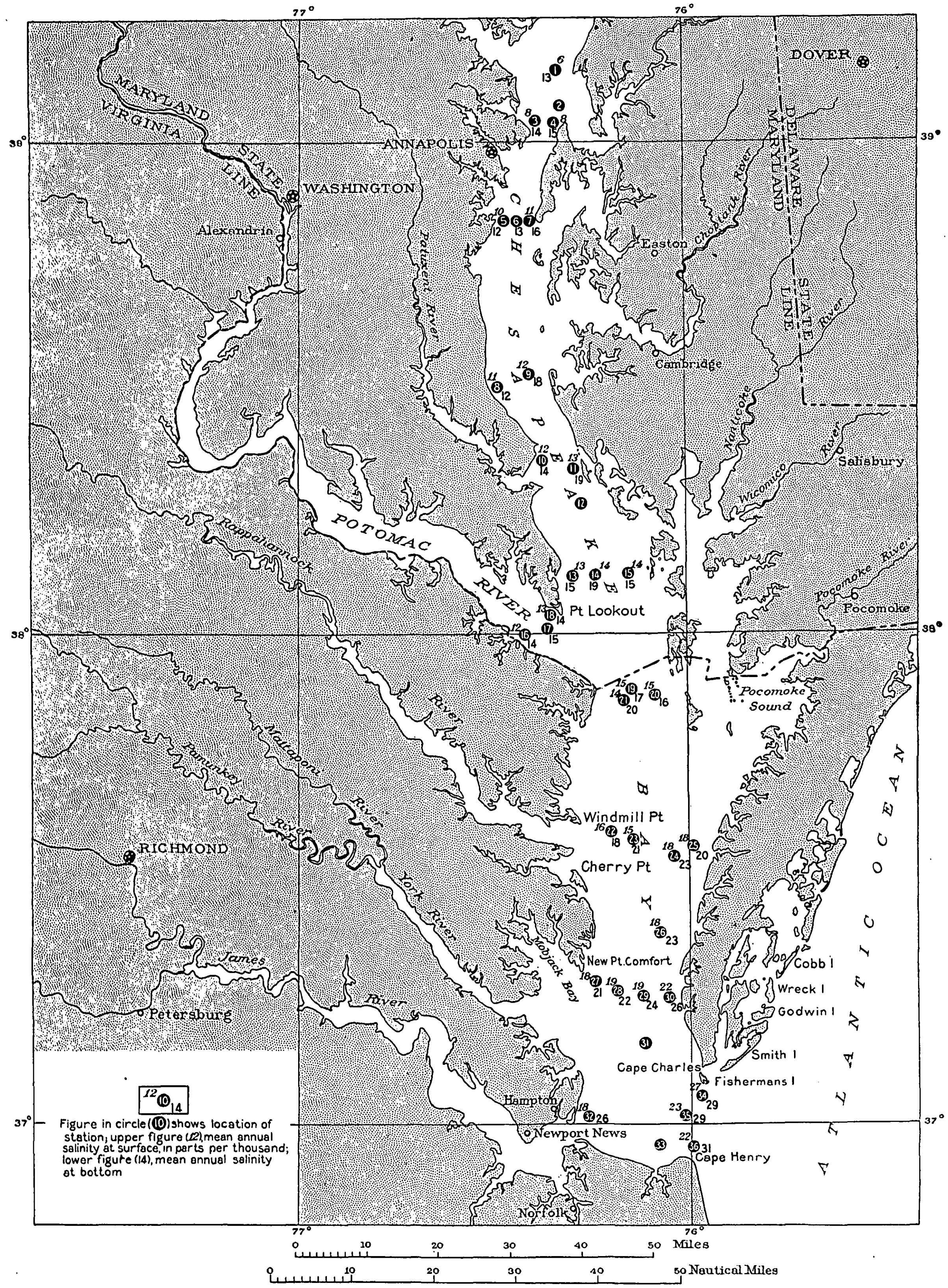
[6] For slight differences between Mediterranean water and average sea water see Bertrand, Freundler, and Ménager, Compt. Rend., vol. 174, p. 1251, 1922.

TABLE 2.—*Location of stations in Chesapeake Bay*—Continued

Station No.	Bureau of Fisheries Nos.		Bearings, latitude, and longitude
7	8734 8743 8795 8805 8863 8870	8923 8956 8965 9016 9047 9075	Bloody Point Light E. ½ N. about ½ mile. Lat. 38° 49′ 55″ N. Long. 76° 24′ 08″ W.
8	8732 8745 8793 8807 8859 8873	8952 8967 9013 9044 9072	Governor's Run Wharf W. ¼ S. ⅞ mile; Spar buoy S 2 B N. ¾ W. Lat. 38° 30′ 13″ N. Long. 76° 28′ 52″ W.
9	8733 8744 8794 8806 8860 8874	8922 8953 8966 9012 9043 9071	James Island. North end of James Island E. ½ N.; bell buoy 18 A N. ¼ E. Lat. 38° 31′ 07″ N. Long. 76° 25′ 09″ W.
10	8731 8746 8792 8808 8858 8875	8921 8951 8968 9011 9042 9070	Cove Point. Cove Point Light N. ⅞ W.; buoy 21 NE. by E. ¾ E. Lat. 38° 21′ 04″ N. Long. 76° 22′ 11″ W.
11	8730 8747 8791 8809 8857 8876	8920 8950 8969 9010 9041 9069	Barren Island. Barren Island Buoy, 16 D, NE. by N. 200 yards. Lat. 38° 20′ 20″ N. Long. 76° 18′ 09″ W.
12	8729 8748 8969		Hooper Island. Hooper Island Light SE.; Cedar Point Light NW. by W. ⅝ W.; Point No Point S. ⅞ W. Lat. 38° 16′ 22″ N. Long. 76° 16′ 36″ W.
13	8726 8751 8788 8812 8854 8879	8917 8947 8971 9007 9038 9066	Point No Point. Point No Point Light NW. by N. ¼ W.; Point Lookout Light SW. by S. ½ S. Lat. 38° 07′ 11″ N. Long. 76° 16′ 48″ W.
14	8727 8750 8789 8811 8855 8877	8918 8948 8970 9008 9039 9067	Point No Point. Point No Point Light W. by N. ½ N.; Point Lookout Light SW. ⅜ W. Lat. 38° 07′ 09″ N. Long. 76° 13′ 32″ W.
15	8728 8749 8790 8810 8856 8878	8919 8949 9009 9040 9068	Holland Island. Point No Point Light W. ⅞ N.; Holland Bar Light SE. ½ S. Lat. 38° 07′ 20″ N. Long. 76° 09′ 44″ W.
16	8723 8752 8785 8813 8851 8880	8914 8944 8974 9004 9035 9063	Mouth of Potomac. Point Lookout Light NE. by E. ¼ E.; bell buoy 5 NW. ½ N. Lat. 37° 59′ 56″ N. Long. 76° 23′ 19″ W.
17	8724 8753 8786 8814 8852 8881	8915 8945 8973 9005 9036 9064	Mouth of Potomac. Point Lookout Light NE. by E. ⅝ E.; Point Lookout buoy, N 2, E. ¼ S. Lat. 38° 01′ 21″ N. Long. 76° 21′ 14″ W.
18	8725 8754 8787 8815 8853 8882	8916 8946 8972 9006 9037 9065	Mouth of Potomac. Point Lookout Light E. by S. ¼ S.; Point Lookout buoy, N 2, SE. ½ S. Lat. 38° 02′ 28″ N. Long. 76° 20′ 43″ W.

TABLE 2.—*Location of stations in Chesapeake Bay*—Continued

Station No.	Bureau of Fisheries Nos.	Bearings, latitude, and longitude
19	8722 8913 8756 8943 8782 8975 8817 9002 8850 9033 8884 9061	Smith Point Light W. ½ N.; Great Wicomico Light SW. by W. ½ W. Lat. 37° 52′ 35″ N. Long. 76° 09′ 05″ W.
20	8755 8942 8783 8976 8816 9003 8849 9034 8883 9062 8912	Smith Point Light W. ¾ N.; Tangier Light SE. ⅜ S. Lat. 37° 52′ 34″ N. Long. 76° 05′ 33″ W.
21	8721 8911 8757 8941 8784 8977 8818 9001 8848 9032 8885 9060	Smith Point Light NW. by N.; buoy NNW.; Great Wicomico Light SW. by W. ½ W. Lat. 37° 51′ 40″ N. Long. 76° 09′ 48″ W
22	8720 8910 8758 8940 8781 8978 8819 9000 8847 9031 8886 9059	Off Rappahannock Spit. Windmill Point Light W. ½ N.; bell buoy SW. by W. ½ W. Lat. 37° 35′ 52″ N. Long. 76° 11′ 37″ W.
23	8719 8909 8759 8939 8781 8979 8819 8999 8846 9030 8887 9058	Off Rappahannock Spit. Windmill Point Light W. by N. ¼ N.; bell buoy W. ⅜ N. Lat. 37° 35′ 20″ N. Long. 76° 09′ 07″ W.
24	8717 8907 8760 8938 8780 8981 8820 8998 8845 9029 8889 9057	Off Sandy Point. Can buoy 1 E. ⅜ S. 3½ miles; buoy 10 C N. by E. ¼ E. Lat. 37° 33′ 02″ N. Long. 76° 02′ 06″ W.
25	8718 8937 8779 8980 8821 8997 8844 9028 8888 9056 8908	Sandy Point. Can buoy 1 SE. ½ E. about 1 mile; spar buoy, o. c. c. w, 10 B, SW. by S. ½ S. Lat. 37° 33′ 51″ N. Long. 75° 59′ 36″ W.
26	8716 8778 8761 8822	New Point Light SW. by W. ⅞ W.; Wolf Trap Light W. ½ N. Lat. 37° 23′ 31″ N. Long. 76° 04′ 49″ W.
27	8715 8906 8762 8936 8777 8982 8823 8996 8843 9027 8890 9055	New Point Comfort. Buoy C 9 NW. by N. ¼ N.; New Point Comfort Light NW. ¾ W.; York Spit Light S. by W. ½ W. Lat. 37° 16′ 50″ N. Long. 76° 14′ 12″ W.
28	8714 8905 8763 8935 8776 8983 8824 8995 8842 9026 8891 9054	Off New Point Comfort. New Point Comfort Light NW. by W. ⅜ W.; York Spit Light SW. ½ W.; buoy C 7 W. Lat. 37° 15′ 58″ N. Long. 76° 11′ 00″ W.
29	8713 8904 8764 8934 8775 8984 8825 8994 8841 9025 8892 9053	Off Cape Charles City. Plantation Light SE. by E.; buoy 10 E. by N. ⅝ N.; buoy 15 S. by E. ⅛ E. Lat. 37° 15′ 50″ N. Long. 76° 07′ 44″ W.
30	8712 8903 8765 8933 8774 8985 8826 8993 8840 9024 8893 9052	Cape Charles City. Plantation Light SE. ⅜ S.; buoy 10 N. ¼ E. Lat. 37° 15′ 18″ N. Long. 76° 04′ 54″ W.
31	8711	South end of 35-foot channel. Buoy S. 4 N. by W. ⅜ W.; buoy 2 SW. ⅛ S. Lat. 37° 09′ 10″ N. Long. 76° 06′ 31″ W.
32	8707 8929 8769 8988 8770 8989 8831 9020 8898 9048	Thimble Shoal. Thimble Shoal Light ENE. ¾ E.; can buoy 15 SE. ⅛ E. Lat. 37° 00′ 35″ N. Long. 76° 15′ 24″ W.
33	8899	Bell buoy 2 N. by W. ⅜ W.; bell buoy 3 W. ¼ N. Lat. 36° 57′ 56″ N. Long. 76° 04′ 52″ W.
34	8710 8902 8766 8932 8773 8986 8827 8992 8839 9023 8894 9051	Cape Charles. Cape Charles Light NE.; buoy E. ½ S.; lightship SW. by S. ¾ S. Lat. 37° 03′ 22″ N. Long. 75° 58′ 24″ W.
35	8709 8901 8767 8931 8772 8991 8828 9022 8838 9050 8895	Between the capes. Lightship S. ⅜ E.; Cape Henry Light S. ¼ W. Lat. 37° 00′ 10″ N. Long. 76° 00′ 42″ W
36	8708 8900 8768 8930 8771 8987 8829 8990 8837 9021 8896 9049	Cape Henry. Cape Henry Light SW. by S. ¾ S.; lightship N. ¾ W. Lat. 36° 56′ 56″ N. Long. 75° 59′ 52″ W.
37	8836	Atlantic Ocean E. ⅝ S. from whistle buoy off Cape Henry; line of 10 fathoms depth; about 30 miles out. Lat. 36° 56′ N. Long. 75° 35′ W.
38	8835	Similar to 37; line of 20 fathoms depth; about 50 miles out. Lat. 36° 56′ N. Long. 75° 11′ W.
39	8834	Similar to 37; line of 40 fathoms depth; about 70 miles out. Lat. 36° 56′ N. Long. 74° 42′ W.
40	8833	Similar to 37; line of 50 fathoms depth; about 83 miles out. Lat. 36° 56′ N. Long. 74° 38′ W.
41	8832	Similar to 37; line of 100 fathoms depth; about 87 miles out. Lat. 36° 56′ N. Long. 74° 35′ W.



MAP OF CHESAPEAKE BAY, SHOWING LOCATION OF SAMPLING STATIONS AND MEAN ANNUAL SALINITY AT SURFACE AND BOTTOM

100874°—29——8

VARIATIONS OF SALINITY

VARIATIONS OVER THE BAY AS A WHOLE

The salinity of the water increases from the head of the bay to its mouth at any given time, but not in a wholly regular way. It is approximately 6 in the latitude of Baltimore and about 24 between Cape Charles and Cape Henry; that of average sea water is about 33. There is a tendency toward higher salinities on the east side of the bay than on the west side at the same latitude. Although this condition has been ascribed to the fact that the principal rivers enter the bay on its west side, the rotation of the earth may also be a factor. It is well known that a body moving freely in any direction on the surface in the Northern Hemisphere is deflected to the right, and many instances of the operation of this tendency have been noted in the movement of natural waters. Thus, the Gulf Stream flows across to Europe and the polar currents are deflected toward Greenland and Labrador. Above Patuxent River there is not much difference in the stream flow into Chesapeake Bay on the east and west sides, and most of the water enters the bay from the Susquehanna at its head, yet there is still a slight difference in salinity on the two sides. This is what would be expected if it is assumed that the outflowing lighter water is deflected to the right and passes south along the west side of the bay. The difference in salinity between the east and west sides of all the lower portion of the bay is marked, and the relations in the channel between the capes are also what would be expected from the operation of the principle cited above.

The principal drainage areas furnishing water to Chesapeake Bay are shown in Table 3, together with estimates of their mean rate of contribution.[7]

TABLE 3.—*Annual inflow into Chesapeake Bay*

	Drainage area (square miles)	Mean rate of contribution (second-feet)
Susquehanna River Basin	27, 400	41, 300
West shore of bay between Susquehanna and Potomac Rivers	2, 390	3, 230
Potomac River Basin	14, 140	14, 850
Rappahannock River Basin above Fredericksburg	1, 590	1, 710
Rappahannock River Basin below Fredericksburg and minor streams tributary to the bay between Potomac River and latitude 37° 30′	1, 310	1, 440
James River above Cartersville	6, 230	7, 540
Appomattox River above Mattoax	745	930
Balance of James River Basin, all of York River Basin, and all minor streams tributary directly to the bay between latitude 37° 30′ and Cape Henry	6, 340	6, 970
East shore of bay between Susquehanna River and Cape Charles	3, 980	5, 580
	64, 125	83, 550
Chesapeake Bay itself	3, 380	[a] 4, 500
Grand total	67, 505	88, 050

[a] Mean annual rainfall on bay about 45 inches; evaporation assumed to be 60 per cent of rainfall. Some later calculations by one of the writers indicate that the annual evaporation is nearer the annual rainfall; if this is correct, the net contribution over the bay itself is negligible.

[7] From U. S. Geol. Survey Water-Supply Paper 234, p. 52, 1909, and other water-supply papers summarized for the writers by J. C. Hoyt, of the Geological Survey.

From the data in Table 3 and the known cross section of Chesapeake Bay it is calculated that the average outward current is about 0.3 nautical mile an hour. The rate naturally varies with the cross section of the bay. This rate, however, appears sufficiently large to warrant a consideration of the effect of the earth's rotation on the direction of the currents. The tides convert the net outflow into a series of impulses, first one way and then the other, and these do not occur in the same direction simultaneously over the whole area of the bay. Any given phase of the tidal impulse occurs about nine hours later in the latitude of Baltimore than at Cape Henry. Winds and seasonal flows also cause large variations in the currents in the bay, and the net result of all of these movements is a greatly accelerated mixing of the water of different densities and salinities.

Determinations by Doctor Cowles at station 14 January 25 and 26, 1921, by means of current meters and at different depths, showed rates of flow both above and below the mean rate given above. The highest rate was 1.70 miles an hour at a depth of 30 meters, the lowest 0.14 mile at the surface. Similar determinations at station 1 on January 27 and 28 ranged from 0.14 mile at a depth of 5 meters to 2.07 miles at the surface. Determinations at station 1 on March 26 and 27 ranged from 0.12 to 1.10 miles, both at the surface and with nearly the same direction of the wind, but on March 30 and 31 at the same station the variation was only from 0.02 to 0.46 mile. At station 14 on June 1 and 2 the rate ranged from 0.04 to 0.83 mile; at station 1 on the two following days the range at the surface was from 0.03 to 1.43 miles and at depth from 0.07 to 0.96 mile. The surface velocities of the ebb tides are about 0.1 mile greater at their maximum than those of the flood tides in the latitude of Point Lookout, whereas at Cape Henry Light the difference is about 0.5 mile, other conditions being similar.

The salinity of Chesapeake Bay water generally increases with depth. In other words, there must be a slow movement of the denser water from the ocean up the bay in the deepest channels, while the lighter water flows out over the heavier. For the reason mentioned above, however, this current also bears slightly toward the right—that is, in general toward the east side of the bay. Between Cape Henry and Cape Charles the net movement is of course outward, but there is also a slight under current of salt water moving inward at depth, chiefly on the Cape Charles side, which maintains the salinity of the bay.

Table 4 gives in a condensed form the average salinities observed at the surface and at the bottom at each station on the dates for which observations are available. The results are also shown graphically by curves in Figures 11, 12, and 13. In preparing these curves all observations for each station were averaged to a single figure for each period during which samples were collected. From the curves figures were then taken for each of the 12 months and averaged to obtain the annual mean for that station at the surface and at the bottom—that is, the annual mean was obtained partly by graphic interpolation and is not exactly the arithmetical mean of the figures in Table 4. As thus calculated each month received a weight of one-twelfth, and no more, in the annual mean. It is realized that the data are not as extended as might be desirable for calculating either monthly or annual averages, yet the curves and averages give a better idea of the relations than could be obtained from numerical data alone.

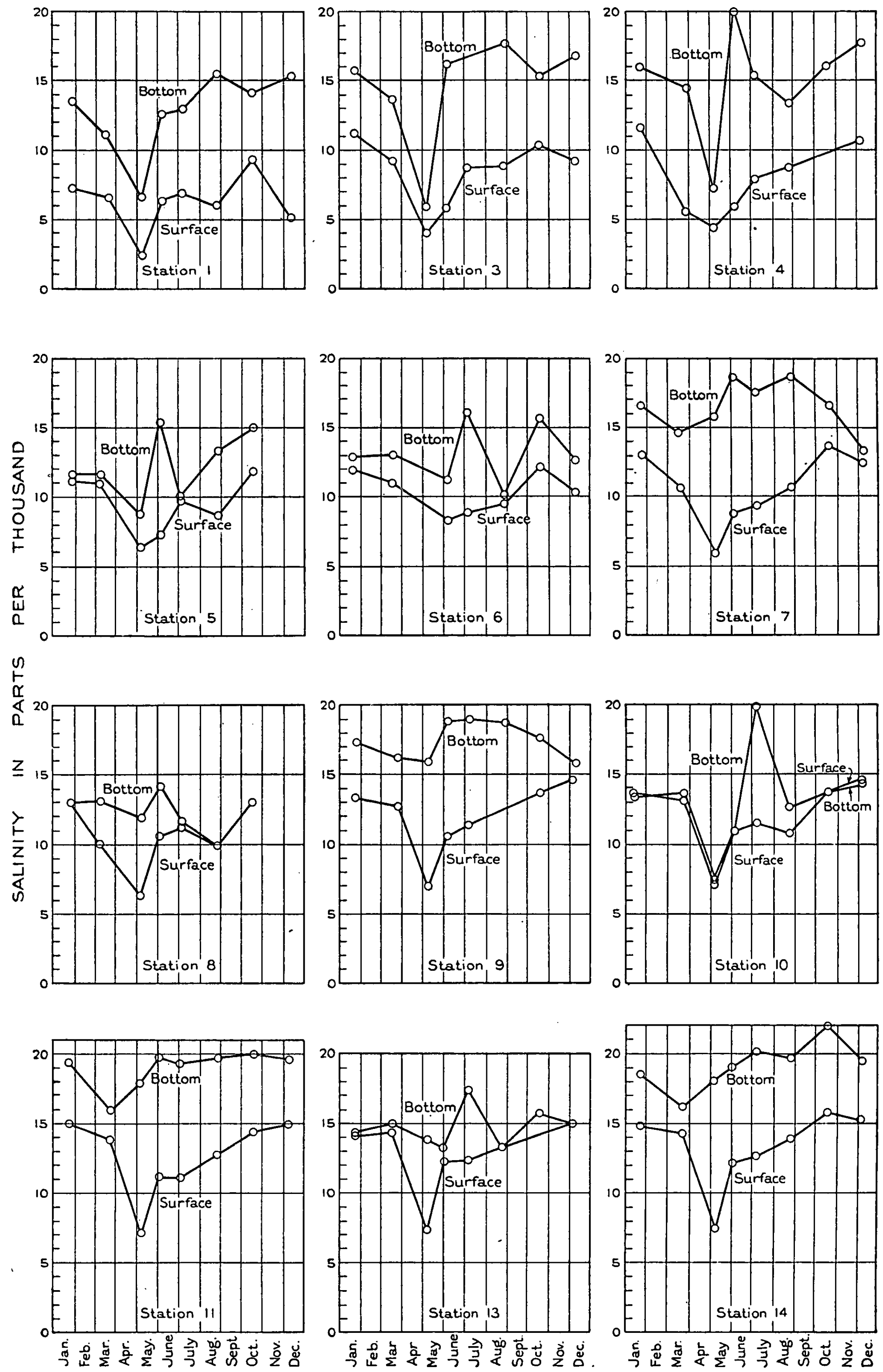


FIGURE 11.—Salinity at stations 1 to 14, Chesapeake Bay, by months

It should be borne in mind that like other measurements dependent on such natural conditions as rainfall and storms, the salinity is subject to occasional temporary and sometimes large variations from the mean, but it constantly tends to return to a fairly larly, in the fall, after the evaporation of the summer, the salinity gradually increases to a slightly higher and more steady figure.

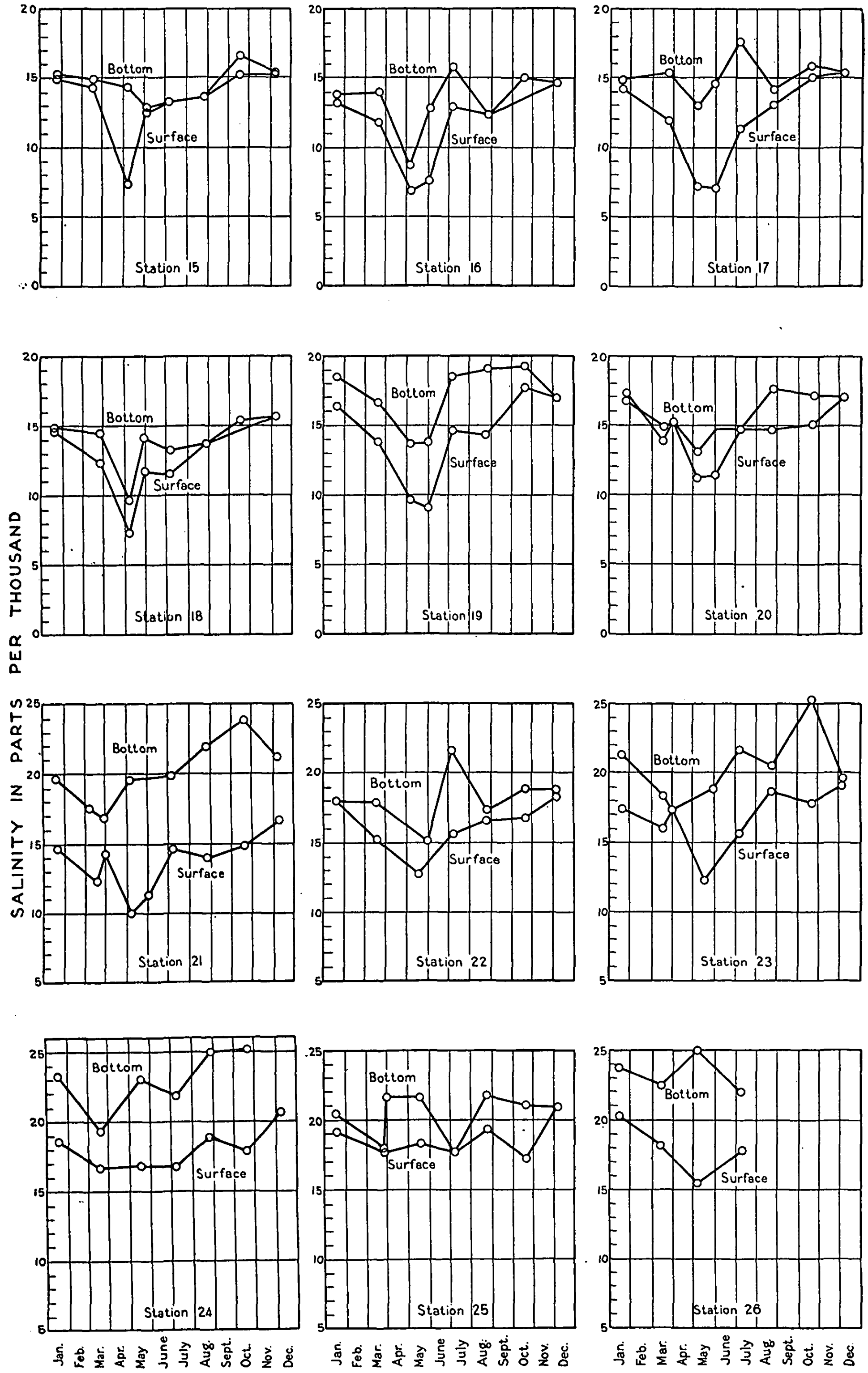


FIGURE 12.—Salinity at stations 15 to 26, Chesapeake Bay, by months

steady and regular figure. As would be expected from the usual spring floods in the Susquehanna River, there is a general tendency toward lower salinities, especially in the upper bay, in the spring. Simi-

VARIATIONS OF SALINITY AT SINGLE STATIONS

The conclusions set forth above are the results of averages and measurements on a large scale. Numerous individual measurements at the different stations, however, show variations of many kinds, each dependent on a separate factor, as might be expected from the nature of the forces involved. In its simplest terms the process that goes on in Chesapeake Bay is merely one of mixing river water with ocean water—a process in which the winds and the tides take part, the former with occasional large effects, the latter with unceasing regularity, and increasing in effect with the nearness to the ocean. Some of the other factors are rainfall, evaporation, and changes in temperature of the water. The adjustments reached are obviously the resultant of a complex interplay of forces, each varying in its own particular way. The discharge of the rivers, the rainfall, and the evaporation vary with the season of the year. The currents in the water are determined not only by the tides, but also by the winds, by the small normal discharge to the ocean, and partly by the configuration of the bottom, although, conversely, the configuration of the bottom is partly dependent on the currents. The density of the water depends both on its salinity and on its temperature. These separate factors may sometimes assist or sometimes oppose each other, so that the corresponding results occasionally vary widely. Illustrations of these relations may be found in the accompanying

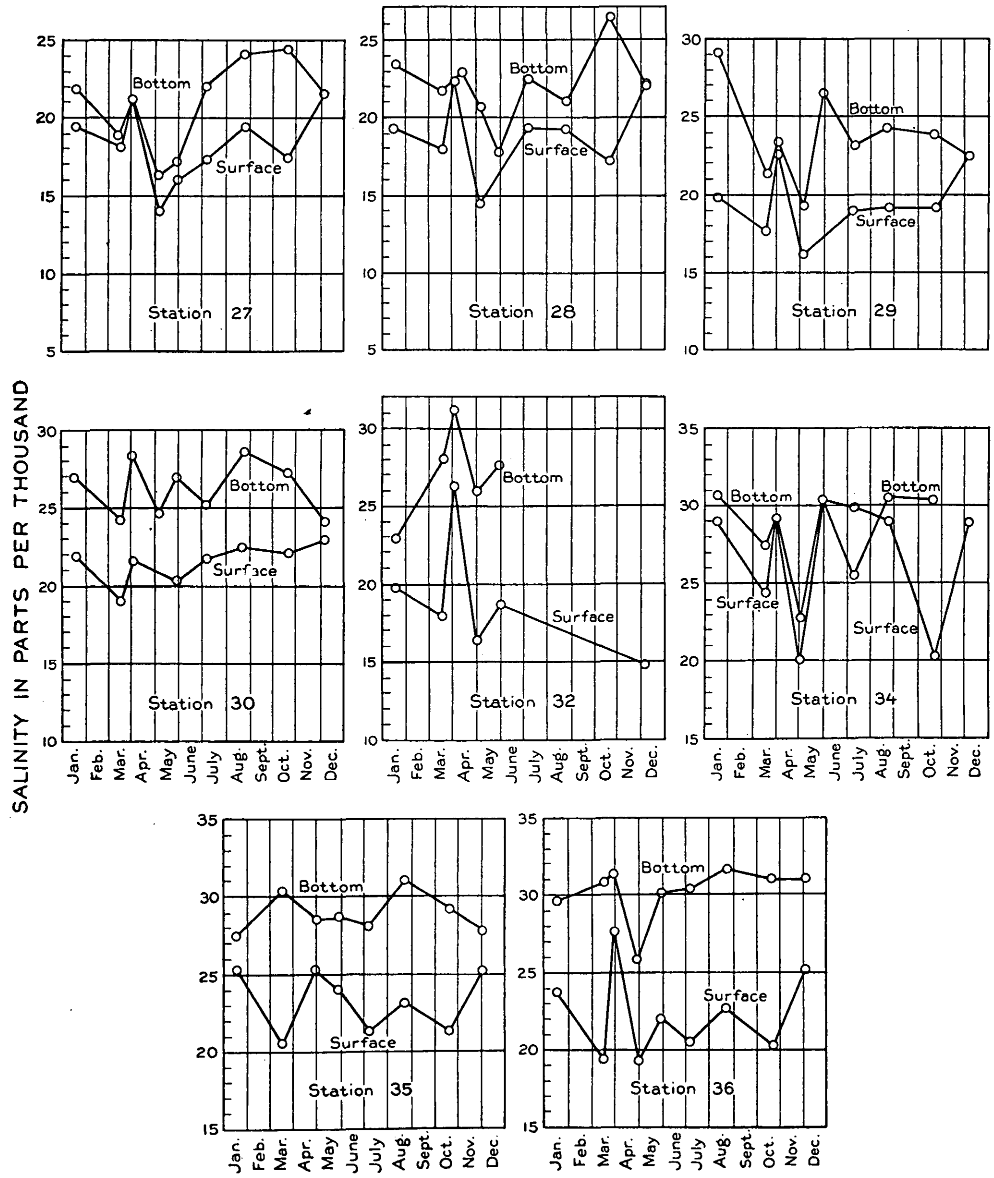


FIGURE 13.—Salinity at stations 27 to 36, Chesapeake Bay, by months

data, such as different salinities at the same station in different years, months, days, or even hours of the day, or, on the other hand, occasionally very slight variations over long intervals. Thus the salinities found in May, 1920, were uniformly low over the whole bay.

When it is noted that the average salinity changes a unit in 3 miles at some localities on the bay and that the tides sweep the water back and forth for greater distances than this in many places it is clear that considerable occasional variations are to be expected at individual stations. Similarly, at many localities the salinity changes on the average as much as a unit in a depth of 5 meters. Greater differences due to incomplete mixing are common.

Continuous records over 24-hour periods at different dates are shown in Table 5 for stations 1 and 14, and two such records are plotted in Figure 15 for four depths at station 14, about the middle of the bay east of Point No Point. These curves show that the surface water and bottom water vary less in salinity than the intermediate waters. The constancy in the bottom water is probably due in part to the lag in its motion caused by friction between the water and the bottom; that of the surface water may be caused by the more thorough mixing brought about by the winds and the waves.

The greatest movement seems to be shown in intermediate waters. In some of these the variations are irregular, as if the sampling bottle had penetrated first one layer then another. In others the variations are clearly due to the tides—that is, flood tides bring denser water, ebb tides lighter water. The differences in density due to differences in temperature are shown in the tables, but most of them are far smaller than those due to differences in salinity, so that only the salinity has been plotted in Figure 15.

The salinity of the water in the deep "holes" of the bay is somewhat more constant, with regard to both depth and the season, than it is in many shallow parts of the bay, as might be expected from analogy with well-known relations in oceanic circulation. The relatively denser water in the "holes" would be expected to be more or less stagnant. In channels this might not be so, however, but sufficient observations have not been made to establish any definite correlations between the density of the water and the flow in the channels.

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*

[For location of the stations see pl. 13. The figures in parentheses indicate the number of observations averaged to obtain the salinity given]

Station 1 (bottom depth 11 meters)

Date	Salinity			
	Surface		Bottom	
Jan. 27, 1921	7. 2	(11)	13. 5	(9)
Mar. 6, 1920	10. 3	(11)	12. 0	(10)
Mar. 26, 1921	3. 7	(15)	------	
Mar. 30, 1922	5. 6	(5)	10. 3	(15)
May 8, 1920	2. 3		6. 5	
June 3, 1921	6. 2	(16)	12. 5	(16)
July 3, 1920	6. 8	(16)	12. 8	(15)
Aug. 26, 1920	6. 0	(16)	15. 5	(16)
Oct. 15, 1920	9. 4	(16)	14. 2	(16)
Dec. 10, 1920	5. 1	(16)	15. 3	(16)
Annual mean	6. 3		12. 9	

Station 2 (bottom depth 13.7 meters)

Mar. 7, 1920	11. 6	15. 1

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 3 (bottom depth 13 meters)

Date	Salinity			
	Surface		Bottom	
Jan. 17, 1920	12. 0		17. 2	
Jan. 27, 1921	10. 4		14. 2	
Mar. 6, 1920	12. 4		14. 8	
Mar. 28, 1921	6. 0		12. 4	
May 7, 1920	4. 0		5. 8	
June 3, 1921	5. 8		16. 2	
July 4, 1920	8. 6		8. 9	
Aug. 26, 1920	8. 8	(2)	17. 7	(2)
Oct. 17, 1920	10. 4		15. 3	
Dec. 9, 1920	9. 1		16. 8	
Annual mean	8. 3		13. 9	

Station 4 (bottom depth 21 meters)

Jan. 17, 1920	12. 3	17. 4
Jan. 27, 1921	10. 9	14. 5
Mar. 28, 1921	5. 3	13. 0
Mar. 29, 1922	5. 7	15. 8
May 7, 1920	4. 4	7. 2
June 3, 1921	5. 9	20. 0
July 4, 1920	7. 9	15. 4
Aug. 26, 1920	8. 7	13. 4
Oct. 17, 1920	------	16. 0
Dec. 9, 1920	10. 6	17. 7
Annual mean	8. 1	14. 9

Station 5 (bottom depth 10 meters)

Jan. 25, 1922	11. 3	12. 1
Jan. 27, 1921	11. 1	11. 1
Mar. 7, 1920	13. 8	14. 1
Mar. 28, 1921	8. 1	9. 2
May 7, 1920	6. 4	8. 8
June 3, 1921	7. 3	15. 4
July 4, 1920	9. 8	10. 1
Aug. 26, 1920	8. 7	13. 4
Oct. 17, 1920	11. 8	15. 0
Annual mean	9. 9	11. 8

Station 6 (bottom depth 13 meters)

Jan. 17, 1920	13. 0	14. 5
Jan. 25, 1922	11. 6	------
Jan. 27, 1921	11. 4	11. 4
Mar. 7, 1920	13. 7	14. 8
Mar. 28, 1921	8. 4	11. 3
June 3, 1921	8. 4	11. 3
July 5, 1920	9. 0	16. 2
Aug. 26, 1920	9. 6	10. 2
Oct. 17, 1920	12. 2	15. 6
Dec. 9, 1920	10. 4	12. 6
Annual mean	10. 5	13. 1

Station 7 (bottom depth 27 meters)

Jan. 17, 1920	13. 6	18. 1
Jan. 25, 1922	13. 3	18. 4
Jan. 27, 1921	12. 1	13. 3
Mar. 7, 1920	13. 8	15. 7
Mar. 29, 1921	7. 4	13. 5
May 7, 1920	5. 8	15. 7
June 3, 1921	8. 4	18. 6
July 5, 1920	9. 4	17. 5
Aug. 26, 1920	10. 6	18. 7
Oct. 17, 1920	13. 7	16. 5
Dec. 9, 1920	12. 4	13. 3
Annual mean	10. 8	15. 5

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 8 (bottom depth 10 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 16, 1920	-----	13. 5
Jan. 25, 1922	13. 0	13. 1
Jan. 26, 1921	12. 4	12. 4
Mar. 8, 1920	15. 0	15. 0
Mar. 29, 1921	-----	11. 5
May 7, 1920	6. 3	11. 9
June 3, 1921	10. 6	14. 3
July 5, 1920	11. 3	11. 7
Aug. 25, 1920	9. 9	9. 9
Oct. 17, 1920	13. 0	13. 0
Annual mean	10. 9	12. 4

Station 9 (bottom depth 22 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 16, 1920	14. 1	18. 6
Jan. 24, 1922	13. 2	19. 8
Jan. 26, 1921	13. 0	13. 7
Mar. 8, 1920	15. 4	15. 6
Mar. 29, 1921	10. 9	16. 2
Mar. 29, 1922	11. 9	16. 9
May 7, 1920	6. 9	15. 9
June 3, 1921	10. 6	18. 9
July 5, 1920	11. 4	19. 0
Aug. 25, 1920	-----	18. 8
Oct. 17, 1920	13. 7	17. 4
Dec. 9, 1920	14. 7	15. 8
Annual mean	12. 3	17. 5

Station 10 (bottom depth 7 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 16, 1920	14. 1	-----
Jan. 24, 1922	13. 8	13. 8
Jan. 26, 1921	13. 1	13. 1
Mar. 8, 1920	15. 6	15. 6
Mar. 28, 1921	11. 4	11. 8
Mar. 29, 1922	12. 3	13. 7
May 7, 1920	7. 0	7. 3
June 2, 1920	11. 0	11. 0
July 5, 1920	11. 5	19. 9
Aug. 25, 1920	10. 7	12. 6
Oct. 18, 1920	13. 8	13. 8
Dec. 8, 1920	14. 6	14. 5
Annual mean	12. 3	13. 5

Station 11 (bottom depth 47 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 16, 1920	14. 9	20. 0
Jan. 25, 1922	15. 8	20. 6
Jan. 26, 1921	14. 4	17. 7
Mar. 8, 1920	15. 9	16. 1
Mar. 28, 1922	11. 9	15. 9
Mar. 30, 1921	13. 7 (6)	-----
May 7, 1920	7. 1	17. 8
June 2, 1921	11. 2	19. 8
July 5, 1920	11. 1	19. 4
Aug. 25, 1920	12. 8	19. 7
Oct. 18, 1920	14. 4	20. 0
Dec. 8, 1920	14. 9	19. 6
Annual mean	13. 1	18. 9

Station 13 (bottom depth 13 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 15, 1920	14. 2	14. 5
Jan. 23, 1922	15. 2	15. 4
Jan. 25, 1921	13. 3	13. 3
Mar. 8, 1920	15. 8	15. 8
Mar. 31, 1921	13. 1	14. 1
May 6, 1920	7. 3	13. 8
June 1, 1921	12. 2	13. 2
July 7, 1920	12. 3	17. 3
Aug. 24, 1920	13. 3	13. 3
Oct. 19, 1920	-----	15. 7
Dec. 7, 1920	15. 0	15. 0
Annual mean	13. 2	14. 8

Station 14 (bottom depth 37 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 15, 1920	14. 7	20. 3
Jan. 23, 1922	15. 4 (15)	19. 8 (16)
Jan. 25, 1921	14. 3 (16)	15. 7 (16)
Mar. 8, 1920	15. 9	16. 4
Mar. 27, 1922	12. 7 (12)	16. 8 (15)
Mar. 30, 1921	14. 2 (16)	15. 3 (16)
May 6, 1920	7. 3	18. 1
June 1, 1921	12. 2 (16)	19. 2 (16)
July 6, 1920	12. 6 (16)	20. 1 (16)
Aug. 24, 1920	13. 8 (9)	19. 6 (15)
Oct. 18, 1920	15. 8 (16)	22. 0 (16)
Dec. 7, 1920	15. 3 (15)	19. 5 (16)
Annual mean	13. 6	19. 2

Station 15 (bottom depth 8 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 15, 1920	15. 0	15. 1
Jan. 24, 1922	15. 1	16. 1
Jan. 26, 1921	14. 5	14. 5
Mar. 8, 1920	16. 1	16. 2
Mar. 28, 1922	12. 7	13. 6
May 6, 1920	7. 3	9. 4
June 2, 1921	12. 5	12. 8
July 6, 1920	13. 3	13. 2
Aug. 25, 1920	13. 6	13. 6
Oct. 19, 1920	15. 2	16. 6
Dec. 8, 1920	15. 2	15. 3
Annual mean	13. 6	14. 7

Station 16 (bottom depth 11 meters)

Date	Salinity: Surface	Salinity: Bottom
Jan. 15, 1920	13. 7	14. 0
Jan. 23, 1922	13. 9	14. 3
Jan. 24, 1921	11. 9	13. 2
Mar. 9, 1920	11. 2	15. 7
Mar. 27, 1922	11. 0	13. 2
Mar. 31, 1921	13. 3	13. 2
May 6, 1920	6. 8	8. 7
June 1, 1921	7. 5	12. 8
July 7, 1920	12. 9	15. 7
Aug. 24, 1920	12. 3	12. 4
Oct. 19, 1920	-----	15. 0
Dec. 7, 1920	14. 6	14. 7
Annual mean	11. 9	13. 5

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 17 (bottom depth 22 meters)

Date	Salinity	
	Surface	Bottom
Jan. 15, 1920	14.6	------
Jan. 23, 1922	14.6	15.5
Jan. 24, 1921	13.6	14.2
Mar. 9, 1920	12.1	15.9
Mar. 27, 1922	10.4	15.3
Mar. 31, 1921	13.1	14.8
May 6, 1920	7.2	13.0
June 1, 1921	7.2	14.6
July 7, 1920	11.4	17.6
Aug. 24, 1920	13.2	14.3
Oct. 19, 1920	15.0	15.9
Dec. 7, 1920	15.4	15.4
Annual mean	12.4	15.2

Station 18 (bottom depth 12 meters)

Date	Surface	Bottom
Jan. 15, 1920	13.9	14.8
Jan. 23, 1922	15.9	15.8
Jan. 25, 1921	14.0	14.0
Mar. 9, 1920	12.6	15.9
Mar. 27, 1922	11.8	13.4
Mar. 31, 1921	12.9	14.6
May 6, 1920	7.2	9.6
June 1, 1921	11.7	14.1
July 7, 1920	11.5	13.3
Aug. 24, 1920	13.6	13.6
Oct. 19, 1920	------	15.4
Dec. 7, 1920	15.6	15.6
Annual mean	13.0	14.1

Station 19 (bottom depth 12.8 meters)

Date	Surface	Bottom
Jan. 14, 1920	16.1	19.4
Jan. 23, 1922	18.2	18.8
Jan. 24, 1921	14.5	17.2
Mar. 9, 1920	14.6	16.6
Mar. 26, 1922	11.6	16.6
Mar. 31, 1921	15.1	16.5
May 6, 1920	9.7	13.6
June 1, 1921	9.1	13.8
July 7, 1920	14.7	18.5
Aug. 23, 1920	14.4	19.1
Oct. 20, 1920	17.7	19.3
Dec. 6, 1920	16.9	16.8
Annual mean	14.5	17.3

Station 20 (bottom depth 12 meters)

Date	Surface	Bottom
Jan. 23, 1922	18.1	19.2
Jan. 24, 1921	15.5	15.5
Mar. 9, 1920	14.2	15.8
Mar. 26, 1922	15.7	12.1
Apr. 1, 1921	15.2	15.3
May 6, 1920	11.2	13.1
June 1, 1921	11.4	14.7
July 7, 1920	14.7	14.8
Aug. 23, 1920	14.7	17.6
Oct. 20, 1920	15.1	17.1
Dec. 6, 1920	17.0	17.0
Annual mean	14.8	16.0

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 21 (bottom depth 44 meters)

Date	Salinity	
	Surface	Bottom
Jan. 14, 1920	14.9	21.8
Jan. 23, 1922	16.0	18.3
Jan. 24, 1921	13.1	18.7
Mar. 9, 1920	13.0	17.5
Mar. 26, 1922	11.6	------
Apr. 1, 1921	14.3	16.8
May 6, 1920	10.0	19.6
June 1, 1921	11.3	------
July 7, 1920	14.6	19.8
Aug. 23, 1920	14.0	21.9
Oct. 20, 1920	14.9	23.8
Dec. 6, 1920	16.6	21.1
Annual mean	13.8	20.3

Station 22 (bottom depth 13 meters)

Date	Surface	Bottom
Jan. 13, 1920	16.9	22.3
Jan. 22, 1922	22.3	17.0
Jan. 24, 1921	14.7	14.7
Mar. 9, 1920	16.2	17.4
Mar. 26, 1922	14.3	18.2
Apr. 1, 1921	16.5	------
May 5, 1920	12.0	------
May 31, 1921	13.3	15.1
July 8, 1920	15.6	21.6
Aug. 23, 1920	16.5	17.3
Oct. 20, 1920	16.7	18.9
Dec. 6, 1920	18.3	18.9
Annual mean	16.0	18.1

Station 23 (bottom depth 13 meters)

Date	Surface	Bottom
Jan. 13, 1920	16.5	23.3
Jan. 22, 1922	18.2	23.0
Jan. 24, 1921	17.7	17.9
Mar. 9, 1920	16.7	17.9
Mar. 26, 1922	15.4	18.9
Apr. 1, 1921	17.1	17.4
May 5, 1920	12.0	------
May 31, 1921	12.6	13.9
July 8, 1920	15.6	21.6
Aug. 23, 1920	18.7	20.5
Oct. 20, 1920	17.9	25.2
Dec. 6, 1920	19.2	19.7
Annual mean	15.1	20.6

Station 24 (bottom depth 15 meters)

Date	Surface	Bottom
Jan. 13, 1920	18.0	23.6
Jan. 22, 1922	21.5	24.5
Jan. 23, 1921	16.2	21.6
Mar. 10, 1920	17.5 (13)	19.2 (13)
Mar. 26, 1922	15.7	19.4
May 5, 1920	14.7	21.0
May 31, 1921	18.9	25.0
July 8, 1920	16.7	21.8
Aug. 23, 1920	18.9	25.0
Oct. 20, 1920	17.9	25.1
Dec. 6, 1920	20.6	------
Annual mean	17.9	22.9

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 25 (bottom depth 8 meters)

Date	Salinity	
	Surface	Bottom
Jan. 13, 1920	18.8	20.1
Jan. 22, 1922	20.6	22.5
Jan. 23, 1921	18.1	18.6
Mar. 26, 1922	17.6	18.0
Apr. 1, 1921	-----	21.6
May 5, 1920	17.7	18.3
May 31, 1921	18.9	24.9
July 8, 1920	17.7	17.7
Aug. 23, 1920	19.4	21.7
Oct. 20, 1920	17.2	21.0
Dec. 6, 1920	21.0	20.9
Annual mean	18.4	20.4

Station 26 (bottom depth 23 meters)

Date	Surface	Bottom
Jan. 13, 1920	20.3	23.8
Mar. 11, 1920	18.2	22.5
May 5, 1920	15.5	24.9
July 8, 1920	17.7	22.0
Annual mean	18.3	23.1

Station 27 (bottom depth 10 meters)

Date	Surface	Bottom
Jan. 12, 1920	19.7	21.9
Jan. 22, 1922	20.1	20.5
Jan. 23, 1921	18.7	23.4
Mar. 11, 1920	18.5	19.0
Mar. 26, 1922	17.8	18.8
Apr. 2, 1921	21.1	21.2
May 5, 1920	14.0	16.3
May 31, 1921	16.1	17.1
July 8, 1920	17.3	22.1
Aug. 23, 1920	19.5	24.2
Oct. 20, 1920	17.3	24.5
Dec. 5, 1920	21.5	21.5
Annual mean	18.4	21.3

Station 28 (bottom depth 13 meters)

Date	Surface	Bottom
Jan. 12, 1920	19.3	22.6
Jan. 22, 1922	19.7	24.0
Jan. 23, 1921	19.0	24.6
Mar. 11, 1920	18.4	19.6
Mar. 26, 1922	17.4	23.7
Apr. 2, 1921	22.3	23.0
May 5, 1920	14.5	20.7
May 31, 1921	----	17.7
July 8, 1920	19.4	22.5
Aug. 22, 1920	19.3	21.0
Oct. 20, 1920	17.1	26.4
Dec. 5, 1920	22.2	22.0
Annual mean	18.7	22.4

Station 29 (bottom depth 28 meters)

Date	Surface	Bottom
Jan. 12, 1920	20.3	24.3
Jan. 22, 1922	21.1	28.5
Jan. 23, 1921	18.2	24.5
Mar. 11, 1920	18.5	20.3
Mar. 26, 1922	16.7	22.3
Apr. 2, 1921	22.7	23.4
May 5, 1920	16.1	19.2
May 31, 1921	----	27.0
July 8, 1920	18.9	23.1
Aug. 22, 1920	19.2	24.3
Oct. 21, 1920	19.0	23.9
Dec. 5, 1920	22.4	22.5
Annual mean	19.3	23.9

TABLE 4.—*Salinity of the water at stations in Chesapeake Bay*—Continued

Station 30 (bottom depth 42 meters)

Date	Salinity	
	Surface	Bottom
Jan. 11, 1920	23.3	29.3
Jan. 22, 1922	24.0	25.9
Jan. 23, 1921	18.4	25.4
Mar. 11, 1920	18.7	22.9
Mar. 25, 1922	19.3	25.4
Apr. 2, 1921	21.6	28.3
May 5, 1920	20.9	24.6
May 31, 1921	20.2	26.9
July 8, 1920	21.7	25.2
Aug. 22, 1920	22.4	28.5
Oct. 21, 1920	22.0	27.1
Dec. 5, 1920	22.8	24.0
Annual mean	21.5	26.2

Station 32 (bottom depth 28 meters)

Date	Surface	Bottom
Jan. 10, 1920	21.3	23.8
Jan. 21, 1922	20.2	23.8
Jan. 22, 1921	17.8	21.2
Mar. 12, 1920	17.7	28.8
Mar. 25, 1922	18.4	27.2
Apr. 2, 1921	26.3	31.2
May 1, 1920	16.3	25.8
May 31, 1921	18.7	27.6
Dec. 4, 1920	14.8	------
Annual mean	17.7	25.8

Station 34 (bottom depth 18 meters)

Date	Surface	Bottom
Jan. 11, 1920	29.4	30.9
Jan. 21, 1922	28.9	31.3
Jan. 22, 1921	28.6	30.0
Mar. 12, 1920	24.5	29.8
Mar. 25, 1922	24.2	25.1
Apr. 2, 1921	29.1	29.0
May 1, 1920	20.0	22.6
May 30, 1921	30.4	30.4
July 9, 1920	29.8	25.4
Aug. 22, 1920	28.9	30.6
Oct. 21, 1920	20.2	30.4
Dec. 5, 1920	28.8	------
Annual mean	26.6	29.3

Station 35 (bottom depth 15 meters)

Date	Surface	Bottom
Jan. 11, 1920	25.6	30.9
Jan. 21, 1922	29.0	24.2
Jan. 22, 1921	21.6	27.4
Mar. 12, 1920	21.7	30.3
Mar. 25, 1922	19.4	30.6
May 1, 1920	25.4	28.6
May 30, 1921	24.1	28.8
July 9, 1920	21.3	28.1
Aug. 22, 1920	23.2	31.1
Oct. 21, 1920	21.3	29.3
Dec. 4, 1920	25.3	27.8
Annual mean	23.1	29.1

Station 36 (bottom depth 24 meters)

Date	Surface	Bottom
Jan. 11, 1920	28.2	31.1
Jan. 21, 1922	23.9	29.3
Jan. 22, 1921	19.2	28.8
Mar. 12, 1920	20.6	30.7
Mar. 25, 1922	18.4	31.1
Apr. 2, 1921	27.7	31.3
May 1, 1920	19.3	25.8
May 30, 1921	22.0	30.1
July 9, 1920	20.5	30.4
Aug. 22, 1920	22.7	31.7
Oct. 21, 1920	20.3	31.0
Dec. 4, 1920	25.2	31.0
Annual mean	22.0	31.3

The mean annual salinities at the surface and at the bottom for certain stations are also shown in Figure 14, together with the depth and the distance from the mouth of the bay. It is obvious from this diagram that the salinity increases more or less regularly in passing down the bay, that it is greater at depth than at the surface, and that the difference between the surface and bottom salinities tends to be greater at the stations where the water is deeper and less at those where it is shallow.

The mean annual salinities at the surface and bottom at all the stations are shown in their approximate locations on a map of the bay in Plate 13. Table 5 gives primarily by its density, and this in turn by either its salinity or its temperature. In the water of Chesapeake Bay the salinity is by far the more influential variable, although in a few places listed in Table 5 the position of the water appears to be determined in part by its temperature—that is, in water of approximately the same salinity the colder water is found to lie deeper because of its greater density. Several of the samples appear to indicate unstable conditions, but these are relatively rare or within the limits of experimental errors.

The densities might have been plotted exactly as the salinities were, and the relations shown would be essentially similar, but the salinities were chosen because of their greater weight in determining the density and as being of more general interest. The relations are quantitatively different from those in sea water, as the variations in salinity in water of the open sea are not nearly as great as those observed in Chesapeake Bay. The temperature accordingly assumes greater significance in determining currents of sea water. Moreover, the differences in temperature between surface and bottom sea water are, on account of the greater depths involved, considerably greater than those observed in Chesapeake Bay.

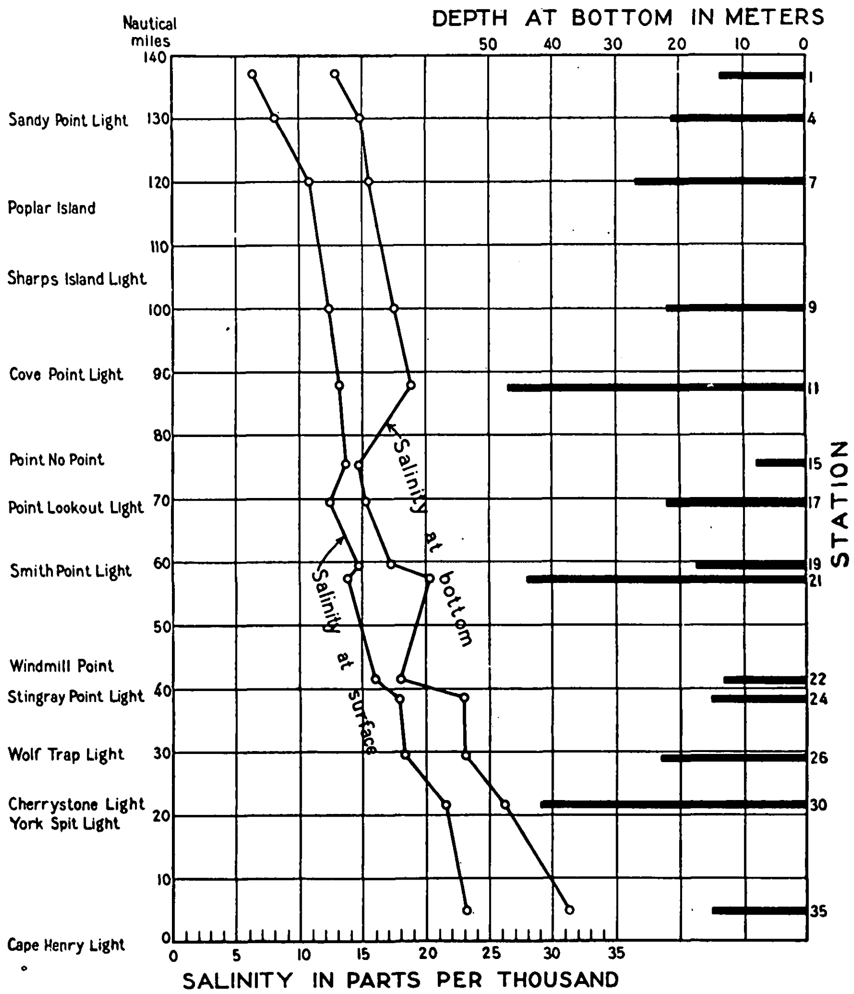


FIGURE 14.—Mean annual salinity and depth at certain stations in Chesapeake Bay

the complete record of all the salinity determinations. The bottom depth was not recorded in all the observations; the largest figure given under "Depth" for a set of observations at the same date and time, if an uneven figure (as 9.1, 25.32), indicates bottom depth.

DENSITY OF THE WATER

In Table 5 is also given the density of each sample of water for its temperature at the time of collection. It is well known that the relative position of any considerable portion of a mass of water is determined

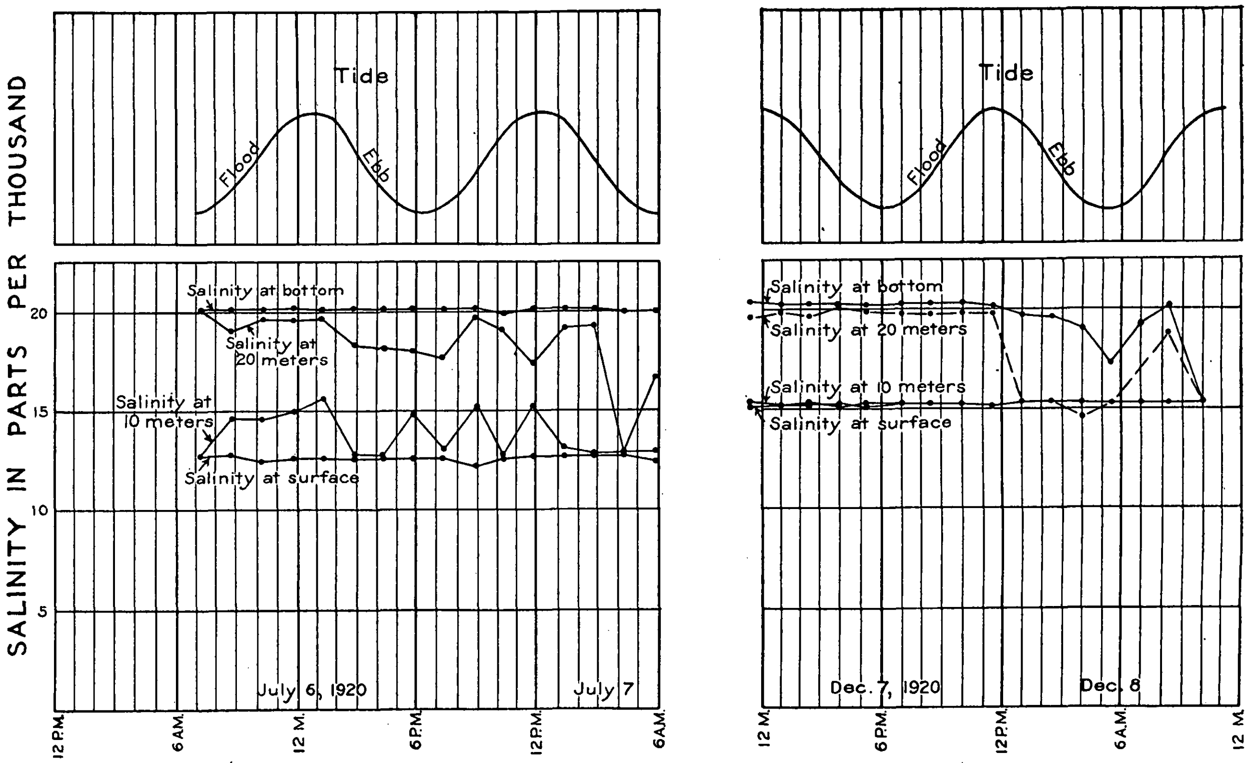


FIGURE 15.—Salinity at station 14, Chesapeake Bay, for 24-hour periods on July 6 and 7 and December 7 and 8, 1920, at surface and at depths of 10 meters, 20 meters, and bottom

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*

Station 1 (bottom blue-gray mud)

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Mar. 6, 10.15 a. m.	Beginning to ebb	0		0.0	10.46	1.00839
		6.1		−1.3	10.91	1.00870
		9.1		−1.3	11.29	1.00830
11.45 a. m.	½ ebb	0		.0	10.35	1.00830
		3.05		−.3	10.32	1.00826
		6.1		2.8	11.73	1.00942
		9.1		.7	10.86	1.00872
1.15 p. m.	¾ ebb	0		.4	10.05	1.00804
		3.05		.0	10.11	1.00810
		6.1		2.0	10.17	1.00818
		9.1		2.8	10.71	1.00858
2.45 p. m.	Slack	0		.2	9.51	1.00761
		3.05		.0	9.76	1.00782
		6.1		−.3	9.41	1.00750
		9.1		1.7	10.52	1.00843
4.15 p. m.	Slack	0		.0	10.45	1.00837
		3.05		2.7	10.42	1.00834
		6.1		2.8	10.44	1.00838
		9.1		3.7	11.87	1.00949
5.45 p. m.	Beginning flood	0		2.2	10.91	1.00876
		3.05		.7	10.96	1.00878
		6.1		.0	10.91	1.00875
		9.1		.2	10.88	1.00872
7.15 p. m.	½ flood	0		.2	10.05	1.00805
		3.05		−.6	10.07	1.00807
		6.1		.2	10.46	1.00839
		9.1		.6	11.01	1.00882
8.45 p. m.	¾ flood	0		.0	9.72	1.00779
		3.05		−.3	9.96	1.00797
		6.1		1.7	11.33	1.00909
		9.1		−.3	14.23	1.01412
10.15 p. m.	Beginning ebb	0		−.3	9.79	1.00783
		3.05		−.6	10.00	1.00801
		6.1		−.3	9.71	1.00778
		9.1		1.7	15.70	1.01261
11.45 p. m.	½ ebb	0		.6	10.58	1.00847
		3.05		−.3	10.68	1.00855
		6.1			10.66	1.00855
		9.1		−.3	12.54	1.01005
Mar. 7, 1.15 a. m.	¾ ebb	6.1		−1.3	10.92	1.00875
		9.1		1.7	10.72	1.00859
May 8, 6.30 a. m.	Flood	0		12.8	2.26	1.00122
		11.37		12.6	6.54	1.00437
July 3, 2.20 p. m.	¼ ebb	0			6.97	1.00538
		5		24.2	7.15	1.00302
		10		20.5	11.79	1.00710
		12.5		21.0	11.10	1.00547
3.50 p. m.	½ ebb	0		24.9	6.20	1.00262
		5		24.6	8.60	1.00369
		10		24.6	12.78	1.00681
		12.5		24.6	11.54	1.00590
5.28 p. m.	Full ebb	0		24.8	5.93	1.00163
		5		24.9	8.64	1.00365
		10		24.6	9.52	1.00424
		12.5		24.9	13.12	1.00699
6.58 p. m.	Beginning flood	0		24.9	6.32	1.00189
		5		24.9	8.75	1.00371
		10		24.1	13.48	1.00746
		12.5		24.4	13.52	1.00743
8.28 p. m.	¼ flood	0		24.6	6.36	1.00201
		5		24.6	10.20	1.00487
		10		24.1	13.03	1.00712
		12.5		23.9	13.35	1.01048
9.58 p. m.	½ flood	0		24.1	6.72	1.00238
		5		24.2	9.54	1.00449
		10		23.9	11.80	1.00626
		12.5		24.1	12.83	1.00697
11.28 p. m.	¾ flood	0		24.1	6.80	1.00245
		5		23.9	8.49	1.00378
		10		23.9	12.24	1.00660
		12.5		23.9	13.31	1.00740

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 1—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
July 4, 12.58 a. m.	Full flood	0	--------	23. 9	6. 90	1. 00252
		5	--------	23. 6	7. 32	1. 00289
		10	--------	23. 6	11. 05	1. 00569
		12. 5	--------	23. 9	13. 02	1. 00691
2.28 a. m.	Beginning flood	0	--------	23. 6	7. 14	1. 00283
		5	--------	23. 9	9. 05	1. 00420
		10	--------	23. 6	10. 87	1. 00567
		12. 5	--------	23. 6	12. 14	1. 00660
3.58 a. m.	½ ebb	0	--------	23. 9	6. 91	1. 00208
		5	--------	23. 6	6. 98	1. 00273
		10	--------	23. 6	11. 08	1. 00580
		12. 5	--------	22. 9	12. 44	1. 00699
5.28 a. m.	Full ebb	0	--------	23. 6	6. 76	1. 00256
		5	--------	23. 9	7. 18	1. 00287
		10	--------	23. 4	9. 64	1. 00487
		12. 5	--------	23. 6	12. 60	1. 00721
6.58 a. m.	Beginning flood	0	--------	23. 9	6. 74	1. 00246
		5	--------	23. 6	7. 66	1. 00323
		10	--------	23. 6	11. 15	1. 00585
		12. 5	--------	23. 9	12. 79	1. 00701
8.28 a. m.	⅝ flood	0	--------	23. 6	7. 20	1. 00289
		5	--------	23. 9	7. 55	1. 00308
		10	--------	23. 4	11. 41	1. 00611
		12. 5	--------	23. 6	12. 46	1. 00682
9.58 a. m.	½ flood	0	--------	23. 9	7. 45	1. 00294
		5	--------	23. 6	8. 82	1. 00485
		10	--------	23. 4	11. 65	1. 00629
		12. 5	--------	23. 6	12. 33	1. 00674
11.28 a. m.	¾ flood	0	------	24. 6	7. 47	1. 00293
		5	--------	23. 6	11. 40	1. 00613
		10	--------	23. 6	12. 09	1. 00656
		12. 5	--------	23. 9	12. 40	1. 00672
12.58 p. m.	Full flood	0	--------	23. 6	7. 47	1. 00309
		5	--------	23. 9	9. 06	1. 00406
		10	--------	23. 9	10. 87	1. 00556
		12. 5	--------	23. 9	--------	--------
Aug. 26, 12 m.		0	--------	23. 5	4. 75	1. 00107
		5	--------	24. 4	14. 21	1. 00782
		Bottom.	--------	24. 2	15. 21	1. 00873
1.30 p. m.		0	--------	24. 0	4. 91	1. 00117
		5	--------	24. 4	15. 21	1. 00867
		Bottom.	--------	24. 4	14. 69	1. 00829
3 p. m.		0	--------	24. 0	5. 75	1. 00170
		5	--------	24. 1	11. 93	1. 00630
		Bottom.	--------	24. 2	16. 11	1. 00940
4.30 p. m.		0	--------	23. 9	5. 86	1. 00187
		5	--------	24. 0	12. 24	1. 00756
		Bottom.	--------	24. 2	15. 70	1. 00912
6 p. m.		0	--------	23. 7	6. 05	1. 00199
		5	--------	24. 8	10. 77	1. 00526
		Bottom.	--------	24. 2	16. 03	1. 00936
7.30 p. m.		0	--------	23. 6	6. 12	1. 00207
		5	--------	24. 2	11. 86	1. 00623
		Bottom.	--------	24. 2	16. 20	1. 00948
9 p. m.		0	--------	23. 4	5. 69	1. 00180
		5	--------	24. 1	13. 09	1. 00716
		Bottom.	--------	24. 2	15. 41	1. 00888
10.30 p. m.		0	--------	23. 8	5. 68	1. 00169
		5	--------	23. 4	13. 86	1. 00794
		Bottom.	--------	24. 4	14. 79	1. 00838
12 p. m.		0	--------	23. 5	6. 14	1. 00216
		5	--------	23. 5	13. 79	1. 00790
		Bottom.	--------	24. 2	15. 80	1. 00917
Aug. 27, 1.30 a. m.		0	--------	23. 4	6. 05	1. 00207
		5	--------	24. 2	14. 38	1. 00811
		Bottom.	--------	24. 2	16. 02	1. 00935
3 a. m.		0	--------	23. 4	6. 15	1. 00214
		5	--------	23. 1	11. 70	1. 00638
		Bottom.	--------	24. 2	16. 11	1. 00971
4.30 a. m.		0	--------	24. 3	6. 51	1. 00219
		5	--------	24. 0	11. 78	1. 00622
		Bottom.	--------	24. 2	15. 94	1. 00928

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 1—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
Aug. 27, 6 a. m.		0		23. 1	7. 04	1. 00290
		5		24. 0	10. 74	1. 00544
		Bottom.		24. 2	15. 69	1. 00910
7.30 a. m.		0		24. 8	7. 22	1. 00259
		5		24. 9	9. 37	1. 00417
		Bottom.		24. 2	14. 11	1. 00792
9 a. m.		0		23. 2	6. 48	1. 00245
		5		24. 0	11. 80	1. 00623
		Bottom.		24. 2	14 90	1. 00851
10.30 a. m.		0		23. 6	5. 62	1. 00170
		5		24. 1	12. 86	1. 00700
		Bottom.		24. 3	15. 72	1. 00909
Oct. 15, 8.20 p. m.		0		19. 8	9. 25	1. 00534
		5		20. 0	12. 48	1. 00774
		Bottom.		19. 9	13. 51	1. 00855
9.50 p. m.		0		19. 6	9. 81	1. 00580
		5		19. 3	11. 62	1. 00724
		Bottom.		20. 1	13. 97	1. 00884
11.20 p. m.		0		19. 5	8. 43	1. 00478
		5		19. 8	12. 55	1. 00785
		Bottom.		20. 2	13. 96	1. 00881
Oct. 16, 12.50 a. m.		0		18. 7	8. 07	1. 00468
		5		19. 2	10. 77	1. 00662
		Bottom.		20. 0	14. 01	1. 00889
2.20 a. m.		0		19. 7	9. 23	1. 00533
		5		19. 4	9. 67	1. 00576
		Bottom.		20. 1	13. 85	1. 00875
3.50 a. m.		0		19. 4	8. 75	1. 00503
		5		19. 6	12. 84	1. 00808
		Bottom.		20. 1	14. 05	1. 00890
5.20 a. m.		0		19. 3	9. 72	1. 00579
		5		19. 0	10. 18	1. 00621
		Bottom.		19. 9	13. 26	1. 00835
6.50 a. m.		0		19. 5	11. 10	1. 00680
		5		19. 9	13. 43	1. 00847
		Bottom.		20. 4	14. 24	1. 00896
8.20 a. m.		0		18. 9	10. 00	1. 00604
		5		19. 2	10. 77	1. 00662
		Bottom.		23. 9	15. 14	1. 00877
9.50 a. m.		0		19. 5	10. 07	1. 00610
		5		19. 6	12. 42	1. 00777
		Bottom.		20. 4	15. 03	1. 00957
11.20 a. m.		0		19. 8	8. 88	1. 00505
		5		19. 7	11. 27	1. 00688
		Bottom.		20. 3	14. 24	1. 00899
12.50 p. m.		0		20. 1	9. 66	1. 00557
		5		19. 6	10. 39	1. 00614
		Bottom.		20. 2	14. 59	1. 00928
2.20 p. m.		0		20. 1	9. 49	1. 00545
		5		19. 5	11. 80	1. 00732
		Bottom.		20. 0	14. 78	1. 00947
3.50 p. m.		0		19. 9	9. 60	1. 00558
		5		19. 7	12. 38	1. 00772
		Bottom.		20. 2	14. 10	1. 00891
5.20 p. m.		0		20. 3	8. 69	1. 00480
		5		19. 8	11. 89	1. 00734
		Bottom.		20. 1	14. 05	1. 00890
6.50 p. m.		0		20. 3	9. 12	1. 00513
		5		19. 7	10. 86	1. 00658
		Bottom.		20. 5	15. 05	1. 00956
Dec. 10, 7.30 a. m.	Full flood	0		7. 0	9. 13	1. 00716
		5		8. 8	13. 85	1. 01070
		Bottom.		9. 9	17. 23	1. 01320
9 a. m.	¼ ebb	0		6. 4	6. 92	1. 00529
		5		8. 6	13. 06	1. 01010
		Bottom.		9. 9	16. 30	1. 01249
10.30 a. m.	½ ebb.	0		5. 6	4. 65	1. 00299
		5		8. 1	12. 50	1. 00971
		Bottom.		10. 4	16. 98	1. 01293
12 m.	¾ ebb	0		5. 4	3. 84	1. 00299
		5		8. 7	12. 21	1. 00943
		Bottom.		10. 2	16. 98	1. 01298

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 1—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
Dec. 10, 1.30 p. m.	Slack	0	--------	6. 0	4. 94	1. 00392
		5	--------	8. 5	13. 48	1. 01043
		Bottom.	--------	8. 3	11. 76	1. 00912
3 p. m.	⅓ flood	0	--------	5. 7	4. 09	1. 00320
		5	--------	7. 3	10. 50	1. 00822
		Bottom.	--------	10. 0	16. 26	1. 01243
4.30 p. m.	½ flood	0	--------	5. 4	3. 77	1. 00293
		5	--------	8. 4	13. 95	1. 01080
		Bottom.	--------	10. 1	16. 93	1. 01294
6 p. m.	¾ flood	0	--------	5. 8	4. 59	1. 00358
		5	--------	8. 9	14. 27	1. 01102
		Bottom.	--------	10. 3	17. 38	1. 01325
7.30 p. m.	Full flood	0	--------	5. 8	6. 16	1. 00491
		5	--------	8. 1	12. 67	1. 00984
		Bottom.	--------	10. 0	16. 40	1. 01254
9 p. m.	Beginning ebb	0	--------	5. 9	5. 21	1. 00414
		5	--------	7. 8	12. 24	1. 00955
		Bottom.	--------	8. 7	13. 85	1. 01069
10.30 p. m.	⅓ ebb	0	--------	5. 9	5. 93	1. 00472
		5	--------	7. 3	8. 42	1. 00659
		Bottom.	--------	9. 2	15. 42	1. 01187
12 p. m.	½ ebb	0	--------	5. 8	5. 70	1. 00452
		5	--------	5. 9	6. 02	1. 00478
		Bottom.	--------	9. 0	14. 02	1. 01180
Dec. 11, 1.30 a. m.	Slack	0	--------	5. 4	4. 30	1. 00335
		5	--------	5. 3	4. 38	1. 00344
		Bottom.	--------	8. 4	13. 11	1. 01016
3 a. m.	Beginning flood	0	--------	5. 4	4. 35	1. 00343
		5	--------	5. 4	4. 45	1. 00350
		Bottom.	--------	8. 7	13. 25	1. 01020
4.30 a. m.	½ flood	0	--------	5. 4	3. 85	1. 00300
		5	--------	8. 2	13. 17	1. 01022
		Bottom.	--------	8. 8	13. 52	1. 01044
6 a. m.	¾ flood	0	--------	5. 4	3. 90	1. 00305
		5	--------	6. 3	4. 74	1. 00370
		Bottom.	--------	9. 2	14. 80	1. 01139
1921						
Jan. 27, 2.35 p. m.	½ ebb; wind	0	6. 6	1. 0	7. 08	1. 00569
	NE., force 1	5	--------	. 5	7. 24	1. 00580
		11. 89	--------	3. 7	--------	--------
4.05 p. m.	¾ ebb	0	--------	1. 3	6. 44	1. 00516
		5	--------	1. 7	7. 51	1. 00603
		11. 89	--------	1. 8	14. 17	1. 01134
5.35 p. m.	Slack	0	--------	1. 3	6. 91	1. 00553
		5	--------	1. 7	9. 90	1. 00554
		11. 89	--------	1. 8	14. 10	1. 01132
7.05 p. m.	Beginning flood	0	--------	. 9	7. 22	1. 00579
		5	--------	3. 6	12. 05	1. 00967
		11. 89	--------	3. 7	14. 20	1. 01134
8.35 p. m.	⅓ flood	0	--------	. 8	8. 49	1. 00681
		5	--------	1. 9	11. 02	1. 00886
		11. 89	--------	3. 7	14. 23	1. 01137
10.05 p. m.	¾ flood	0	--------	. 6	8. 27	1. 00663
		5	--------	1. 3	11. 29	1. 00907
		11. 89	--------	3. 7	14. 01	1. 01125
11.35 p. m.	Full flood	0	--------	. 8	8. 53	1. 00684
		5	--------	1. 2	--------	--------
		11. 89	--------	3. 3	--------	--------
Jan. 28, 1.05 a. m.	Beginning flood	0	--------	. 4	7. 64	1. 00610
		5	--------	3. 2	13. 63	1. 01092
		11. 89	--------	3. 7	13. 97	1. 01113
2.35 a. m.	⅓ ebb	0	--------	. 3	6. 92	1. 00552
		5	--------	1. 5	6. 91	1. 00554
		11. 89	--------	3. 5	13. 80	1. 01104
4.05 a. m.	¾ ebb	0	--------	3. 1	6. 23	1. 00502
		5	--------	3. 9	13. 13	1. 01054
		11. 89	--------	3. 5	13. 95	1. 01117
6.35 a. m.	Slack	0	--------	. 3	5. 99	1. 00478
		5	--------	1. 6	8. 54	1. 00684
		11. 89	--------	. 9	8. 70	1. 00700

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 1—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921—Continued						
Mar. 26, 7.30 p. m.	¾ flood	0		10.2	2.45	1.00167
		5		9.7	7.06	1.00530
		7		9.4	7.18	1.00542
9 p. m.	Flood	0		10.8	4.02	1.00283
		5		9.3	------	
		7		------	6.46	------
10.30 p. m.	⅓ ebb	0		10.0	5.39	1.00398
		7		9.3	7.69	1.00584
12 p. m.	⅔ ebb	0		10.8	3.71	1.00259
		7		9.3	7.49	1.00568
Mar. 27, 1.30 a. m.	Slack	0		12.0	3.10	1.00197
		7		9.4	8.23	1.00627
3 a. m.	Beginning flood	0		10.9	3.62	1.00257
		7		11.0	6.49	1.00473
4.30 a. m.	½ flood	0		10.7	5.43	1.00394
		7		9.8	7.22	1.00542
6 a. m.	¾ flood	0		11.0	3.70	1.00255
		7		9.4	8.02	1.00607
7.30 a. m.	Full flood	0		11.1	3.10	1.00208
		7		10.4	6.52	1.00481
9 a. m.	Beginning ebb	0		11.7	3.36	1.00221
		7		9.3	7.84	1.00596
10.30 a. m.	½ ebb	0		12.1	3.60	1.00236
		7		9.4	8.35	1.00633
12 m.	¾ ebb	0		11.9	3.63	1.00251
		7		9.1	9.76	1.00748
1.30 p. m.	Slack	0		13.7	3.71	1.00222
		7		9.9	7.75	1.00582
3 p. m.	Beginning flood	0		12.2	3.35	1.00214
		7		9.9	7.56	1.00567
4.30 p. m.	⅓ flood	0		12.7	3.61	1.00227
		7		10.4	5.92	1.00436
6 p. m.	¾ flood	0		13.3		
		7		10.5	------	------
June 3, 5.07 p. m.		0	23.8	21.0	6.13	1.00270
		5		18.0	11.91	1.00773
		10.98		15.7	15.80	1.01116
7.30 p. m.		0		21.0	6.06	1.00265
		5		16.5	14.30	1.00985
		10.98		15.7	15.78	1.01114
8.50 p. m.		0		21.1	5.68	1.00235
		5		19.7	8.09	1.00509
		10.98		16.3	14.46	1.01003
10.30 p. m.		0		20.7	5.45	1.00226
		5		20.7	5.53	1.00234
		10.98		16.6	14.97	1.01033
11.50 p. m.		0		20.6	5.72	1.00240
		5		20.6	6.04	1.00272
		10.98		16.6	13.95	1.00956
June 4, 1.20 a. m.		0		20.5	5.55	1.00238
		5		18.8	7.01	1.00385
		10.98		16.0	9.87	1.00657
3.50 a. m.		0		20.2	6.14	1.00291
		5		19.5	9.87	1.00567
		10.98		15.7	15.92	1.01122
4.20 a. m.		0		20.4	7.15	1.00363
		5		18.0	11.91	1.00773
		10.98		15.5	16.00	1.01137
5.50 a. m.		0		20.5	6.57	1.00316
		5		19.7	9.74	1.00573
		10.98		15.9	14.31	1.00998
7.20 a. m.		0		20.6	6.42	1.00302
		5		19.6	9.32	1.00543
		10.98		15.9	15.07	1.01057
8.50 a. m.		0		20.6	6.56	1.00319
		5		19.3	8.05	1.00455
		10.98		18.4	10.74	1.00676
10.20 a. m.		0		21.1	6.42	1.00391
		5		20.4	7.44	1.00384
		10.98		20.1	12.37	1.00762
11.50 a. m.		0		21.1	5.57	1.00226
		5		21.0	9.15	1.00498
		10.98		19.3	5.66	1.00273

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 1—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921—Continued						
June 4, 1.20 p. m.		0		21. 3		
		5		20. 7	6. 35	1. 00295
		10. 98		19. 9	8. 46	1. 00471
2.50 p. m.		0		21. 3	6. 24	1. 00271
		5		20. 9	6. 36	1. 00301
		10. 98		19. 5	8. 54	1. 00487
4.20 p. m.		0		21. 5	7. 29	1. 00345
		5		20. 3	7. 37	1. 00379
		10. 98		19. 3	7. 83	1. 00436
1922						
Mar. 29, 7 p. m.	¾ flood; sea moderate; wind N., force 2; hazy.	0	10. 00	8. 6	4. 77	1. 00362
		5		6. 3	7. 75	1. 00613
		11		4. 8	3. 80	1. 00306
8.30 p. m.		0		9. 0	5. 22	1. 00389
		5		6. 4	8. 22	1. 00650
		11		5. 0	10. 33	1. 00825
10 p. m.		0		8. 3	4. 86	1. 00369
		5		6. 4	8. 02	1. 00638
		11		4. 8	11. 18	1. 00887
11.30 p. m.		0		8. 0	4. 50	1. 00345
		5		6. 0	9. 58	1. 00758
		11		4. 9	11. 70	1. 00933
Mar. 30, 1 a. m.		0			8. 89	
		5			6. 06	
		11		4. 7	11. 75	1. 00936
2.30 a. m.		0		8. 2	3. 94	1. 00300
		5		8. 0	4. 66	1. 00368
		11		4. 9	10. 69	1. 00852
4 a. m.		0		8. 2	11. 50	1. 00892
		5		8. 0	4. 09	1. 00314
		11		4. 8	3. 80	1. 00306
5.30 a. m.		0		8. 0	4. 30	1. 00330
		5		8. 0	4. 42	1. 00356
		11		5. 4	11. 69	1. 00929
7 a. m.		0		8. 1	4. 44	1. 00340
		5		7. 5	11. 18	1. 00864
		11		5. 4	4. 85	1. 00386
8.30 a. m.		0		7. 8	4. 89	1. 00377
		5		7. 7	5. 71	1. 00442
		11		5. 0	12. 45	1. 00991
10 a. m.		0		8. 0	5. 20	1. 00401
		5		7. 0	6. 73	1. 00528
		11		4. 6	8. 03	1. 00641
11.30 a. m.		0		7. 9	5. 69	1. 00441
		5		7. 4	7. 68	1. 00600
		11		4. 5	14. 20	1. 01132
1 p. m.		0		7. 7	5. 18	1. 00402
		5		6. 8	9. 13	1. 00717
		11		4. 6	14. 13	1. 01125
2.30 p. m.		0		7. 9	4. 71	1. 00360
		5		7. 4	7. 04	1. 00647
		11		5. 0	12. 48	1. 00994
4 p. m.		0		7. 8	4. 67	1. 00361
		5		7. 8	5. 20	1. 00402
		11		4. 8	13. 90	1. 01107

Station 2

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Mar. 6, 9.50 a. m.	Full flood	0		3. 9	11. 63	1. 00932
		5		. 0	11. 55	1. 00926
		10		—. 3	12. 65	1. 01014
		13. 7		—. 3	15. 13	1. 01214

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 3

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 17, 2.30 p. m.		0		0.9	12.01	1.00963
		13.7		.9	17.16	1.01378
Mar. 6, 12.44 p. m.	¼ ebb	0		−3.9	12.43	1.00997
		5.0		1.1	13.00	1.01044
		10.0		−.3	13.26	1.01063
		12.8		−.3	14.78	1.01186
May 7, 4.47 p. m.	¾ ebb	0		12.8	4.01	1.00266
		13.18		12.8	5.76	1.00393
July 4, 4 p. m.	¾ ebb	0		23.6	8.58	1.00392
		10		23.6	8.78	1.00408
		Bottom.		23.4	8.89	1.00422
Aug. 26, 9.30 a. m.		0		23.2	8.11	1.00366
		Bottom.		24.1	17.69	1.01064
10.05 a. m.		0		23.6	9.46	1.00461
		Bottom.		24.1	17.67	1.01061
Oct. 17, 7.40 a. m.		0		19.5	10.42	1.00628
		5		19.2	10.61	1.00659
		Bottom.		20.6	15.30	1.00973
Dec. 9, 4.18 p. m.	½ flood	0		7.2	9.14	1.00715
		Bottom.		10.3	16.78	1.01279
1921						
Jan. 27, 11.05 a. m.	Beginning ebb; sea choppy; wind NE., force 3.	0	−1.1	1.3	10.43	1.00837
		12.81		3.7	14.25	1.01142
Mar. 28, 9.50 a. m.	Beginning ebb; sea smooth; wind SW., force 2.	0	16.6	11.8	6.00	1.00425
		10		8.4	11.97	1.00929
		15		8.1	12.41	1.00961
June 3, 2.50 p. m.	¼ flood; sea smooth; wind S., force 1	0	23.3	21.3	5.75	1.00235
		12.81		15.6	16.16	1.01146
1922						
Mar. 29, 4.30 p. m.	¼ flood; wind N., force 0	0	14.44	9.1	5.28	1.00399
		12.8		5.3	11.46	1.00908

Station 4

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 17, 3.17 p. m.		0		−0.1	12.28	1.00984
		20.1		.9	17.37	1.01394
May 7, 6.09 p. m.	Slack ebb	0		12.6	4.35	1.00287
		19.55		12.8	7.16	1.00501
July 4, 2.45 p. m.	½ ebb	0		23.9	7.89	1.00333
		10		23.9	8.70	1.00393
		Bottom.		23.9	15.44	1.00900
Aug. 26, 10.05 a. m.		0		23.5	9.46	1.00461
		Bottom.		24.1	17.67	1.01061
Oct. 17, 6.34 a. m.		0		19.2		
		Bottom.		21.1	16.03	1.01016
Dec. 9, 5.24 p. m.	½ flood	0		7.4	10.64	1.00831
		10		9.6	16.68	1.01280
		Bottom.		10.0	17.65	1.01349
1921						
Jan. 27, 12.30 p. m.	¼ ebb; sea moderate; wind NE., force 2	0	2.7	1.6	10.88	1.00874
		10		2.0	11.97	1.00962
		20.13		3.8	14.46	1.01155
Mar. 28, 7 a. m.	Flood; sea smooth; wind SW., force 2	0	16.1	12.4	5.26	1.00359
		10		8.9	10.21	1.00784
		18		7.7	12.99	1.01015
June 3, 3.37 p. m.	½ flood; sea smooth; wind S., force 1	0	22.7	20.8	5.85	1.00254
		10		18.1	11.91	1.00770
		22.7		14.9	19.66	1.01426
1922						
Mar. 29, 5.27 p. m.	½ flood; sea smooth; wind N., force 1	0		9.2	5.65	1.00426
		10		6.0	10.30	1.00815
		20		5.2	15.79	1.01251

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 5

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Mar. 7, 2.46 p. m.	½ ebb	0		0. 0	13. 77	1. 01105
		9. 1		—. 6	14. 12	1. 01131
May 7, 2.30 p. m.	½ ebb	0		12. 8	6. 42	1. 00444
		9. 54		12. 6	8. 83	1. 00613
July 4, 6.20 p. m.	Beginning flood	0		23. 4	9. 75	1. 00484
		10		23. 6	10. 08	1. 00506
Aug. 26, 5.40 a. m.		0		23. 2	8. 67	1. 00408
		Bottom.		24. 2	13. 41	1. 00739
Oct. 17, 12.05 p. m.		0		20. 0	11. 81	1. 00742
		Bottom.		19. 8	14. 97	1. 00966
Dec. 9, 1.40 p. m.	Beginning flood	0		7. 2		
		Bottom.		7. 2		
1921						
Jan. 27, 7.10 a. m.	½ flood; sea moderate; wind NE., force 2	0	—2. 2	1. 3	11. 13	1. 00894
		10. 07		1. 3	11. 14	1. 00895
Mar. 28, 1.25 p. m.	Ebb; sea choppy; wind SW. by S., force 3	0	18. 8	14. 9	8. 11	1. 00557
		9		15. 8	9. 16	1. 00607
June 3, 10.55 a. m.	Full ebb; sea smooth; wind S., force 1	0	22. 7	20. 4	7. 29	1. 00379
		10. 06		16. 0	15. 36	1. 01077
1922						
Jan. 25, 3.15 p. m.	¾ flood; wind N. by E., force 2	0	—1. 11	. 9	11. 34	1. 00910
		10. 06		1. 3	12. 06	1. 00969
Mar. 29, 12.28 p. m.	¾ ebb; sea smooth; wind NW., force 2	0	18. 33	8. 5	9. 75	1. 00753
		9. 6		7. 3	10. 19	1. 00797

Station 6

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 17, 9.57 a. m.		0		—0. 1	12. 98	1. 01041
		12. 8		. 15	14. 48	1. 01162
Mar. 7, 10.49 p. m.	¾ ebb	0		—. 3	13. 67	1. 01096
		5		—. 3	13. 70	1. 01100
		10		1. 7	14. 40	1. 01157
		13		—. 3	14. 81	1. 01188
July 5, 6.05 a. m.	½ ebb	0		21. 9	9. 02	1. 00468
		5		22. 6	9. 42	1. 00480
		10		22. 6	9. 57	1. 00492
		Bottom.		22. 9	16. 22	1. 00988
Aug. 26, 6.13 a. m.		0		23. 2	9. 54	1. 00475
		Bottom.		23. 6	10. 17	1. 00512
Oct. 17, 11.20 a. m.		0		19. 9	12. 22	1. 00756
		Bottom.		20. 0	15. 62	1. 01011
Dec. 9, 12.57 p. m.	Slack ebb	0		7. 2	10. 42	1. 00811
		Bottom.		7. 4	12. 55	1. 00981
1921						
Jan. 27, 7.53 a. m.	¾ flood; sea moderate; wind NE., force 2	0	—1. 6	1. 8	11. 38	1. 00915
		12. 81		1. 9	11. 39	1. 00916
Mar. 28, 3.03 p. m.	Flood; sea choppy; wind SW. by S., force 3	0	21. 1	10. 0	8. 37	1. 00631
		14		9. 6	11. 32	1. 00869
June 3, 11.31 a. m.	Beginning flood; sea smooth; wind S., force 1	0	22. 2	21. 1	6. 09	1. 00272
		12. 81		15. 8	15. 86	1. 01119
1922						
Jan. 25, 3.58 p. m.	¾ flood; wind N. by E., force 3	0	—3. 33	. 4	11. 59	1. 00931
		12. 81		2. 5		
Mar. 29, 1.19 p. m.	¾ ebb; sea smooth; wind NW., force 2	0	18. 33	8. 4	9. 76	1. 00754
		12. 00		5. 8	11. 09	1. 00879

Station 7

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 17, 8.47 a. m.		0		—0. 1	13. 57	1. 01089
		25. 0		. 65	18. 14	1. 01457
Mar. 7, 4.53 p. m.	Slack ebb	0		—. 3	13. 77	1. 01104
		10		—. 3	14. 58	1. 01169
		20		1. 7	15. 58	1. 01250
		25		. 0	15. 68	1. 01259

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 7—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920—Continued						
May 7, 1.18 p. m.	Beginning ebb	0		12. 5	5. 81	1. 00400
		25. 32		12. 3	15. 66	1. 01164
July 5, 7.15 a. m.	½ ebb	0		21. 9	9. 40	1. 00497
		5		22. 1	11. 22	1. 00628
		10		22. 1	14. 10	1. 00844
		20		22. 4	16. 89	1. 01047
		Bottom.		22. 1	17. 49	1. 01100
Aug. 26, 7.05 a. m.		0		23. 7	10. 65	1. 00545
		Bottom.		24. 0	18. 74	1. 01144
Oct. 17, 10.05 a. m.		0		19. 4	13. 70	1. 00879
		10		19. 9	14. 46	1. 00925
		20			16. 00	
		Bottom.		20. 2	16. 50	1. 01074
Dec. 9, 11.50 a. m.	Full ebb	0		7. 9	12. 42	1. 00967
		10		8. 3	12. 68	1. 00984
		20		8. 8	12. 84	1. 00990
		Bottom.		8. 1	13. 33	1. 01036
1921						
Jan. 27, 8.50 a. m.	¾ flood; sea moderate; wind NE., force 2	0	−3. 3	2. 0	12. 14	1. 00975
		10		2. 0	12. 33	1. 00982
		20		2. 1	12. 36	1. 00993
		37. 45		2. 4	13. 27	1. 01064
Mar. 29, 11.10 a. m.	Ebb; sea choppy; wind NNE., force 3	0	3. 3	10. 5	7. 43	1. 00551
		10		10. 5	8. 29	1. 00618
		20		9. 9	10. 38	1. 00788
		30		8. 4	13. 53	1. 01048
June 3, 12.34 p. m.	¼ flood; sea smooth; wind S., force 1	0	22. 2	21. 1	8. 36	1. 00437
		10		18. 8	12. 05	1. 00767
		20		15. 2	17. 96	1. 01290
		27. 45		15. 0	18. 64	1. 01346
1922						
Jan. 25, 4.50 p. m.	Full flood; wind N. by E., force 2	0	−4. 44	0. 8	13. 26	1. 01064
		10		1. 9	15. 97	1. 01281
		20		3. 2	18. 95	1. 01514
		27. 90		2. 5	18. 36	1. 01471
Mar. 29, 2.13 p. m.	Full ebb; sea moderate; wind N., force 2; partly cloudy.	0	14. 44	8. 2	9. 84	1. 00761
		10		7. 2	11. 00	1. 00862
		20		4. 5	15. 26	1. 01216
		26. 5		4. 0	16. 79	1. 01340

Station 8

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 16, 1.49 p. m.		0		0. 2		
		10. 1		. 1	13. 51	1. 01085
Mar. 8, 8.49 a. m.	Slack	0		−. 3	14. 98	1. 01201
		10		−1. 1	15. 03	1. 01205
May 7, 9.10 a. m.	¾ flood	0		12. 8	6. 29	1. 00434
		9. 54		12. 6	11. 88	1. 00868
July 5, 2 p. m.	Beginning ebb	0		24. 6	11. 30	1. 00570
		5		24. 3	11. 36	1. 00583
		Bottom.		24. 4	11. 69	1. 00605
Aug. 25, 6.15 p. m.		0		24. 1	9. 86	1. 00475
		Bottom.		24. 0	9. 87	1. 00475
Oct. 17, 3.20 p. m.		0		19. 4	12. 99	1. 00814
		Bottom.		19. 4	13. 03	1. 00816
1921						
Jan. 26, 4.50 p. m.	½ flood; sea moderate; wind NNE., force 2	0	1. 1	2. 3	12. 44	1. 00999
		9. 15		2. 3	12. 40	1. 00997
Mar. 29, 3.50 p. m.	Flood; sea choppy; wind NNE., force 2	0	4. 4	10. 7		
		10		9. 9	11. 50	1. 00874
June 3, 6.31 a. m.	⅓ ebb; sea smooth; calm	0	15. 0	20. 6	10. 63	1. 00620
		9. 15		16. 7	14. 28	1. 00981
1922						
Jan. 25, 12.05 p. m.	½ flood; sea moderate; wind N. by E., force 3.	0	1. 11	0. 7	13. 03	1. 01045
		9. 15		0. 8	13. 14	1 01056
Mar. 29, 9.10 a. m.	¼ ebb; sea smooth; wind NW., force 2	0	12. 22	6. 4	11. 91	1. 00938
		9. 14		5. 6	13. 23	1. 01049

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 9

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 16, 2.45 p. m.		0		0. 15	14. 13	1. 01134
		22. 8		. 65	18. 59	1. 01493
Mar. 8, 6.36 a. m.	½ flood	0		—. 8	15. 37	1. 01234
		10		—. 3	15. 57	1. 01249
		20		1. 1	15. 80	1. 01269
		22		—. 3	15. 58	1. 01250
May 7, 10.12 a. m.	Flood	0		12. 8	6. 85	1. 00477
		22. 72		12. 6	15. 91	1. 01178
July 5, 12.18 p. m.	¼ flood	0		23. 8	11. 44	1. 00602
		10		23. 6	11. 62	1. 00618
		20		23. 1	18. 61	1. 01158
		Bottom.		23. 6	18. 95	1. 01171
Aug. 25, 6.59 p. m.		0		24. 1		
		Bottom.		24. 2	18. 79	1. 01142
Oct. 17, 4.15 p. m.		0		20. 2	13. 72	1. 00865
		10		19. 4	14. 73	1. 00958
		Bottom.		20. 3	17. 44	1. 01141
Dec. 9, 6.54 a. m.	¼ ebb	0		7. 8	14. 69	1. 01145
		10		7. 9	14. 57	1. 01134
		Bottom.		7. 9	15. 80	1. 01233
1921						
Jan. 26, 5.50 p. m.	¾ flood; sea moderate; wind NNE., force 2	0	0. 0	2. 7	13. 04	1. 01047
		10		2. 6	12. 95	1. 01040
		22. 42		3. 4	13. 73	1. 01100
Mar. 29, 2 p. m.	Ebb; sea choppy; wind NNE., force 2	0	2. 7	10. 8	10. 87	1. 00814
		10		11. 6	11. 13	1. 00823
		19		7. 5	16. 18	1. 01265
June 3, 5.15 a. m.	¼ ebb; sea smooth; calm	0	14. 4	19. 4	10. 58	1. 00614
		10		19. 3	10. 62	1. 00647
		22. 41		15. 3	18. 93	1. 01362
1922						
Jan. 24, 10.55 a. m.	¼ flood; sea choppy; wind N. by E., force 4	0	—1. 11	1. 7	13. 17	1. 01057
		10		1. 6	13. 53	1. 01086
		21. 96		2. 6	19. 76	1. 01573
Mar. 29, 7.58 a. m.	Beginning ebb; sea smooth; wind NW., force 1.	0	10. 00	7. 3	11. 89	1. 00931
		10		6. 3	12. 87	1. 01016
		22. 00		4. 6	16. 89	1. 01342

Station 10

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 16, 11.29 a. m.		0		0. 4	14. 10	1. 01132
Mar. 8, 9.29 a. m.	Beginning ebb	0		. 2	15. 56	1. 01249
		7. 3		—. 6	15. 62	1. 01253
May 7, 7 a. m.	¾ flood	0		12. 8	6. 96	1. 00486
		7. 27		12. 6	7. 30	1. 00516
July 5, 4.40 p. m.	Beginning ebb	0		24. 1	11. 46	1. 00520
		Bottom.		23. 9	19. 88	1. 01231
Aug. 25, 4 p. m.		0		24. 0	10. 67	1. 00538
		Bottom.		23. 9	12. 64	1. 00662
Oct. 18, 6 p. m.		0		19. 5	13. 77	1. 00882
		Bottom.		19. 2	13. 77	1. 00884
Dec. 8, 3.58 p. m.	Full flood	0		8. 2	14. 56	1. 01132
		Bottom.		8. 4	14. 52	1. 01126
1921						
Jan. 26, 2.52 p. m.	½ flood; sea moderate; wind N., force 2	0	0. 0	2. 3	13. 11	1. 01051
		7. 32		2. 3	13. 12	1. 01052
Mar. 28, 6 p. m.	Flood; sea smooth; wind NNE., force 1	0	6. 6	10. 6	11. 40	1. 00858
		7		10. 8	11. 84	1. 00889
June 2, 7.45 p. m.	⅝ ebb; sea moderate; wind E., force 2	0	18. 8	20. 8	10. 97	1. 00641
		7. 32		20. 7	11. 02	1. 00648
1922						
Jan. 24, 8.40 p. m.	Slack; choppy; wind N. by E., force 4	0	—3. 88	1. 1	13. 82	1. 01109
		7. 32		. 9	13. 83	1. 01111
Mar. 29, 6.07 a. m.	Full flood; calm; hazy	0	8. 89	7. 3	12. 34	1. 00965
		7. 00		5. 7	13. 71	1. 01016

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 11

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 16, 9.46 a. m.		0		0. 8	14. 87	1. 01192
		40. 3		. 8	20. 00	1. 01606
Mar. 8, 10.23 a. m.	Ebb	0		. 4	15. 90	1. 01277
		10		. 0	16. 09	1. 01292
		20		. 2	16. 10	1. 01292
		30		. 0	16. 06	1. 01290
		40		. 2	16. 13	1. 01295
		47. 5		—. 3	16. 13	1. 01295
May 7, 5.34 a. m.	¾ flood	0		12. 6	7. 12	1. 00501
		20		12. 8	7. 13	1. 00498
		47. 27		12. 6	17. 80	1. 01322
July 5, 6.05 p. m.	¼ ebb	0		24. 1	11. 09	1. 00569
		10		23. 4	15. 44	1. 00913
		20		23. 6	14. 99	1. 00874
		30		23. 4	19. 12	1. 01189
		40		22. 1	19. 37	1. 01242
		Bottom.		22. 4	19. 38	1. 01235
Aug. 25, 2.30 p. m.		0		24. 2	12. 83	1. 00695
		Bottom.		23. 9	19. 70	1. 01219
Oct. 18, 6.50 a. m.		0		19. 5	14. 36	1. 00927
		10		19. 5	15. 08	1. 00982
		20		20. 1	15. 37	1. 01090
		30		19. 6	17. 08	1. 01130
		40		20. 0	26. 08	1. 01801
		Bottom.		19. 4	20. 04	1. 01359
Dec. 8, 2.33 p. m.	¾ flood	0		8. 6	14. 93	1. 01155
		10		8. 2	15. 01	1. 01166
		20		9. 5	18. 35	1. 01411
		30		9. 9	19. 68	1. 01509
		40		9. 9	19. 75	1. 01515
		Bottom.		9. 9	19. 85	1. 01522
1921						
Jan. 26, 1.38 p. m.	¼ flood; sea moderate; wind N., force 2	0	0. 5	2. 6	14. 44	1. 01158
		10		3. 3	14. 78	1. 01185
		20		3. 4	14. 59	1. 01168
		30		3. 7	17. 46	1. 01393
		40		3. 8		
		47. 58		3. 9	17. 70	1. 01412
Mar. 30, 8.20 a. m.	Ebb; sea choppy; wind SE., force 2	0	7. 2	10. 2	13. 94	1. 01059
		20		10. 7	14. 20	1. 01073
		46		10. 2	16. 60	1. 01266
June 2, 6.30 p. m.	¾ ebb; sea moderate; wind E., force 3	0	21. 6	20. 0	11. 20	1. 00677
		10		20. 0	11. 68	1. 00714
		20		15. 5	19. 42	1. 01397
		30		15. 3	19. 66	1. 01421
		40		15. 3	19. 80	1. 01429
		47. 58		15. 1	19. 78	1. 01431
1922						
Jan. 25, 7.45 a. m.	Full ebb; sea choppy; wind N., force 4	0	—7. 77	1. 4	15. 81	1. 01262
		10		2. 2	16. 53	1. 01325
		20		2. 7	19. 54	1. 01564
		30		2. 5	19. 86	1. 01590
		40		3. 2	20. 43	1. 01631
		47. 50		2. 9	20. 63	1. 01645
Mar. 28, 5.23 p. m.	Tide slack; sea moderate; wind S., force 3; hazy.	0	11. 11	7. 7	11. 88	1. 00926
		10		7. 2	11. 90	1. 00932
		20		4. 9	15. 42	1. 01225
		30		5. 2	11. 81	1. 00937
		40		4. 9	13. 67	1. 01087
		47. 55		4. 6	15. 93	1. 01267

Station 12

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 16, 7.55 a. m.		0		0. 45	15. 02	1. 01205
		38. 5		—. 3	20. 78	1. 01669
Mar. 8, 12 m.	Slack	0		. 6	16. 11	1. 01294
		10		. 7	16. 14	1. 01296
		20		. 6	16. 14	1. 01295
		30		. 7	16. 16	1. 01297
		35		. 6	16. 22	1. 01298

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 13

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 15, 12.52 p. m.		0		0. 95	14. 18	1. 01139
		12. 8		. 7	14. 49	1. 01164
Mar. 8, 4.35 p. m.	¾ ebb	0		. 3	15. 82	1. 01271
		10		. 3	15. 79	1. 01267
		12. 8		0	15. 77	1. 01266
May 6, 3.45 p. m.	¾ flood	0		13. 1	7. 28	1. 00506
		10		13. 1	8. 70	1. 00615
		12. 72		13. 3	13. 75	1. 01001
July 7, 7.49 a. m.	Slack ebb	0		23. 7	12. 27	1. 00666
		Bottom.		23. 5	17. 27	1. 01048
Aug. 24, 8.59 a. m.		0		25. 8	13. 35	1. 00693
		Bottom.		25. 6	13. 31	1. 00696
Oct. 19, 12.28 p. m.		0		20. 0		
		Bottom.		19. 7	15. 71	1. 01024
Dec. 7, 10.04 a. m.	½ flood	0		8. 7	15. 03	1. 01163
		Bottom.		8. 7	15. 00	1. 01161
1921						
Jan. 25, 8.43 a. m.	Full ebb; sea choppy; wind NNE., force 4	0	3. 3	2. 9	13. 28	1. 01066
		12. 81		2. 9	13. 31	1. 01069
Mar. 31, 12.55 p. m.	Ebb; sea choppy; wind S., force 2	0	16. 6	11. 1	13. 09	1. 00982
		16. 6		10. 8	14. 05	1. 01061
June 1, 1.40 p. m.	½ ebb; sea smooth; calm	0	31. 6	22. 5	12. 20	1. 00693
		12. 81		19. 1	13. 19	1. 00848
1922						
Jan. 23, 3.22 p. m.	¾ ebb; sea moderate; wind NNE., force 3	0	1. 11	2. 8	15. 22	1. 01220
		12. 81		3. 1	15. 37	1. 01231
Mar. 27, 12.06 p. m.	⅓ flood; smooth; wind SE., force 1	0	12. 22	6. 9	12. 43	1. 00976
		12. 0		5. 7	13. 63	1. 01070

Station 14

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 15, 2.09 p. m.		0		0. 7	14. 74	1. 01185
		40. 3		. 7	20. 28	1. 01628
Mar. 8, 3.08 p. m.	½ ebb	0		. 7	15. 87	1. 01274
		10		0	15. 86	1. 01274
		20		. 7	15. 87	1. 01274
		30		0	16. 15	1. 01297
		35. 7		. 4	16. 36	1. 01313
May 6, 5.10 p. m.	Flood	0		13. 1	7. 30	1. 00509
		20		13. 3	13. 28	1. 00964
		38. 18		13. 1	18. 09	1. 01337
July 6, 7.19 a. m.	Full ebb	0		23. 8	12. 75	1. 00701
		10		23. 4	12. 75	1. 00710
		20		23. 2	20. 22	1. 01278
		30		23. 6	19. 70	1. 01227
		36. 60		23. 9	20. 22	1. 01268
8.49 a. m.	Beginning flood	0		22. 8	12. 76	1. 00727
		10		22. 8	14. 68	1. 00871
		20		22. 0	19. 11	1. 01225
		30		22. 0	20. 26	1. 01312
		36. 60		22. 0	20. 22	1. 01307
10.19 a. m.	½ flood	0		23. 0	12. 50	1. 00702
		10		23. 3	14. 66	1. 00846
		20		22. 2	19. 72	1. 01265
		30		22. 1	20. 20	1. 01304
		36. 60		22. 0	20. 22	1. 01307
11.49 a. m.	¾ flood	0		23. 2	12. 56	1. 00704
		10		23. 7	14. 95	1. 00866
		20		22. 1	19. 60	1. 01232
		30		22. 1	20. 04	1. 01292
		36. 60		22. 1	20. 25	1. 01307
1.19 p. m.	Full flood	0		24. 0	12. 57	1. 00782
		10		23. 1	15. 63	1. 00934
		20		22. 0	19. 64	1. 01264
		30		22. 0	19. 98	1. 01291
		36. 60		22. 1	20. 10	1. 01301

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
July 6, 2.49 p. m.	Beginning ebb	0	--------	25. 3	12. 53	1. 00727
		10	--------	23. 3	12. 82	1. 00664
		20	--------	22. 6	18. 40	1. 01156
		30	--------	22. 5	20. 10	1. 01287
		36. 60	--------	22. 2	20. 19	1. 01294
4.19 p. m.	½ ebb	0	--------	24. 8	12. 60	1. 00664
		10	--------	23. 3	12. 74	1. 00712
		20	--------	23. 1	18. 25	1. 01131
		30	--------	22. 5	20. 00	1. 01279
		36. 60	--------	22. 7	20. 16	1. 01286
5.49 p. m.	Full ebb	0	--------	23. 5	12. 68	1. 00701
		10	--------	23. 1	14. 90	1. 00899
		20	--------	24. 4	18. 01	1. 01072
		30	--------	22. 6	20. 10	1. 01284
		36. 60	--------	22. 2	20. 19	1. 01301
7.19 p. m.	¼ flood	0	--------	24. 4	12. 68	1. 00781
		10	--------	23. 5	13. 01	1. 00725
		20	--------	22. 8	17. 77	1. 01104
		30	--------	22. 5	20. 04	1. 01282
		36. 60	--------	22. 0	20. 16	1. 01304
8.49 p. m.	½ flood	0	--------	23. 7	12. 16	1. 00696
		10	--------	23. 2	15. 12	1. 00894
		20	--------	22. 0	19. 70	1. 01270
		30	--------	22. 1	20. 00	1. 01289
		36. 60	--------	22. 0	20. 20	1. 01307
10.19 p. m.	¾ flood	0	--------	23. 6	12. 58	1. 00694
		10	--------	22. 8	12. 72	1. 00724
		20	--------	22. 4	19. 08	1. 01213
		30	--------	22. 0	19. 68	1. 01267
		36. 60	--------	--------	19. 91	--------
11.49 p. m.	¾ flood	0	--------	23. 6	12. 68	1. 00701
		10	--------	22. 6	15. 20	1. 00915
		20	--------	21. 9	17. 30	1. 01092
		30	--------	22. 0	19. 69	1. 01267
		36. 60	--------	22. 4	20. 02	1. 01284
July 7, 1.19 a. m.	Beginning ebb	0	--------	23. 8	12. 68	1. 00696
		10	--------	23. 4	13. 12	1. 00739
		20	--------	22. 9	19. 18	1. 01207
		30	--------	22. 0	20. 06	1. 01297
		36. 60	--------	22. 0	20. 02	1. 01294
2.49 a. m.	¼ ebb	0	--------	23. 8	12. 73	1. 00877
		10	--------	24. 8	12. 77	1. 01050
		20	--------	21. 9	19. 22	1. 01238
		30	--------	22. 0	20. 02	1. 01294
		36. 60	--------	21. 6	20. 08	1. 01309
4.19 a. m.	½ ebb	0	--------	23. 8	12. 76	1. 00701
		10	--------	23. 8	12. 99	1. 00719
		20	--------	22. 8	12. 95	1. 00733
		30	--------	22. 0	19. 18	1. 01231
		36. 60	--------	21. 9	19. 98	1. 01304
5.49 a. m.	¾ ebb	0	--------	23. 7	12. 40	1. 00679
		10	--------	23. 8	12. 93	1. 00814
		20	--------	22. 0	16. 63	1. 01038
		30	--------	22. 0	20. 01	1. 01293
		36. 60	--------	21. 8	20. 00	1. 01298
Aug. 24, 10.45 a. m.	--	0	--------	25. 5	14. 18	1. 00760
		10	--------	25. 8	14. 01	1. 00737
		20	--------	24. 8	18. 70	1. 01119
		30	--------	25. 0	20. 30	1. 01233
		Bottom.	--------	24. 8	20. 49	1. 01253
12.15 p. m.	--	0	--------	25. 6	13. 95	1. 00742
		10	--------	25. 3	13. 89	1. 00745
		20	--------	25. 5	13. 91	1. 00741
		30	--------	25. 5	15. 14	1. 00832
		Bottom.	--------	25. 0	20. 47	1. 01245
1.45 p. m.	--	0	--------	25. 5	13. 69	1. 00725
		10	--------	25. 7	13. 70	1. 00719
		20	--------	25. 6	13. 72	1. 00719
		30	--------	25. 5	13. 73	1. 00727
		Bottom.	--------	24. 8	20. 39	1. 01241

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
Aug. 24, 3.15 p. m.		0		25.5	13.62	1.00719
		10		25.5	13.63	1.00722
		20		25.2	17.54	1.01021
		30		24.8	20.08	1.01222
		Bottom.		24.8	20.57	1.01259
4.45 p. m.		0		25.5	13.72	1.00719
		10		25.5	13.72	1.00719
		20		25.5	13.77	1.00720
		30		25.0	19.76	1.01192
		Bottom.		24.8	20.50	1.01254
6.15 p. m.		0		25.6	13.75	1.00726
		10		25.5	13.79	1.00722
		20		25.1	17.97	1.01055
		30		24.9	20.09	1.01220
		Bottom.		24.8	20.56	1.01255
7.45 p. m.		0		25.6	13.67	1.00719
		10		25.4	13.75	1.00720
		20		25.3	17.24	1.00994
		30		25.0	19.16	1.01147
		Bottom.		24.8	20.37	1.01243
9.15 p. m.		0		25.5	13.75	1.00721
		10		25.3	14.25	1.00771
		20		25.6	17.28	1.00989
		30		25.4	17.31	1.00997
		Bottom.		25.4	17.73	1.01028
10.45 p. m.		0		25.4	13.63	1.00722
		10		25.2	14.27	1.00777
		20		25.5	16.61	1.00942
		30		25.4	17.06	1.00978
		Bottom.		25.2	18.83	1.01116
Aug. 25, 12.15 a. m.		0		25.5	13.77	1.00720
		10		25.0	14.27	1.00769
		20		25.0	14.18	1.00774
		30		25.3	18.33	1.01076
		Bottom.		25.0	19.28	1.01156
1.45 a. m.		0		25.0	13.85	1.00748
		10		25.0	14.13	1.00761
		20		24.6	14.36	1.00788
		30		25.2	17.66	1.01030
		Bottom.		25.1	19.21	1.01151
3.15 a. m.		0		25.0	13.76	1.00743
		10		25.0	13.77	1.00744
		20		24.6	13.93	1.00767
		30		25.2	16.50	1.00943
		Bottom.		25.1	18.86	1.01122
4.45 a. m.		0		24.8	13.78	1.00750
		10		25.0	13.78	1.00745
		20		25.5	16.47	1.00832
		30		25.2	18.79	1.01119
		Bottom.		25.1	19.18	1.01146
6.15 a. m.		0		24.8	13.85	1.00755
		10		25.0	13.87	1.00752
		20		25.0	16.37	1.00938
		30		25.1	18.81	1.01119
		Bottom.		25.1	18.99	1.01130
7.45 a. m.		0		24.8	13.93	1.00762
		10		24.9	14.04	1.00767
		20		25.2	17.66	1.01030
		30		25.1	19.05	1.01137
		Bottom.		25.1	19.13	1.01138
9.15 a. m.		0		24.8	13.84	1.00755
		10		24.8	14.06	1.00771
		20		25.2	15.46	1.00865
		30		25.2	19.17	1.01142
		Bottom.		25.2		
Oct. 18, 10.30 a. m.		0	19.7	19.7	15.90	1.01039
		10		19.7	16.75	1.01103
		20		19.5	20.57	1.01390
		30		19.3	22.30	1.01533
		Bottom.		19.7	22.24	1.01518
12 m.		0		19.7	15.89	1.01038
		10		19.6	15.90	1.01041
		20		19.5	20.20	1.01370
		30		19.3	22.24	1.01528
		Bottom.		19.7	22.34	1.01527

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920—Continued						
Oct. 18, 1.30 p. m.		0		19. 7	15. 90	1. 01039
		10		19. 6	15. 90	1. 01039
		20		19. 6	16. 04	1. 01052
		30		19. 3	22. 34	1. 01536
		Bottom.		19. 3	22. 32	1. 01534
3 p. m.		0		19. 6	15. 86	1. 01039
		10		19. 6	15. 90	1. 01042
		20		19. 4	21. 24	1. 01450
		30		19. 3	22. 32	1. 01534
		Bottom.		19. 3	22. 42	1. 01542
4.30 p. m.		0		19. 9	15. 95	1. 01039
		10		19. 8	15. 90	1. 01037
		20		19. 7	20. 85	1. 01413
		30		19. 6	22. 22	1. 01520
		Bottom.		19. 7	22. 37	1. 01527
6 p. m.		0		19. 6	15. 98	1. 01048
		10		19. 7	16. 05	1. 01051
		20		19. 6	16. 06	1. 01054
		30		19. 4	21. 35	1. 01458
		Bottom.		19. 6	21. 83	1. 01490
7.30 p. m.		0		19. 6	15. 92	1. 01042
		10		19. 6	15. 91	1. 01042
		20		19. 6	17. 59	1. 01170
		30		19. 4	21. 85	1. 01496
		Bottom.		19. 6	22. 21	1. 01519
9 p. m.		0		19. 6	15. 92	1. 01042
		10		19. 5	15. 90	1. 01042
		20		19. 7	16. 78	1. 01106
		30		19. 8	21. 93	1. 01493
		Bottom.		19. 6	22. 02	1. 01505
10.30 p. m.		0		19. 7	15. 85	1. 01035
		10		19. 6	16. 00	1. 01049
		20		19. 5	20. 68	1. 01404
		30		19. 4	21. 92	1. 01502
		Bottom.		19. 7	22. 03	1. 01503
12 p. m.		0		19. 6	15. 38	1. 01002
		10		19. 9	15. 96	1. 01039
		20		19. 7	20. 93	1. 01419
		30		19. 3	22. 04	1. 01589
		Bottom.		19. 4	22. 14	1. 01595
Oct. 19, 1.30 a. m.		0		19. 8	15. 79	1. 01028
		10		19. 5	15. 80	1. 01034
		20		19. 9	20. 89	1. 01412
		30		19. 3	21. 88	1. 01500
		Bottom.		19. 3	22. 14	1. 01521
3 a. m.		0		19. 9	15. 77	1. 01025
		10		19. 5	15. 80	1. 01026
		20		19. 7	20. 72	1. 01403
		30		19. 3	21. 82	1. 01495
		Bottom.		19. 3	22. 03	1. 01512
4.30 a. m.		0		19. 8	15. 68	1. 01020
		10		19. 4	15. 72	1. 00932
		20		19. 7	20. 48	1. 01385
		30		19. 3	21. 75	1. 01491
		Bottom.		19. 3	22. 05	1. 01513
6 a. m.		0		19. 4	15. 76	1. 01035
		10		19. 9	15. 75	1. 01024
		20		19. 6	20. 85	1. 01416
		30		19. 8	21. 61	1. 01468
		Bottom.		19. 4	21. 86	1. 01497
7.30 a. m.		0		19. 6	15. 71	1. 01027
		10		19. 8	15. 76	1. 01026
		20		20. 1	18. 40	1. 01219
		30		19. 4	21. 99	1. 01506
		Bottom.		19. 5	21. 95	1. 01503
9 a. m.		0		19. 6	15. 81	1. 01034
		10		19. 9	15. 75	1. 01023
		20		19. 9	20. 89	1. 01391
		30		19. 4	21. 87	1. 01498
		Bottom.		19. 5	21. 94	1. 01503
Dec. 7, 11.30 a. m.	¾ flood	0		8. 7	15. 14	1. 01171
		10		8. 7	15. 34	1. 01186
		20		10. 1	19. 51	1, 01493
		30		10. 1	20. 10	1. 01539
		Bottom.		10. 1	20. 28	1. 01553

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
Dec. 7, 1 p. m	Flood	0	--------	8.8	15.20	1.01175
		10	--------	8.6	15.22	1.01178
		20	--------	10.0	19.85	1.01520
		30	--------	10.0	19.19	1.01470
		Bottom.	--------	10.1	20.21	1.01547
2.30 p. m	⅓ ebb	0	--------	8.7	15.33	1.01185
		10	--------	8.6	15.31	1.01183
		20	--------	9.9	19.69	1.01510
		30	--------	10.1	20.20	1.01546
		Bottom.	--------	9.9	20.29	1.01557
4 p. m	¾ ebb	0	--------	8.7	15.03	1.01151
		10	--------	8.6	15.21	1.01178
		20	--------	10.0	20.01	1.01533
		30	--------	10.1	20.13	1.01542
		Bottom.	--------	10.1	20.21	1.01547
5.30 p. m	Slack	0	--------	8.7	15.16	1.01207
		10	--------	8.6	15.24	1.01179
		20	--------	9.9	19.90	1.01588
		30	--------	10.0	15.36	1.01172
		Bottom.	--------	10.1	20.17	1.01530
7 p. m	Beginning flood	0	--------	8.7	15.37	1.01189
		10	--------	8.7	15.37	1.01189
		20	--------	10.0	19.88	1.01531
		30	--------	10.0	20.17	1.01545
		Bottom.	--------	10.1	20.24	1.01549
8.30 p. m	⅓ flood	0	--------	8.5	15.24	1.01180
		10	--------	8.6	15.26	1.01182
		20	--------	10.3	19.82	1.01514
		30	--------	10.0	20.08	1.01539
		Bottom.	--------	10.0	20.28	1.01554
10 p. m	¾ flood	0	--------	8.6	15.31	1.01185
		10	--------	8.6	15.31	1.01185
		20	--------	10.0	19.90	1.01525
		30	--------	9.8	20.17	1.01548
		Bottom.	--------	10.0	20.36	1.01560
11.30 p. m	Flood	0	--------	8.5	15.12	1.01172
		10	--------	8.6	15.14	1.01173
		20	--------	10.2	19.62	1.01212
		30	--------	9.9	--------	--------
		Bottom.	--------	9.8	20.10	1.01544
Dec. 8 1 a. m	Beginning ebb	0	--------	8.5	15.30	1.01186
		10	--------	8.8	15.32	1.01184
		20	--------	8.6	15.40	1.01192
		30	--------	9.8	18.53	1.01424
		Bottom.	--------	10.2	19.78	1.01512
2.30 a. m	½ ebb	0	--------	8.4	--------	--------
		10	--------	8.6	15.40	1.01192
		20	--------	8.6	15.42	1.01195
		30	--------	9.0	16.20	1.01250
		Bottom.	--------	9.8	19.65	1.01508
4 a. m	¾ ebb	0	--------	8.4	15.38	1.01192
		10	--------	8.5	15.37	1.01191
		20	--------	8.6	14.63	1.01135
		30	--------	9.1	15.76	1.01214
		Bottom.	--------	9.8	19.08	1.01463
5.30 a. m	Slack	0	--------	8.3	15.33	1.01190
		10	--------	8.4	15.30	1.01187
		20	--------	8.4	15.36	1.01192
		30	--------	8.6	15.42	1.01193
		Bottom.	--------	9.4	16.86	1.01297
7 a. m	¼ flood	0	--------	8.3	15.41	1.01195
		10	--------	8.4	15.42	1.01196
		20	--------	8.4	--------	--------
		30	--------	8.8	15.43	1.01183
		Bottom.	--------	9.7	19.33	1.01484
8.30 a. m	⅓ flood	0	--------	9.5	15.37	1.01180
		10	--------	8.7	15.38	1.01190
		20	--------	9.8	18.92	1.01952
		30	--------	9.9	20.21	1.01550
		Bottom.	--------	9.8	20.19	1.01560
10 a. m	½ flood	0	--------	8.3	15.44	1.01199
		10	--------	8.4	15.44	1.01198
		20	--------	8.6	15.41	1.01193
		30	--------	9.2	15.44	1.01189
		Bottom.	--------	9.7	15.45	1.01184

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued.

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921						
Jan. 25, 10.30 a. m.	Beginning flood; sea rolling; wind NNE., force 4.	0	−4. 4	3. 1	13. 64	1. 01094
		10	--------	3. 0	13. 72	1. 01099
		20	--------	3. 0	13. 80	1. 01106
		30	--------	3. 7	16. 80	1. 01342
		33. 85	--------	3. 8	17. 95	1. 01432
12 m.	½ flood	0	--------	3. 2	13. 64	1. 01092
		10	--------	3. 0	13. 72	1. 01099
		20	--------	3. 2	14. 55	1. 01165
		30	--------	3. 3	15. 34	1. 01227
		33. 85	--------	3. 7	17. 18	1. 01373
1.30 p. m.	¾ flood	0	--------	3. 0	13. 97	1. 01120
		10	--------	3. 1	14. 05	1. 01126
		20	--------	3. 2	14. 97	1. 01198
		30	--------	3. 5	16. 12	1. 01287
		33. 85	--------	3. 9	17. 62	1. 01408
3 p. m.	Full flood	0	--------	3. 1	14. 15	1. 01133
		10	--------	3. 1	14. 23	1. 01140
		20	--------	3. 1	14. 64	1. 01171
		30	--------	3. 0	14. 87	1. 01191
		33. 85	--------	4. 1	18. 13	1. 01445
4.30 p. m.	Beginning ebb	0	--------	3. 1	14. 52	1. 01164
		10	--------	3. 1	14. 75	1. 01180
		20	--------	3. 0	14. 77	1. 01182
		30	--------	3. 0	14. 87	1. 01191
		33. 85	--------	4. 0	18. 07	1. 01441
6 p. m.	⅓ ebb	0	--------	3. 5	14. 65	1. 01171
		10	--------	3. 9	14. 75	1. 01180
		20	--------	3. 1	14. 66	1. 01173
		30	--------	3. 4	14. 63	1. 01171
		33. 85	--------	3. 1	15. 13	1. 01211
7.35 p. m.	¾ ebb	0	--------	3. 0	14. 26	1. 01143
		10	--------	3. 0	14. 26	1. 01143
		20	--------	2. 9	14. 34	1. 01150
		30	--------	3. 0	14. 64	1. 01173
		33. 85	--------	3. 3	14. 78	1. 01183
9 p. m.	Slack	0	--------	3. 0	14. 21	1. 01138
		10	--------	3. 0	14. 25	1. 01141
		20	--------	2. 9	14. 48	1. 01161
		30	--------	3. 1	15. 21	1. 01217
		33. 85	--------	3. 3	15. 02	1. 01202
10.30 p. m.	Beginning flood	0	--------	3. 0	14. 20	1. 01138
		10	--------	2. 9	14. 23	1. 01140
		20	--------	3. 1	14. 34	1. 01149
		30	--------	2. 9	14. 56	1. 01167
		33. 85	--------	3. 1	14. 38	1. 01150
12 p. m.	½ flood	0	--------	2. 9	14. 36	1. 01151
		10	--------	2. 8	14. 34	1. 01153
		20	--------	3. 3	14. 52	1. 01162
		30	--------	3. 3	15. 54	1. 01164
		33. 85	--------	3. 1	14. 52	1. 01163
Jan. 26, 1.30 a. m.	¾ flood	0	--------	4. 0	14. 42	1. 01151
		10	--------	2. 8	14. 46	1. 01159
		20	--------	3. 9	14. 44	1. 01154
		30	--------	2. 9	14. 48	1. 01161
		33. 85	--------	3. 1	14. 54	1. 01166
3 a. m.	Full flood	0	--------	3. 9	14. 59	1. 01165
		10	--------	3. 7	14. 56	1. 01167
		20	--------	3. 9	14. 59	1. 01168
		30	--------	3. 7	14. 59	1. 01168
		33. 85	--------	3. 9	14. 61	1. 01171
4.30 a. m.	¼ ebb	0	--------	3. 0	14. 38	1. 01152
		10	--------	3. 8	14. 36	1. 01151
		20	--------	3. 0	14. 44	1. 01156
		30	--------	3. 8	14. 87	1. 01191
		33. 85	--------	3. 8	15. 01	1. 01201
6 a. m.	½ ebb	0	--------	3. 8	14. 44	1. 01159
		10	--------	3. 7	14. 42	1. 01155
		20	--------	3. 7	14. 39	1. 01145
		30	--------	3. 9	14. 58	1. 01168
		33. 85	--------	3. 1	14. 68	1. 01175
7.30 a. m.	¾ ebb	0	--------	3. 8	14. 48	1. 01158
		10	--------	3. 9	14. 61	1. 01167
		20	--------	3. 9	14. 64	1. 01173
		30	--------	3. 9	14. 53	1. 01165
		33. 85	--------	3. 8	14. 68	1. 01165

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921—Continued						
Jan. 26, 9 a. m.	Slack	0		3.8	14.20	1.01135
		10		3.6	14.26	1.01140
		20		3.8	14.26	1.01140
		30		3.9	14.34	1.01149
		33.85		3.8	14.62	1.01172
Mar. 29, 11.40 a. m.	Ebbing; sea choppy; wind SE., force 1	0	11.6	11.4	14.26	1.01069
		10		11.0	14.46	1.01090
		24		10.8	15.86	1.01201
1.10 p. m.		0		11.4	14.15	1.01060
		10		10.9	14.49	1.01092
		24		10.8	15.82	1.01202
Mar. 30, 2.40 p. m.		0		11.6	14.13	1.01057
		10		11.3	14.12	1.01059
		24		10.7	15.77	1.01194
4.10 p. m.		0		10.7	14.15	1.01071
		10		10.2	14.05	1.01070
		24		11.0	14.65	1.01104
5.40 p. m.		0		11.6	14.30	1.01069
		10		11.3	14.40	1.01081
		24		10.5	16.76	1.01275
7.10 p. m.		0		10.9	14.34	1.00987
		10		11.5	14.41	1.01079
		24		10.9	15.42	1.01087
8.40 p. m.		0		11.3	14.33	1.01075
		10		11.2	14.58	1.01095
		24		10.8	15.16	1.01153
10.10 p. m.		0		11.2	14.40	1.01082
		10		11.1	14.68	1.01105
		24		10.9	15.83	1.01198
11.40 p. m.		0		11.3	14.40	1.01082
		10		11.1	14.66	1.01106
		24		10.8	14.48	1.01095
Mar. 31, 1.10 a. m.		0		11.3	14.40	1.01081
		10		11.0	14.35	1.01081
		24		11.0	14.79	1.01116
3.40 a. m.		0		11.1	14.22	1.01069
		10		11.1	14.35	1.01079
		24		11.4	14.75	1.01107
4.10 a. m.		0		11.3	13.71	1.01029
		10		10.6	14.34	1.01086
		24		11.1	15.14	1.01140
5.40 a. m.		0		10.9	13.64	1.01028
		10		11.3	14.48	1.01087
		24		10.9	14.15	1.01078
7.10 a. m.		0		11.0	14.05	1.01058
		10		11.3	14.55	1.01094
		24		11.3	14.91	1.01121
8.40 a. m.		0		11.0	13.61	1.01021
		10		11.4	14.44	1.01084
		24		11.3	15.84	1.01193
10.10 a. m.		0		11.4	14.31	1.01070
		10		11.4	14.65	1.01098
		24		11.2	14.83	1.01116
June 1, 3.30 p. m.	2/3 ebb; sea tide ripples; wind NW., force 1	0	32.2	20.4	12.07	1.00733
		10		17.6	17.18	1.01283
		20		17.2	18.77	1.01312
		30		17.5	16.44	1.01130
		40.26		17.2	19.25	1.01349
4.50 p. m.		0		21.5	11.94	1.00697
		10		19.0	12.98	1.00833
		20		19.0	19.20	1.01304
		30		16.9	19.17	1.01348
		40.26		16.9	19.27	1.01356
6.20 p. m.		0		20.9	12.05	1.00725
		10		18.4	13.81	1.00910
		20		17.1	19.18	1.01346
		30		17.8	17.34	1.01190
		40.26		17.3	18.98	1.01326
7.50 p. m.		0		21.1	12.11	1.00720
		10		18.8	18.91	1.01288
		20		17.1	13.36	1.00903
		30		17.7	18.62	1.01290
		40.26		17.1	18.99	1.01333

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921—Continued						
June 1, 9.20 p. m.		0		20.8	12.03	1.00719
		10		17.6	18.17	1.01257
		20		17.2	19.07	1.01335
		30		18.9	13.02	1.00838
		40.26		17.4	18.86	1.01315
10.50 p. m.		0		21.1	11.85	1.00701
		10		18.8	13.12	1.00849
		20		17.3	18.88	1.01317
		30		18.6		
		40.26		17.2	18.93	1.01323
June 2, 12.20 a. m.		0		20.3	11.85	1.00719
		10		18.0	14.03	1.00934
		20		17.2	18.87	1.01322
		30		17.9	19.13	1.01323
		40.26		17.1	19.41	1.01363
1.50 a. m.		0		19.6	12.07	1.00751
		10		18.8	13.11	1.00848
		20		17.2	18.99	1.01329
		30		17.0	19.17	1.01347
		40.26		17.1	19.22	1.01349
3.20 a. m.		0		19.8	12.07	1.00747
		10		18.2	14.99	1.01004
		20		17.1	18.98	1.01331
		30		17.2	19.22	1.01343
		40.26		17.1	19.27	1.01353
June 3, 4.30 a. m.		0		19.5	12.28	1.00770
		10		19.4	12.48	1.00788
		20		17.3	18.99	1.01328
		30		17.1	19.05	1.01338
		40.26		17.1	19.25	1.01351
6.20 a. m.		0		19.5	12.44	1.00782
		10		19.2	12.52	1.00795
		20		17.3	18.73	1.01306
		30		17.1	19.05	1.01337
		40.26		17.2	19.12	1.01339
7.50 a. m.		0		19.4	12.48	1.00787
		10		19.1	12.87	1.00823
		20		17.3	18.94	1.01325
		30		17.2	19.20	1.01344
		40.26		17.1	19.22	1.01348
9.20 a. m.		0		19.5	12.62	1.00783
		10		19.3	12.70	1.00805
		20		17.3	18.58	1.01244
		30		17.3	18.90	1.01320
		40.26		17.1	19.13	1.01341
10.50 a. m.		0		19.2	12.79	1.00815
		10		19.2	12.82	1.00817
		20		17.1	18.34	1.01319
		30		17.1	19.05	1.01336
		40.26		17.1	19.37	1.01360
12.20 p. m.		0		19.2	12.62	1.00802
		10		19.3	12.79	1.00815
		20		17.1	18.92	1.01327
		30		17.2	19.11	1.01339
		40.26		17.2	19.25	1.01349
1.50 p. m.		0		19.8	12.58	1.00786
		10		19.5	12.71	1.00802
		20		17.1	19.26	1.01352
		30		17.0	19.30	1.01356
		40.26		16.6	19.40	1.01371
1922						
Jan. 23, 4.50 p. m.	Beginning flood; sea moderate; wind NNE., force 4; hazy.	0	1.11	2.6	15.37	1.01232
		10		2.6	15.38	1.01233
		20		2.7	18.22	1.01459
		30		2.5	16.56	1.01328
		36.60		2.7	19.60	1.01569
6.20 p. m.		0		2.3	15.45	1.01241
		10		2.4	16.31	1.01308
		20		3.0	18.94	1.01514
		30		2.8	20.41	1.01632
		36.60		2.8	20.41	1.01632

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1922—Continued						
Jan. 23, 7.50 p. m.		0	--------	2. 6	15. 46	1. 01240
		10	--------	2. 3	16. 40	1. 01315
		20	--------	2. 4	20. 31	1. 01626
		30	--------	2. 8	20. 46	1. 01637
		36. 60	--------	2. 8	20. 31	1. 01625
9.20 p. m.		0	--------	2. 4	15. 47	1. 01242
		10	--------	2. 2	15. 85	1. 01271
		20	--------	3. 2	18. 64	1. 01489
		30	--------	2. 8	20. 03	1. 01602
		36. 60	--------	2. 8	20. 01	1. 01600
10.50 p. m.		0	--------	2. 2	15. 46	1. 01241
		10	--------	2. 2	15. 91	1. 01277
		20	--------	3. 3	19. 94	1. 01597
		30	--------	2. 8	20. 12	1. 01613
		36. 60	--------	2. 8	20. 15	1. 01616
Jan. 24, 12.20 a. m.		0	--------	2. 7	16. 37	1. 01307
		10	--------	2. 3	15. 47	1. 01241
		20	--------	2. 6	15. 42	1. 01238
		30	--------	3. 1	17. 08	1. 01336
		36. 60	--------	2. 8	19. 94	1. 01596
1.50 a. m.		0	--------	2. 3	15. 39	1. 01235
		10	--------	2. 2	15. 74	1. 01262
		20	--------	2. 8	16. 34	1. 01307
		30	--------	2. 5	16. 20	1. 01299
		36. 60	--------	3. 2	20. 47	1. 01636
3.20 a. m.		0	--------	2. 9	15. 24	1. 01222
		10	--------	2. 2	15. 40	1. 01234
		20	--------	2. 5	15. 98	1. 01280
		30	--------	2. 9	16. 43	1. 01317
		36. 60	--------	2. 8	18. 01	1. 01441
4.50 a. m.		0	--------	2. 5	15. 22	1. 01220
		10	--------	2. 0	15. 16	1. 01217
		20	--------	2. 8	16. 43	1. 01317
		30	--------	2. 0	15. 23	1. 01223
		36. 60	--------	3. 0	17. 35	1. 01389
6.20 a. m.		0	--------	2. 7	15. 14	1. 01214
		10	--------	2. 2	15. 05	1. 01207
		20	--------	2. 6	16. 23	1. 01302
		30	--------	3. 0	16. 48	1. 01320
		36. 60	--------	2. 8	19. 79	1. 01583
7.50 a. m.		0	--------	2. 2	15. 14	1. 01214
		10	--------	3. 3	15. 15	1. 01212
		20	--------	3. 3	20. 61	1. 01650
		30	--------	3. 5	20. 85	1. 01669
		36. 60	--------	3. 0	20. 95	1. 01675
9.20 a. m.		0	--------	2. 2	15. 15	1. 01215
		10	--------	2. 2	--------	--------
		20	--------	3. 2	15. 24	1. 01220
		30	--------	2. 9	20. 85	1. 01667
		36. 60	--------	2. 8	21. 01	1. 01682
10.50 a. m.		0	--------	2. 5	15. 25	1. 01222
		10	--------	2. 2	15. 50	1. 01244
		20	--------	2. 4	20. 61	1. 01649
		30	--------	3. 0	21. 05	1. 01979
		36. 60	--------	4. 3	20. 14	1. 01602
12.20 p. m.		0	--------	2. 2	15. 30	1. 01228
		10	--------	2. 2	15. 58	1. 01250
		20	--------	2. 4	--------	--------
		30	--------	2. 5	17. 71	1. 01419
		36. 60	--------	3. 2	20. 63	1. 01651
1.50 p. m.		0	--------	2. 4	15. 16	1. 01216
		10	--------	2. 3	16. 32	1. 01308
		20	--------	2. 4	17. 55	1. 01416
		30	--------	2. 0	16. 39	1. 01314
		36. 60	--------	2. 4	19. 81	1. 01586
3.20 p. m.		0	--------	2. 5	15. 15	1. 01216
		10	--------	2. 5	16. 14	1. 01293
		20	--------	2. 6	17. 94	1. 01436
		30	--------	2. 2	16. 43	1. 01318
		36. 60	--------	2. 4	17. 91	1. 01435

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1922—Continued						
Mar. 27, 1.43 p. m.	¼ flood; sea smooth; wind SE., force 1	0		6.2	12.22	1.00965
		10		5.6	15.10	1.01196
		20		5.9	13.43	1.01064
		30			16.77	
		40.0		6.8	13.68	1.01075
3.13 p. m.		0		7.2	15.54	1.01219
		10		5.6	12.11	1.00961
		20		5.4	13.89	1.01174
		30		5.9	13.14	1.01040
		40.0		6.0	15.67	1.01238
4.43 p. m.		0		7.2	12.21	1.00957
		10		5.8	14.54	1.01152
		20		5.7	16.95	1.01342
		30		5.6	17.12	1.01355
		40.0		5.4	17.22	1.01366
6.13 p. m.		0		7.2	12.15	1.00953
		10		5.6	14.16	1.01122
		20		5.8	17.06	1.01350
		30		5.7	17.18	1.01359
		40.0		5.5	17.25	1.01366
7.43 p. m.		0		7.0	12.08	1.00947
		10		5.5	14.71	1.01168
		20		5.8	16.75	1.01325
		30		5.7	17.10	1.01353
		40.0		5.5	17.18	1.01361
9.13 p. m.		0		7.0	12.21	1.00959
		10		5.5	14.31	1.01135
		20		5.7	16.51	1.01306
		30		5.4	17.12	1.01357
		40.0		5.5	17.25	1.01366
10.43 p. m.		0		7.1	12.30	1.00965
		10		5.6	13.82	1.01095
		20		5.7	15.95	1.01263
		30		5.6	17.00	1.01346
		40.0		5.3	17.30	1.01372
Mar. 28, 12.13 a. m.		0		7.0	12.32	1.00968
		10		6.0	{13.52 / 15.91}	
		20		5.8	16.83	1.01331
		30		5.6	17.35	1.01374
		40.0		5.4	17.16	1.01359
1.43 a. m.		0		7.6	12.30	1.00961
		10		5.6	16.04	1.01269
		20		5.5	17.10	1.01354
		30		5.6	17.18	1.01361
		40.0		5.4	17.34	1.01374
3.13 a. m.		0		7.2	14.07	1.01102
		10		5.8	16.17	1.01278
		20		5.6	16.86	1.01335
		30		5.7	16.92	1.01338
		40.0		5.5	17.11	1.01355
4.43 a. m.		0		7.3	12.36	1.00968
		10		7.0	13.76	1.01080
		20		5.5	16.81	1.01331
		30		5.8	17.12	1.01354
		40.0		5.6	17.31	1.01371
6.13 a. m.		0		7.1	12.30	1.00966
		10		6.6	13.42	1.01056
		20		5.7		
		30		5.5	16.91	1.01338
		40.0		5.6	17.18	1.01360
7.43 a. m.		0		7.2	12.28	1.00962
		10		6.0	13.62	1.01076
		20		5.5	16.56	1.01311
		30		5.6	17.05	1.01349
		40.0		5.5		
9.13 a. m.		0		7.2	12.26	1.00960
		10		7.1	13.42	1.01052
		20		5.7	16.50	1.01304
		30		5.4	17.93	1.01419
		40.0		5.4	17.18	1.01361

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 14—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1922—Continued						
Mar. 28, 10.43 a. m.		0		7. 3	12. 17	1. 00953
		10		5. 9	12. 25	1. 00970
		20		5. 7	16. 07	1. 01271
		30		5. 8	16. 97	1. 01341
		40. 0		5. 4	17. 08	1. 01352
12.13 p. m.		0		7. 6	11. 18	1. 00863
		10				
		20		5. 4	17. 06	1. 01351
		30		5. 6	17. 15	1. 01357
		40. 0		5. 4	17. 20	1. 01361
Station 15						
1920						
Jan. 15, 3.44 p. m.		0		0. 7	15. 04	1. 01207
		7. 3		. 7	15. 10	1. 01213
Mar. 8, 2.10 p. m.	¼ ebb	0		1. 4	16. 10	1. 01292
		7. 33		1. 1	16. 16	1. 01297
May 6, 6.24 p. m.	¼ ebb	0		12. 8	7. 32	1. 00514
		7. 27		12. 6	9. 42	1. 00675
July 6, 4.55 a. m.	Slack ebb	0		24. 4	13. 26	1. 00723
		Bottom.		23. 1	13. 24	1. 00755
Aug. 25, 11.37 a. m.		0		24. 8	13. 61	1. 00737
		Bottom.		24. 7	13. 63	1. 00741
Oct. 19, 11.25 a. m.		0		19. 6	15. 15	1. 00984
		Bottom.		19. 7	16. 60	1. 01089
Dec. 8, 12.03 p. m.	¾ flood	0		8. 5	15. 23	1. 01182
		Bottom.		8. 2	15. 34	1. 01192
1921						
Jan. 26, 10.50 a. m.	Slack ebb; sea broken; wind NNE., force 2	0	−3. 3	3. 5	14. 49	1. 01162
		7. 78		3. 6	14. 53	1. 01165
June 2, 3.55 p. m.	½ ebb; sea moderate; wind E., force 3	0	26. 6	19. 9	12. 53	1. 00779
		8. 23		19. 5	12. 83	1. 00810
1922						
Jan. 24, 5.14 p. m.	¾ ebb; choppy; wind NNE., force 4	0	−3. 88	2. 5	15. 05	1. 01207
		9. 15		2. 3	16. 08	1. 01289
Mar. 28, 2.15 p. m.	Full flood; wind SSE., force 2	0	12. 22	8. 3	12. 74	1. 00987
		9. 15		7. 4	13. 63	1. 01066
Station 16						
1920						
Jan. 15, 8.15 a. m.		0		−0. 05	13. 74	1. 01103
		11. 9		−. 05	13. 96	1. 01121
Mar. 9, 6.33 a. m.	Slack	0		. 2	11. 22	1. 00900
		5		. 3	12. 74	
		10		. 7	15. 74	1. 01263
May 6, 11.28 a. m.	⅛ flood	0		13. 8	6. 76	1. 00456
		10. 91		13. 6	8. 73	1. 00610
July 7, 9.58 a. m.	½ flood	0		24. 3	12. 89	1. 00697
		Bottom.		21. 8	15. 67	1. 01171
Aug. 24, 5.50 a. m.		0		25. 3	12. 27	1. 00623
		Bottom.		25. 3	12. 44	1. 00634
Oct. 19, 2.05 p. m.		0		20. 9		
		Bottom.		19. 7	15. 00	1. 00972
Dec. 7, 7.05 a. m.	Slack ebb	0		8. 8	14. 56	1. 01117
		Bottom.		8. 8	14. 65	1. 01121
1921						
Jan. 24, 4.24 p. m.	¼ ebb; sea choppy; wind NNW., force 3	0	5. 5	3. 5	11. 91	1. 00954
		11. 44		3. 4	13. 19	1. 01054
Mar. 31, 3.55 p. m.	Flood; sea choppy; wind S., force 4	0	18. 3	12. 1	13. 28	1. 00983
		11. 89		11. 2	13. 21	1. 00990
June 1, 10.55 a. m.	Beginning ebb; calm; wind force 0; cloudy	0	31. 6	20. 5	7. 47	1. 00383
		10. 98		19. 0	12. 82	1. 00820
1922						
Jan. 23, 12.35 p. m.	Beginning ebb; moderate swell; wind NNE., force 4.	0	1. 67	2. 7	13. 90	1. 01115
		10. 98		3. 4	14. 26	1. 01142
Mar. 27, 8.45 a. m.	Slack; sea smooth; wind SW., force 1	0		9. 0	11. 01	1. 00846
		12. 0		5. 8	13. 17	1. 01044

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 17

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 15, 9.57 a. m.		0		0.7	14.63	1.01176
		10.5		.7	14.71	1.01182
Mar. 9, 7.25 a. m.	Beginning ebb	0		.4	12.13	1.00973
		10		.7	15.93	1.01279
		21.9		.3	15.91	
May 6, 12.45 p. m.	¼ flood	0		13.8	7.22	1.00491
		10		13.8	12.21	1.00885
		21.81		13.6	13.03	1.00948
July 7, 10.37 a. m.	½ flood	0		22.4	11.38	1.00629
		10		23.1	15.14	1.00897
		Bottom.		22.9	17.62	1.01090
Aug. 24, 6.33 a. m.		0		26.0	13.19	1.00672
		10		25.5	15.02	1.00814
		Bottom.		24.8	14.25	1.00806
Oct. 19, 2.51 p. m.		0		20.4	14.99	1.00954
		10		19.7	15.32	1.00995
		Bottom.		19.7	15.92	1.01040
Dec. 7, 8 a. m.	Beginning flood	0		8.9	15.36	1.01186
		10		8.9	15.34	1.01183
		Bottom.		8.9	15.37	1.01186
1921						
Jan. 24, 5.22 p. m.	⅓ ebb; sea choppy; wind NNW., force 3	0	5.0	4.0	13.60	1.01087
		10		3.6	13.61	1.01088
		21.96		3.6	14.15	1.01132
Mar. 31, 3.20 p. m.	Flood; sea choppy; wind S., force 4	0	18.3	13.4	13.09	1.00973
		10		10.9	14.15	1.01068
		14.64		11.0	14.81	1.01116
June 1, 11.47 a. m.	⅓ ebb; sea smooth; wind ENE., force 1; cloudy.	0	30.0	22.2	7.17	1.00326
		10		19.1	12.59	1.00803
		21.96		19.6	14.58	1.00967
1922						
Jan. 23, 1.20 p. m.	¼ ebb; slight sea; wind NNE., force 3	0	1.67	3.9	14.62	1.01169
		10		3.7	15.37	1.01227
		21.96			15.48	
Mar. 27, 9.30 a. m.	Beginning flood; smooth; wind SE., force 1	0	11.11	8.0	10.39	1.00801
		10		6.7	13.31	1.01053
		21.0		7.8	15.32	1.01194

Station 18

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 15, 11.13 a. m.		0		0.95	13.88	1.01113
		21		.7	14.76	1.01186
Mar. 9, 8.35 a. m.	¼ ebb	0		.4	12.62	
		5		.3	14.52	
		10.5		.7	15.90	1.01277
May 6, 1.43 p. m.	½ flood	0		13.8	7.22	1.00491
		10		13.1	9.56	1.00668
July 7, 11.40 a. m.	¾ flood	0		24.5	11.47	1.00586
		Bottom.		24.1	13.26	1.00730
Aug. 24, 7.18 a. m.		0		26.0	13.56	1.00701
		Bottom.		25.5	13.60	1.00718
Oct. 19, 3.38 p. m.		0		19.9		
		Bottom.		20.0	15.39	1.00994
Dec. 7, 8.39 a. m.	¼ flood	0		8.9	15.61	1.01205
		Bottom.		8.9	15.61	1.01205
1921						
Jan. 25, 7.10 a. m.	¾ ebb; sea choppy; wind NNE., force 2	0	−3.8	2.9	13.95	1.01119
		10.98		2.9	13.96	1.01120
Mar. 31, 2.12 p. m.	Flood; sea choppy; wind S., force 3	0	17.2	12.5	12.93	1.00951
		12		11.0	14.59	1.01098
June 1, 12.25 p. m.	⅓ ebb; sea smooth; wind ENE., force 1	0	30.0	20.3	11.67	1.00705
		10.5		17.3	14.10	1.00955
1922						
Jan. 23, 1.55 p. m.	½ ebb; sea moderate; wind NNE., force 3	0	1.67	2.7	15.85	1.01271
		10.53		3.1	15.81	1.01264
Mar. 27, 10.18 a. m.	¼ flood; smooth; wind SE., force 1	0	11.11	7.8	11.76	1.00916
		10.0		7.1	13.40	1.01050

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 19

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 14, 10.30 a. m		0		0.95	16.13	1.01295
		12.8		.95	19.37	1.01555
Mar. 9, 11.48 a. m	Slack	0		1.0	14.58	1.01169
		5		.9	13.80	
		10		.9	15.97	1.01282
		12.8		.9	16.55	
May 6, 5 a. m	¼ ebb	0		12.6	9.71	1.00702
		12.73		12.8	13.62	1.00998
July 7, 5.04 p. m	¾ flood	0		22.5	14.70	1.00881
		Bottom.		23.2	18.47	1.01176
Aug. 23, 6.11 p. m		0		25.5	14.40	1.00777
		Bottom.		25.2	19.11	1.01138
Oct. 20, 7.04 a. m		0		19.6	17.68	1.01176
		Bottom.		20.2	19.33	1.01286
Dec. 6, 4.18 p. m	¾ ebb	0		9.5	16.90	1.01298
		Bottom.		9.5	16.76	1.01287
1921						
Jan. 24, 1.28 p. m	¾ flood; sea choppy; wind NNW., force 3	0	6.6	3.8	14.45	1.01155
		11.90		3.8	17.22	1.01374
Mar. 31, 6.30 p. m	Flood; sea choppy; wind S., force 3	0	16.1	11.5	15.08	1.01131
		12.81		11.0	16.48	1.01246
June 1, 7 a. m	½ flood; wind NNE., force 1	0	20.0	19.8	9.10	1.00526
		12.81		18.9	13.77	1.00895
1922						
Jan. 23, 9 a. m	⅓ flood; sea rolling; wind NNE., force 4	0	2.22	2.9	18.19	1.01450
		12.81		2.8	18.78	1.01503
Mar. 26, 6.31 p. m	Full ebb; sea moderate; wind S. by E., force 2.	0	9.44	8.0	11.55	1.00898
		12.81		6.7	16.60	1.01305

Station 20

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Mar. 9, 10.56 a. m	¾ ebb	0		0.6	14.21	1.01140
		5		.6	14.86	1.01193
		10		.7	15.77	1.01265
May 6, 6.15 a. m	½ ebb	0		12.8	11.15	1.00808
		5		12.6	12.34	1.00902
		10		12.8		
		Bottom.			13.09	1.00953
July 7, 4.10 p. m	¾ flood	0		24.5	14.71	1.00829
		Bottom.		24.4	14.79	1.00838
Aug. 23, 5.45 p. m		0		26.0	14.73	1.00783
		Bottom.		25.3	17.64	1.01025
Oct. 20, 6.08 a. m		0		20.3	15.08	1.00963
		Bottom.		19.8	17.14	1.01131
Dec. 6, 3.21 p. m	½ ebb			9.4	16.99	1.01304
		Bottom.		9.3	16.96	1.01306
1921						
Jan. 24, 12.43 p. m	⅔ flood; sea choppy; wind NNW., force 3	0	6.1	3.9	15.47	1.01236
		10.53		3.9	15.54	1.01242
Apr. 1, 5.30 p. m	Flood; sea choppy; wind N., force 5	0	7.7	11.2	15.17	1.01142
		12.8		11.5	15.26	1.01145
June 1, 7.53 a. m	⅔ flood; sea smooth; wind NNE., force 1	0	20.0	19.9	11.42	1.00932
		10.62		18.5	14.70	1.00966
1922						
Jan. 23, 9.55 a. m	Full flood; sea moderate; wind NNE., force 4.	0	2.22	2.8	18.10	1.01449
		12.23		2.7	19.18	1.01536
Mar. 26, 6.10 p. m	¾ ebb; sea smooth; wind SSW., force 1	0	10.00	7.7	15.65	1.01223
		13.0		6.0	12.09	1.00956

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 21

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 14, 8.50 a. m.		0		0. 45	14. 85	1. 01192
		42. 1		. 45	21. 78	1. 01749
Mar. 9, 1.02 p. m.	Beginning flood	0		. 3	13. 00	1. 01044
		10		. 3	15. 58	1. 01250
		20		1. 0	16. 88	1. 01355
		30		. 6	17. 31	1. 01390
		40		. 7	17. 36	1. 01393
		44. 3		. 6	17. 53	1. 01408
May 6, 8.19 a. m.	¾ ebb	0		13. 3	9. 97	1. 00696
		10		13. 1	15. 76	1. 01157
		20		13. 3	18. 15	1. 01339
		30		13. 1	18. 98	1. 01407
		40		13. 1	19. 08	1. 01414
		44. 09		13. 3	19. 59	1. 01449
July 7, 6.25 p. m.	Flood	0		24. 7	14. 56	1. 00812
		Bottom.		22. 4	19. 82	1. 01268
Aug. 23, 4.35 p. m.		0		26. 0	14. 03	1. 00735
		10		26. 0	13. 97	1. 00732
		20		26. 0	13. 89	1. 00726
		30		25. 2	17. 76	1. 01035
		Bottom.		24. 8	21. 93	1. 01302
Oct. 20, 8.10 a. m.		0		20. 0	14. 87	1. 00954
		10		19. 8	18. 27	1. 01216
		20		19. 3	22. 80	1. 01569
		30		19. 5	----------	----------
		40		19. 1	23. 66	1. 01617
		Bottom.		19. 2	23. 79	1. 01641
Dec. 6, 1.47 p. m.	¼ ebb	0		9. 5	16. 62	1. 01277
		10		9. 5	16. 65	1. 01279
		20		9. 7	18. 25	1. 01401
		30		10. 0	20. 53	1. 01574
		40		10. 0	20. 97	1. 01607
		Bottom.		10. 0	21. 10	1. 01617
1921						
Jan. 24, 11.17 a. m.	½ flood; sea broken; wind N., force 2; sky partly cloudy and hazy.	0	5. 0	3. 9	13. 12	1. 01050
		10		4. 6	13. 54	1. 01080
		20		3. 9	17. 51	1. 01495
		30		4. 0	18. 03	1. 01437
		40		4. 1	18. 65	1. 01484
		43. 01		4. 0	18. 72	1. 01491
Apr. 1, 6.30 p. m.	Flood; sea choppy; wind N., force 3	0	8. 8	10. 9	14. 30	1. 01079
		10		10. 9	14. 39	1. 01086
		26		11. 2	16. 84	1. 01269
June 1, 5.25 a. m.	¼ flood; sea smooth; calm	0	20. 0	19. 6	11. 25	1. 00096
		10		18. 8	13. 85	1. 00903
		20		17. 7	18. 98	1, 01307
		30		17. 5	19. 65	1. 01372
		40		17. 8	20. 85	1. 01456
		43. 92		17. 7	----------	----------
1922						
Jan. 23, 7.30 p. m.	¼ flood; sea rolling; wind NE., force 4	0	2. 22	3. 4	15. 96	1. 01276
		10		3. 0	15. 27	1. 01224
		20		3. 2	15. 99	1. 01280
		30		2. 7	16. 01	1. 01285
		40		3. 3	16. 00	1. 01280
		43. 92		2. 8	18. 27	1. 01463
Mar. 26, 5.21 p. m.	¾ ebb; sea moderate; wind S., force 2	0	12. 22	8. 1	11. 62	1. 00905
		10		6. 2	17. 10	1. 01348
		20		6. 2	17. 89	1. 01410
		30		6. 5	18. 26	1. 01438
		40		6. 2	18. 34	1. 01447
		43. 0		6. 6	----------	----------

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 22

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 13, 4.48 p. m.		0		0.7	16.85	1.01353
		12.8		.7	22.26	1.01786
Mar. 9, 4.06 p. m.	½ flood	0		1.1	16.22	1.01303
		5		1.3	16.23	1.01303
		10		1.2	16.34	1.01311
		12.8		1.1	17.38	1.01396
May 5, 6.14 a. m.		0		13.8	11.95	1.00855
		13.18		13.6		
July 8, 5.25 a. m.		0		24.3	15.57	1.00906
		Bottom.		24.2	21.55	1.01352
Aug. 23, 1.38 a. m.		0		26.0	16.45	1.00916
		Bottom.		26.0	17.33	1.00982
Oct. 20, 10.45 a. m.		0		19.8	16.74	1.01101
		Bottom.		20.1	18.90	1.01258
Dec. 6, 10.25 a. m.	¾ flood	0		9.5	18.25	1.01403
		Bottom.		9.5	18.88	1.01452
1921						
Jan. 24, 8.10 a. m.	Slack ebb; sea broken; wind N., force 3	0	4.4	3.7	14.69	1.01175
		12.81		3.7	14.72	1.01178
Apr. 1, 8.26 p. m.	Ebb; sea choppy; wind N., force 1	0	8.8	11.1	16.48	1.01244
		10		11.2	17.08	1.01287
		14.64		11.3		
May 31, 4.40 p. m.	Full ebb; sea rolling; wind ENE., force 1	0	25.5	20.0	13.27	1.00834
		13.17		19.1	15.08	1.00991
1922						
Jan. 22, 5.40 p. m.	Beginning flood; calm	0	8.89	3.5	22.33	1.01781
		12.81		3.8	17.04	1.01360
Mar. 26, 2.49 p. m.		0		9.3	14.28	1.01098
		13.0		7.0	18.18	1.01427

Station 23

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 13, 3.20 p. m.		0		0.7	16.48	1.01323
		12.8		.7	23.27	1.01867
Mar. 9, 4.55 p. m.	¾ flood	0		1.4	16.62	1.01334
		5		1.4	16.70	1.01340
		10		1.4	16.73	1.01342
		12.8		1.1	17.88	1.01435
May 5, 6.14 p. m.	½ flood	0		13.8	11.95	1.00855
		13.18		13.6		
July 8, 5.25 a. m.		0		24.3	15.57	1.00906
		Bottom.		24.2	21.55	1.01352
Aug. 23, 12.50 a. m.		0		26.0	18.71	1.01085
		Bottom.		25.1	20.48	1.01243
Oct. 20, 11.25 a. m.		0		20.1	17.90	1.01182
		Bottom.		19.2	25.21	1.01756
Dec. 6, 9.37 a. m.	½ flood	0		9.5	19.24	1.01481
		10		9.5	19.43	1.01495
		Bottom.		9.5	19.66	1.01511
1921						
Jan. 24, 7 a. m.	Full ebb; sea broken; wind N., force 2	0	5.0	4.2	17.66	1.01407
		12.81		4.0	17.93	1.01428
Apr. 1, 8.42 p. m.	Ebb; sea choppy; wind N., force 1	0	9.4	11.0	17.14	1.01297
		12.81		11.3	17.42	1.01314
May 31, 4.20 p. m.	Full ebb; sea rolling; wind ENE., force 2	0	25.5	20.0	12.61	1.00859
		12.81		19.8	13.86	1.00882
1922						
Jan. 22, 5 p. m.	Beginning flood; calm	0	10.0	3.2	18.19	1.01454
		12.81		3.8	22.99	1.01831
Mar. 26, 1.55 p. m.	Beginning ebb; wind S., force 1	0	15.0	7.8	15.40	1.01201
		13.0		6.8	18.85	1.01480

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 24

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 13, 11.50 a. m.		0		1.45	18.05	1.01448
		14.7		1.45	23.55	1.01888
Mar. 10, 12.46 a. m.	½ ebb	0		1.4	17.23	1.01383
		5		1.4	17.25	1.01384
		10		1.4	18.01	1.01445
		14.6		1.4	19.92	1.01599
2.16 a. m.	¾ ebb	0		1.7	17.69	1.01419
		5		1.7	17.82	1.01429
		10		1.4	17.66	1.01418
		14.6		1.7	17.72	1.01421
3.46 a. m.	¾ ebb	0		1.7	17.50	1.01404
		5		1.7	17.65	1.01416
		10		1.7	19.17	1.01538
		14.6		1.7	19.94	1.01599
5.16 a. m.	Slack	0		1.7	17.60	1.01411
		5		1.4	17.90	1.01437
		10		1.4	18.94	1.01520
		14.6		1.4	19.74	1.01584
6.46 a. m.	Beginning flood	0		1.4	17.56	1.01409
		5		1.4	17.58	1.01411
		10		1.4	19.07	1.01531
		14.6		1.4	19.57	1.01570
8.16 a. m.	¼ flood	0		1.7	17.52	1.01405
		5		1.7	17.58	1.01401
		10		1.7	18.63	1.01494
		14.6		1.7	18.69	1.01499
9.46 a. m.	½ flood	0		1.7	17.50	1.01404
		5		1.7	17.55	1.01407
		10		1.7	17.58	1.01410
		14.6		1.7	18.36	1.01472
11.16 a. m.	¾ flood	0		1.9	17.39	1.01394
		5		1.9	17.35	1.01392
		10		1.7	17.87	1.01434
		14.6		1.7	19.16	1.01537
12.46 p. m.	Beginning ebb	0		2.0	17.38	1.01393
		5		2.0	17.79	1.01426
		10		1.7	18.80	1.01505
		14.6		1.7	19.55	1.01568
2.16 p. m.	¼ ebb	0		2.7	17.38	1.01391
		5		2.4	17.94	1.01437
		10		2.2	18.22	1.01460
		14.6		2.2	19.56	1.01566
3.46 p. m.	¾ ebb	0		3.0	17.52	1.01401
		5		2.7	17.86	1.01430
		10		2.7	18.55	1.01485
		14.6		2.7	19.57	1.01565
5.16 p. m.	Beginning flood	0		2.7	17.60	1.01409
		5		2.2	17.96	1.01439
		10		3.2	17.95	1.01430
		14.6		2.7	17.80	1.01425
6.46 p. m.	¼ flood	0		1.7	17.71	1.01420
		5		1.7	18.01	1.01444
		10		1.7	18.56	1.01488
		14.6		1.7	19.49	1.01561
May 5, 4.22 p. m.	¼ flood	0		14.3	14.66	1.01053
		10		14.5	20.55	1.01501
		14.54		14.3	21.04	1.01542
July 8, 7.20 a. m.	Slack ebb	0		24.8	16.70	1.00969
		Bottom.		22.5	21.76	1.01411
Aug. 23, 11.44 a. m.		0		26.0	18.94	1.01102
		Bottom.		24.0	24.98	1.01612
Oct. 20, 1.35 p. m.		0		20.3	17.90	1.01176
		Bottom.		19.7	25.12	1.01736
Dec. 6, 7.05 a. m.	¼ flood	0		9.8	20.58	1.01580
		Bottom.		9.8		
1921						
Jan. 23, 5.23 p. m.	¾ ebb; sea choppy; wind W., force 1	0	11.1	5.4	16.21	1.01285
		10		4.6	16.20	1.01288
		14.64		4.2	21.59	1.01117
Apr. 1, 10.13 p. m.	Ebb; sea choppy; wind N., force 1	0	10.0	11.3	19.49	1.01475
		12.81		11.4	19.67	1.01489
May 31, 2.55 p. m.	¾ ebb; sea moderate; wind NNE., force 2	0	25.0	19.0	18.85	1.01280
		10		18.5	19.54	1.01346
		15.61		17.6	25.02	1.01771

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 24—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1922						
Jan. 22, 3.50 p. m	Full ebb; calm	0	12. 22	3. 9	21. 46	1. 01731
		10	--------	4. 9	23. 47	1. 01861
		15. 55	--------	3. 9	24. 45	1. 01946
Mar. 26, 12.35 p. m	Full flood; wind SW., force 1	0	15. 00	8. 2	15. 69	1. 01219
		10	--------	6. 9	18. 82	1. 01477
		16. 5	--------	6. 8	19. 44	1. 01527

Station 25

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 13, 1.20 p. m	----------	0	--------	0. 6	18. 83	1. 01511
		7. 8	--------	. 7	20. 08	1. 01612
May 5, 3.20 p. m	Slack ebb	0	--------	14. 3	17. 72	1. 01288
		7. 72	--------	14. 3	18. 27	1. 01330
July 8, 8.45 a. m	¼ flood	0	--------	24. 8	17. 72	1. 01046
		Bottom.	--------	24. 8	17. 70	1. 01045
Aug. 23, 10.50 a. m	----------	0	--------	26. 5	19. 41	1. 01122
		Bottom.	--------	25. 3	21. 66	1. 01314
Oct. 20, 12.54 p. m	----------	0	--------	20. 6	17. 20	1. 01115
		Bottom.	--------	19. 7	20. 99	1. 01424
Dec. 6, 8.05 a. m	⅛ flood	0	--------	9. 6	20. 95	1. 01612
		Bottom.	--------	9. 6	20. 91	1. 01690
1921						
Jan. 23, 4.29 p. m	½ ebb; sea smooth; wind NNW., force 1	0	12. 2	5. 3	18. 05	1. 01419
		7. 78	--------	4. 6	18. 58	1. 01476
Apr. 1, 9.36 p. m	Ebb; sea choppy; wind N., force 1	0	10. 0	11. 4	--------	--------
		13. 5	--------	11. 6	21. 64	1. 01635
May 31, 2 p. m	½ ebb; sea moderate; wind NNE., force 2	0	24. 4	19. 4	18. 92	1. 01274
		8. 34	--------	17. 6	24. 92	1. 01771
1922						
Jan. 22, 2.55 p. m	¾ ebb; calm	0	12. 22	4. 5	20. 56	1. 01635
		8. 24	--------	4. 9	22. 53	1. 01887
Mar. 26, 11.37 a. m	¾ flood; sea smooth; wind SW., force 1	0	14. 44	8. 2	17. 61	1. 01369
		8. 23	--------	7. 6	18. 00	1. 01406

Station 26

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 13, 9.01 a. m	----------	0	--------	1. 7	20. 26	1. 01626
		22. 0	--------	1. 7	23. 84	1. 01910
Mar. 11, 9.04 a. m	Ebb	0	--------	2. 7	18. 17	1. 01453
		10	--------	2. 7	19. 34	1. 01547
		20	--------	2. 4	21. 48	1. 01716
		23. 7	--------	2. 4	22. 51	1. 01801
May 5, 12.49 p. m	¾ ebb	0	--------	14. 0	15. 54	1. 01127
		10	--------	13. 8	23. 06	1. 01707
		20	--------	13. 8	24. 73	1. 01834
		23. 63	--------	14. 0	24. 91	1. 01845
July 8, 10.30 a. m	¾ flood	0	--------	24. 9	17. 72	1. 01044
		Bottom.	--------	24. 8	21. 99	1. 01354

Station 27

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 12, 5.38 p. m	----------	0	--------	1. 7	19. 74	1. 01583
		10. 0	--------	1. 7	21. 90	1. 01755
Mar. 11, 11.35 a. m	Beginning flood	0	--------	2. 7	18. 48	1. 01478
		5	--------	2. 7	18. 23	1. 01459
		10	--------	2. 7	18. 96	1. 01517
May 5, 10.27 a. m	½ ebb	0	--------	13. 8	13. 95	1. 01008
		10	--------	13. 6	16. 25	1. 01188
July 8, 12.30 p. m	Slack	0	--------	25. 3	17. 28	1. 00998
		Bottom.	--------	24. 2	22. 06	1. 01238

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 27—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
Aug. 23, 5.40 a. m.		0		26. 0	19. 48	1. 01142
		5		25. 5	20. 79	1. 01255
		Bottom.		24. 0	24. 20	1. 01553
Oct. 20, 4.42 p. m.		0		21. 3	17. 31	1. 01108
		Bottom.		19. 6	24. 53	1. 01694
Dec. 5, 2.20 p. m.	¾ flood	0		10. 4	21. 51	1. 01644
		Bottom.		10. 2	21. 51	1. 01647
1921						
Jan. 23, 12.27 p. m.	¼ ebb; sea tide rips; wind W., force 2	0	13. 3	5. 4	18. 73	1. 01483
		10. 07		4. 8	23. 39	1. 01856
Apr. 2, 8.48 a. m.	Ebb; sea smooth; wind NNE., force 1	0	11. 6	11. 4	21. 14	1. 01600
		8		11. 1	21. 23	1. 01612
May 31, 10.12 a. m.	Beginning ebb; sea choppy; wind NNE., force 3.	0	19. 4	19. 5	16. 10	1. 01057
		9. 15		19. 1	17. 10	1. 01135
1922						
Jan. 22, 11.15 a. m.	½ ebb; light swell; wind NW., force 1	0	7. 78	4. 1	20. 06	1. 01606
		10. 06		4. 3	20. 53	1. 01633
Mar. 26, 8.55 a. m.	¼ flood; sea smooth; wind SW., force 1	0	13. 33	7. 8	17. 83	1. 01390
		8. 0		7. 4	18. 82	1. 01473
Station 28						
1920						
Jan. 12, 4.30 p. m.		0		1. 7	19. 34	1. 01551
		12. 3		1. 7	22. 60	1. 01811
Mar. 11, 1 p. m.	½ flood	0		2. 7	18. 44	1. 01475
		5		2. 7	18. 48	1. 01477
		10		2. 7	19. 36	1. 01548
		12. 8		2. 7	19. 64	1. 01570
May 5, 9.22 a. m.	½ ebb	0		13. 3	14. 53	1. 01018
		12. 73		13. 6	20. 65	1. 01525
July 8, 1.38 p. m.	¾ ebb	0		25. 8	19. 37	1. 01135
		Bottom.		22. 0	22. 49	1. 01480
Aug. 22, 5.05 p. m.		0		27. 0	19. 27	1. 01104
		10		25. 5	20. 99	1. 01270
		Bottom.		22. 2		
Oct. 20, 5.25 p. m.		0		20. 3	17. 14	1. 01116
		Bottom.		19. 5	26. 44	1. 01842
Dec. 5, 1.26 p. m.	¾ flood	0		10. 4	22. 21	1. 01701
		Bottom.		10. 2	21. 95	1. 01681
1921						
Jan. 23, 11.17 a. m.	Beginning ebb; sea smooth; wind W., force 2	0	10. 5	4. 9	19. 02	1. 01510
		Bottom.		5. 0	24. 56	1. 01946
Apr. 2, 9.43 a. m.	Ebb; sea smooth; wind NNE., force 1	0	11. 6	11. 3	22. 34	1. 01617
		11. 6	11. 6	11. 3	23. 01	1. 01747
May 31, 9.30 a. m.	Beginning ebb; sea choppy; wind NNE., force 3.	0	18. 8	19. 0		
		12. 81	18. 8	19. 0	17. 73	1. 01194
1922						
Jan. 22, 10.15 a. m.	⅓ ebb; sea moderate; wind NW., force 1	0	7. 22	3. 6	19. 67	1. 01569
		12. 81	7. 22	4. 5	24. 03	1. 01907
Mar. 26, 7.59 a. m.	Beginning flood; sea smooth; wind SW., force 1.	0	12. 22	7. 6	17. 42	1. 01360
		13	12. 22	7. 6	23. 74	1. 01855
Station 29						
1920						
Jan. 12, 2.40 p. m.		0		1. 7	20. 34	1. 01631
		12. 8		1. 7	24. 33	1. 01948
Mar. 11, 2.53 p. m.	¾ flood	0		3. 2	18. 54	1. 01482
		5		2. 9	18. 97	1. 01517
		10		2. 9	19. 73	1. 01577
		13. 3		2. 9	20. 31	1. 01623
May 5, 7.48 a. m.	½ ebb	0		13. 8	16. 07	1. 01171
		5		13. 6		
		10		13. 8	22. 37	1. 01654
		13. 18		13. 6	19. 22	1. 01416

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 29—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920—Continued						
July 8, 2.50 p. m.	¾ ebb	0		24.8	18.88	1.01132
		Bottom.		22.1	23.06	1.01853
Aug. 22, 4.16–4.38 p. m.		0		27.5	19.20	1.01077
		10		25.1	24.00	1.01507
		Bottom.		25.0	24.34	1.01536
Oct. 21, 6.56–7.26 a. m.		0		19.9	18.96	1.01267
		Bottom.		20.0	23.87	1.01635
Dec. 5, 12.34–12.51 p. m.	½ flood	0		10.2	22.43	1.01718
		Bottom.		10.4	22.50	1.01723
1921						
Jan. 23, 10.10 a. m.	¾ flood; sea smooth; wind W., force 2	0	8.3	5.0	18.18	1.01439
		12.81		5.0	24.53	1.01943
Apr. 2, 10.04 a. m.	Ebb; sea smooth; wind NNE., force 1	0	11.6	11.3	22.72	1.01723
		12.81		11.1	23.38	1.01777
May 31, 8.22 a. m.	Full flood; sea choppy; wind NNE., force 3	0	18.3	18.9		
		12.81		16.9	26.98	1.01946
1922						
Jan. 22, 9.13 a. m.	¼ ebb; heavy swell; wind NW., force 1	0	5.56	3.8	21.08	1.01679
		12.81		4.8	28.50	1.02259
Mar. 26, 6.56 a. m.	Slack; sea smooth; wind SW., force 1	0	9.44	7.8	16.65	1.01297
		13		6.9	22.26	1.01744

Station 30

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 11, 5.25 p. m.		0		1.95	23.32	1.01867
		38.5		1.95	29.34	1.02347
Mar. 11, 4.42 p. m.	Flood	0		3.4	18.70	1.01493
		10		3.2	19.62	1.01567
		20		3.2	20.13	1.01606
		30		3.2	20.81	1.01661
		40		2.9	22.94	1.01831
		42.9		2.9	23.09	1.01843
May 5, 5.50 a. m.	¾ ebb	0		13.8	20.87	1.01539
		10		13.6	23.40	1.01737
		20		13.6	23.75	1.01863
		30		14.5		
		40		13.5	25.32	1.01886
		42.72		13.5	24.63	1.01833
July 8, 4.45 p. m.	⅞ ebb	0		24.2	21.72	1.01361
		Bottom.		21.9	25.23	1.01689
Aug. 22, 3.10 p. m.		0		27.0	22.36	1.01736
		10		23.0	26.94	1.01787
		20		22.2	27.43	1.01847
		30		21.3	28.09	1.01920
		40		21.2	28.19	1.01930
		45.75		21.3	28.46	1.01948
Oct. 21, 10 a. m.		0		20.4	21.99	1.01482
		10		20.1	24.84	1.01705
		20		20.0	26.18	1.01809
		30		19.4	27.02	1.01888
		40		19.3	27.08	1.01895
		Bottom.		19.3	27.06	1.01903
Dec. 5, 10.20 a. m.	¼ flood	0		10.3	22.78	1.01744
		10		10.3	22.88	1.01752
		20		10.2	22.89	1.01753
		30		10.2	22.86	1.01752
		40		10.2	22.88	1.01753
		Bottom.		10.2	23.96	1.01838
1921						
Jan. 23, 8.20 a. m.	¼ flood; sea smooth; wind SW., force 2	0	7.7	4.9	18.36	1.01495
		10		4.8	22.35	1.01737
		20		4.9	24.61	1.01925
		30		4.8	18.74	1.01498
		40		4.9	26.07	1.02056
		Bottom.		4.9	25.42	1.02041
Apr. 2, 10.37 a. m.	Ebb; sea smooth; wind NNE., force 1	0	11.6	12.1	21.56	1.01621
		10		11.2	23.47	1.01783
		20		11.3	24.62	1.01870
		30		11.4	28.23	1.02147
		43.5		11.5	28.27	1.02148

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 30—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1921—Continued						
May 31, 5.32 p. m.	⅝ flood; sea choppy; wind NNE., force 3	0	16. 6	18. 7	20. 18	1. 01386
		10		18. 1	23. 30	1. 01639
		20		18. 0	26. 30	1. 01895
		30		17. 1	26. 92	1. 01935
		43. 92		17. 1	26. 85	1. 01930
1922						
Jan. 22, 7.32 a. m.	Full flood; sea moderate; wind NNW., force 1.	0	3. 33	4. 40	23. 96	1. 01903
		10		4. 0	25. 21	1. 02006
		20		4. 5	25. 71	1. 02040
		30		4. 1	25. 89	1. 02058
		44. 83		4. 2	25. 88	1. 02056
Mar. 25, 6.17 p. m.	¼ flood; sea smooth; wind SE., force 1	0	15	7. 3	19. 33	1. 01512
		10		7. 7	21. 09	1. 01646
		20		7. 0	23. 91	1. 01874
		30		6. 7	25. 10	1. 01971
		41		6. 8	25. 37	1. 01991

Station 31

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 10, 3.30 p. m.		0		2. 7	21. 33	1. 01703
		2. 7		2. 7	23. 78	1. 01898
Jan. 11, 2.05 p. m.		0		2. 4	24. 79	1. 01983
		7. 3		2. 4	25. 89	1. 02069

Station 32

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Jan. 10, 3.30 p. m.		0		2. 7	21. 33	1. 01706
		27		2. 7	23. 78	1. 01901
Mar. 12, 2.39 p. m.	Beginning flood	0		4. 7	17. 73	1. 01409
		10		4. 7	18. 22	1. 01448
		20		4. 7	21. 78	1. 01746
		28. 8		4. 7	28. 81	1. 02281
May 1, 10.53 a. m.	½ ebb	0		14. 8	16. 34	1. 01174
		10		14. 6	19. 82	1. 01467
		20		14. 8	24. 54	1. 01800
		27. 99		14. 6	25. 78	1. 01899
Dec. 4, 11.55 a. m.	¾ ebb	0		9. 6	14. 78	1. 01132
		10		9. 6	18. 01	1. 01382
		20		10. 0	22. 69	1. 01741
		Bottom.		10. 1		
1921						
Jan. 22, 11.02 a. m.	¾ ebb; sea smooth; wind SW	0	11. 1	4. 8	17. 75	1. 01410
		10		4. 4	18. 82	1. 01498
		20		4. 4	19. 46	1. 01550
		27. 91		4. 4	21. 20	1. 01686
Apr. 2, 3.30 p. m.	Flood; sea smooth; wind SE., force 1	0	13. 3	13. 4	26. 30	1. 01964
		10		11. 6	25. 38	1. 01925
		23		11. 4	31. 22	1. 02379
May 30, 10.49 p. m.	¾ ebb; sea choppy; wind NNE., force 3	0	18. 8	19. 7	18. 72	1. 01253
		10		19. 6	19. 49	1. 01312
		20		19. 9	25. 84	1. 01785
		27. 81		16. 8	27. 63	1. 02094
1922						
Jan. 21, 11.45 a. m.	½ flood; sea choppy; wind WSW., force 1	0	13. 33	8. 9	20. 15	1. 01560
		10		4. 2	20. 99	1. 01571
		20		9. 4	22. 65	1. 01746
		27. 90		4. 2	23. 75	1. 01889
Mar. 25, 10.18 a. m.	Full flood; wind N. by E., force 2	0	14. 44	7. 8	18. 38	1. 01432
		10		5. 6	26. 25	1. 02073
		20		6. 6	27. 21	1. 02138
		27. 45		6. 4	27. 19	1. 02138

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 33

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 11, 9.45 a. m.		0		2. 45	25. 62	1. 02044
		14. 7		2. 45	30. 88	1. 02462
Dec. 4, 2.04 p. m.	¼ flood	0		10. 0	20. 64	1. 01581
		Bottom.		10. 9	28. 30	1. 02161

Station 34

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 11, 11.45 a. m.		0		3. 2	29. 42	1. 02338
		16. 5		3. 2	30. 90	1. 02462
Mar. 12, 8.35 a. m.	½ ebb	0		3. 7	24. 53	1. 01952
		10		3. 7	27. 34	1. 02175
		16. 7		3. 4	29. 80	1. 02371
May 1, 5.32 p. m.	Flood	0		14. 0	20. 00	1. 01264
		5		13. 8	20. 02	1. 01274
		10		13. 8	23. 34	1. 01727
		18. 18		13. 6	22. 60	1. 01675
July 9, 6.07 a. m.	¼ flood	0		22. 4	29. 78	1. 02019
		Bottom.		18. 2	25. 40	1. 01794
Aug. 22, 1.12 p. m.		0		22. 2	28. 94	1. 01960
		10		21. 5	29. 73	1. 02039
		18. 3		20. 9	30. 60	1. 02120
Oct. 21, 12.43 p. m.		0		20. 4	20. 22	1. 01350
		10		20. 0	29. 49	1. 02060
		Bottom.		19. 8	30. 38	1. 02133
Dec. 5, 7.30 a. m.	Full ebb	0		11. 5	28. 77	1. 02188
		10		11. 2	28. 86	1. 02182
		Bottom.		11. 2		
1921						
Jan. 22, 4.23 p. m.	Slack ebb; sea smooth; wind WSW., force 1	0	10. 0	5. 1	28. 58	1. 02261
		10		5. 0	28. 29	1. 02239
		18. 30		5. 5	29. 98	1. 02367
Apr. 2, 1.22 p. m.	Ebb; sea smooth; wind NNE., force 1	0	11. 6	11. 4	29. 07	1. 02117
		14. 64		10. 1	29. 01	1. 02229
May 30, 4.09 p. m.	⅔ flood; sea choppy; wind NE., force 4	0	17. 7	17. 1	30. 40	1. 02199
		10		17. 0	30. 30	1. 02093
		18. 30		16. 8	30. 40	1. 02206
1922						
Jan. 21, 4.20 p. m.	¾ flood; rain; sea smooth; wind NNE., force 3.	0	7. 22	4. 6	28. 88	1. 02291
		10		4. 9	30. 35	1. 02404
		18. 30		5. 0	31. 26	1. 02405
Mar. 25, 3.33 p. m.	Beginning flood; sea smooth; wind SE., force 1.	0	17. 78	8. 0	24. 22	1. 01886
		10		7. 0	26. 69	1. 02092
		16. 00		7. 1	25. 06	1. 01963

Station 35

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Jan. 11, 9.45 a. m.		0		2. 4	25. 62	1. 02048
		14. 7		2. 4	30. 88	1. 02467
Mar. 12, 10.28 a. m.	Full ebb	0		4. 4	21. 72	1. 01725
		10		4. 4	30. 29	1. 02402
		15. 5		4. 4	30. 30	1. 02403
May 1, 3.55 p. m.	Half flood	0		13. 8	25. 40	1. 01886
		5		13. 6	27. 72	1. 02069
		10		13. 8	28. 34	1. 02112
		15. 90		13. 6	28. 58	1. 02134
July 9, 7.48 a. m.	¼ flood	0		23. 6	21. 26	1. 01345
		Bottom.		18. 8	28. 08	1. 01983
Aug. 22, 11.56 a. m.		0		26. 0	23. 18	1. 01419
		10		19. 4	29. 09	1. 02044
		Bottom.		17. 3	31. 08	1. 02242
Oct. 21, 1.49 p. m.		0		20. 4	21. 30	1. 01430
		10		19. 9	29. 50	1. 02063
		Bottom.		20. 3	29. 31	1. 02039
Dec. 4, 5.38 p. m.	Full flood	0		10. 6	25. 29	1. 01934
		10		10. 6	27. 44	1. 02100
		Bottom.		11. 0	27. 78	1. 02178

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 35—Continued

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1921						
Jan. 22, 2.54 p. m.	¾ ebb; sea smooth; wind W., force 1	0	11. 1	5. 5	21. 57	1. 01707
		10		5. 4	26. 52	1. 02097
		11. 1		5. 4	27. 43	1. 02168
May 30, 3.07 p. m.	½ flood; sea choppy; wind ENE., force 4	0	18. 3	18. 4	24. 08	1. 01688
		10		16. 5		
		15. 56		16. 5	28. 84	1. 02094
1922						
Jan. 21, 3 p. m.	½ flood; sea choppy; wind N., force 2	0	13. 89	9. 5	29. 04	1. 02246
		10		11. 5	27. 44	1. 02086
		15. 55		5. 6	24. 16	1. 01908
Mar. 25, 2 p. m.	¾ ebb; sea smooth; wind E., force 1	0	20. 00	8. 3	19. 42	1. 01511
		10		6. 5	30. 15	1. 02370
		15. 00		6. 4	30. 63	1. 02408

Station 36

Date and time of collection	Tide, etc.	Depth (meters)	Air	Sample	Salinity (parts per thousand)	Density
1920						
Jan. 11, 7.50 a. m.		0		3. 4	28. 19	1. 02245
		27		3. 4	31. 11	1. 02478
Mar. 12, 11.46 a. m.	Slack	0		4. 7	20. 64	1. 01638
		10		4. 7	30. 38	1. 02407
		20		4. 4	30. 70	1. 02435
		23. 7		4. 4	30. 74	1. 02439
May 1, 2.02 p. m.	Slack ebb	0		14. 3	19. 26	1. 01407
		10		14. 1	20. 02	1. 01450
		20		13. 6	25. 31	1. 01883
		24. 09		13. 8	25. 77	1. 01914
July 9, 9.02 a. m.	½ flood	0		24. 2	20. 54	1. 01267
		Bottom.			30. 39	
Aug. 22, 10.13 a. m.		0		27. 0	22. 75	1. 01339
		10		20. 2	29. 05	1. 02021
		20		17. 2	31. 26	1. 02263
		Bottom.		15. 5	31. 74	1. 02338
Oct. 21, 2.39 p. m.		0		20. 4	20. 28	1. 01353
		10		19. 9	28. 18	1. 01937
		Bottom.		19. 7	30. 97	1. 02180
Dec. 4, 4.25 p. m.	¾ flood	0		10. 5	25. 20	1. 01934
		10		10. 8	28. 76	1. 02199
		20		11. 3	30. 22	1. 02303
		Bottom.		11. 6	30. 96	1. 02356
1921						
Jan. 22, 1.24 p. m.	½ ebb; sea smooth; wind SW., force 1; sky cloudy.	0	11. 6	5. 9	19. 22	1. 01517
		10		6. 0	28. 29	1. 02229
		20		6. 0	28. 10	1. 02214
		22. 87		5. 9	28. 76	1. 02268
Apr. 2, 1.45 p. m.	Flood; sea smooth; wind SE., force 1	0	12. 2	12. 1	27. 74	1. 02097
		10		10. 1	31. 15	1. 02395
		23		9. 9	31. 33	1. 02419
May 30, 2 p. m.	¼ flood; sea choppy; wind, ENE., force 3	0	18. 8	19. 0	21. 98	1. 01509
		10		17. 4	27. 91	1. 02002
		22. 88		15. 2	30. 13	1. 02261
1922						
Jan. 21, 2 p. m.	¼ flood; sea choppy; wind SSW., force 2	0	14. 44	12. 9	23. 91	1. 01789
		10		5. 1	27. 40	1. 02169
		20		5. 9	29. 15	1. 02298
		23. 79		5. 6	29. 26	1. 02321
Mar. 25, 12.40 p. m.	¾ ebb; sea smooth; wind N., force 1	0	17. 78	8. 9	18. 36	1. 01420
		10		6. 6	30. 65	1. 02407
		24		6. 5	31. 10	1. 02445

TABLE 5.—*Salinity and density of water at different depths at 41 stations in Chesapeake Bay*—Continued

Station 37

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.)		Salinity (parts per thousand)	Density
			Air	Sample		
1920						
Aug. 22, 5.48 a. m.		0		21. 7	32. 55	1. 02146
		Bottom.		11. 0	30. 66	1. 02340

Station 38

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Aug. 21, 11.05 p. m.		0		25. 3	29. 74	1. 01931
		Bottom.		8. 9	33. 58	1. 02606

Station 39

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Aug. 21, 8.40 p. m.		0		24. 1	29. 91	1. 01886
		20		17. 8	33. 26	1. 02396
		Bottom.		8. 5	33. 29	1. 02586

Station 40

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Aug. 21, 7 p. m.		0		24. 6	29. 76	1. 01854
		20		10. 4	33. 65	1. 02489
		40		10. 5	34. 13	1. 02620
		Bottom.		10. 8	34. 45	1. 02640

Station 41

Date and time of collection	Tide, etc.	Depth (meters)	Temperature (° C.) Air	Temperature (° C.) Sample	Salinity (parts per thousand)	Density
1920						
Aug. 21, 5.13 p. m.		0		25. 0	33. 84	1. 02249
		20		10. 5	29. 78	1. 02283
		40		11. 1	35. 78	1. 02740
		60		11. 3	38. 41	1. 02940
		80		11. 4	38. 45	1. 02941
		Bottom.		10. 7	35. 01	1. 02687

ORIGIN OF THE SILICEOUS MOWRY SHALE OF THE BLACK HILLS REGION[1]

By William W. Rubey

ABSTRACT

The Mowry shale, a relatively thin member of hard platy shale in the lower part of the Upper Cretaceous series, is widespread throughout the northern Rocky Mountain States. Its peculiar lithologic characteristics are due chiefly to its hardness, which in turn is caused by the presence of a large amount of silica. The problem of the origin of this silica is thus a fundamental problem in the origin of the Mowry shale. In the present paper the discussion of the probable origin of this silica is developed by considering the significance of each type of evidence as it is stated, instead of by the usual method of first completely describing and then interpreting the observed facts.

Field, chemical, and microscopic evidence indicates almost certainly that the silica in the Mowry shale was in some way derived from the alteration of volcanic ash. As a probable method of this derivation, it is suggested that the original ash was unusually siliceous, that it was decomposed by long exposure to sea water, and that silica dissolved from it was precipitated by decaying organic matter. A minor amount of secondary silicification may have occurred during consolidation and weathering. The few siliceous tests of organisms found fossilized in the shale are considered merely incidental constituents of the shale. The small amounts of clay, silt, and sand in the shale may be in part more or less altered volcanic products and in part normal clastic sediments.

Whatever may be the method of derivation of the silica, the mere presence of large quantities of volcanic ash in the Mowry shale is stratigraphically significant, for it increases confidence in the reliability of the member for purposes of correlation.

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FIELD OBSERVATIONS

The Mowry shale is well known to geologists who have worked in the Cretaceous rocks of the northern Rocky Mountain States. Its abundance of fish scales, unusual silvery-gray color, porcelaneous hardness where weathered, excellence as a natural base for automobile roads, topographic prominence, and great areal extent make it easily recognizable and extremely useful for correlation. It has been recognized in Wyoming, Montana, western South Dakota, and northern Colorado.[2] Throughout most of Wyoming it lies between the Thermopolis shale and the Frontier formation and is from 100 to 300 feet thick,[3] but it thickens southwestward, and in extreme southwestern Wyoming the Aspen formation, locally more than 2,000 feet thick,[4] occupies the stratigraphic position of the Mowry shale and, according to current interpretations, of some lower beds, and has the same fauna and lithologic character.[5] In its type locality near Buffalo, Wyo.,[6] and elsewhere to the north and west, the Mowry consists of hard shale and thin sandstone, but southward and eastward little sandstone is present.

STRATIGRAPHIC RELATIONS AND LITHOLOGY OF MOWRY SHALE

Where the Mowry shale is turned up around the northwest flank of the Black Hills uplift in northeastern Wyoming, it consists of 100 to 150 feet of hard shale in the lower part of the Graneros shale. Here it makes a continuous hogback that is generally pine-covered but supports little grass, and the bare ground is made up of hard platy silvery-gray[7] chips of shale. (See pl. 14, *A*.) In fresh exposures the Mowry is seen to consist of moderately thin bedded, exceptionally hard shale with a few thin layers of very fine grained sandstone. It is interlaminated with beds of bentonite from less than 1 inch to more than 1 foot thick. Although bentonite beds occur throughout the Cretaceous rocks of the region, they are especially abundant in the upper part of the Mowry shale, but even at this horizon they constitute only a small proportion of the total thickness. Where unweathered the shale is black or very dark gray and shows a dull earthy luster, but on weathered surfaces it is light bluish gray or even

[1] Paper presented before the Geological Society of Washington Feb. 9, 1927 (The origin of the Mowry shale: Washington Acad. Sci. Jour., vol. 17, p. 235 (abstract), 1927).

[2] See Geis, W. H., The origin of light oils in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 7, fig. 1, p. 481, 1923, for a map of the distribution of the Mowry shale.

[3] Wilmarth, M. G., Tentative correlation of geologic formations in Wyoming (a separate chart), U. S. Geol. Survey., April, 1925.

[4] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 64-65, 1907.

[5] Reeside, J. B., jr., personal communication.

[6] Darton, N. H., Geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, p. 187, 1905.

[7] At Red Hill, in secs. 5 and 6, T. 54 N., R. 66 W., near Missouri Buttes, in Crook County, Wyo., the Mowry shale is conspicuously red, but the red color is clearly a result of the infiltration of iron oxides from red clay in the overlying White River (?) deposits.

white and has a glazed appearance under the hand lens. The fracture is commonly subconchoidal. (See pl. 14, *B*.) The hardness or crushing strength of the shale is such that it resists crushing in the hand or between the teeth, but even the hardest pieces are readily scratched with a knife. On the mineral scale the shale commonly has a hardness of 3 to 4.[8] Although apparently regularly bedded, the numerous planes of jointing or fissility that simulate bedding are not strictly parallel, and on close examination these planes suggest concretionary structure. True concretions, however, are rare, even in the few localities where the beds contain calcite. In some places the joint planes are stained yellow and brown, presumably with iron oxide.

Near the Black Hills the Mowry shale member of the Graneros shale overlies by gradational contact 5 to 50 feet of soft shale which Collier has named the Nefsy shale member.[9] The Nefsy in turn lies upon the Newcastle sandstone member,[10] a variable unit of sandstone, shale, lignite, bentonite, and phosphatic nodules from a few inches to 75 feet thick. The Mowry underlies, with sharp lithologic change, the Belle Fourche shale member [11] of the Graneros, a partial equivalent of the Frontier formation of western Wyoming. The Belle Fourche member consists of 450 to 850 feet of soft dark shale that in its upper part contains bentonite beds and many calcareous concretions. The lower 25 to 200 feet contains abundant concretions of manganiferous siderite about a foot in diameter, and this zone forms a low scarp near the Mowry hogback. The contact between the soft dull-gray concretion-bearing shale of the Belle Fourche and the hard shale of the Mowry is further emphasized by a persistent bed of bentonite from 1 to 4 feet thick at the top of the Mowry shale. This bed was traced 175 miles along its outcrop in northeastern Wyoming, and it can be recognized with reasonable certainty in South Dakota beyond the limits of this mapping.

As elsewhere throughout its area of distribution, the Mowry shale of the Black Hills contains many fish scales (see pls. 14, *B*; 15, *A*,*B*), some bone fragments, and an exceedingly sparse invertebrate marine fauna quite similar to that of the Greenhorn formation, which in this region immediately overlies the Belle Fourche member of the Graneros. In fact, so similar are the two faunas that there is reason for considering the assemblage an environmental facies that indicates simply Benton age.[12] Some fragments of Mowry shale contain a few hollow but well-preserved molds or shells of Radiolaria of the suborder Nasselaria (and Spumellaria?). (See pl. 16, *A*.) These small pits, about 0.1 millimeter in diameter, are best seen on fresh surfaces of the shale. In no specimens were these fossils common, and even in thin sections cut especially to examine as many radiolarians as possible, they constituted less than 5 per cent of the rock. No diatoms or foraminifers were noted in the many specimens examined under binoculars.

The very dark color of fresh Mowry shale and the hard light-gray and laminated surface of the weathered rock suggest that it may be an impure oil shale, and in fact it has been reported as such elsewhere.[13] However, crude heating tests on typical samples of the Mowry shale from the Black Hills region gave little indication of the presence of bituminous matter, and E. T. Erickson, of the Geological Survey, estimated their content of oil at less than 1 gallon to the ton. A sample of Mowry shale from sec. 35, T. 57 N., R. 66 W., Crook County, Wyo., analyzed by the Bureau of Mines, Department of Commerce, contained only 0.07 per per cent of organic matter soluble in chloroform.

HARDNESS OF THE SHALE DETERMINES OTHER CHARACTERISTICS

Many and possibly all the peculiar characteristics of the Mowry shale of this region are closely related to or even caused by its exceptional hardness or crushing strength, and this hardness, as discussed in another part of this paper, is shown by chemical analyses to be almost certainly due to unusual amounts of silica. The topographic prominence of the Mowry and the absence of soil at its outcrops are directly the result of its hardness and resistance to weathering. The hard and smooth yet never slippery surface of roads where its exposures are crossed can be explained by its induration, freedom from irregularities of hardness, and binding qualities.[14] The light-gray color so typical of the outcrops of Mowry shale is also in large part the result of resistance to weathering, for the dark organic material is removed more rapidly than the rock disintegrates. The most widely known characteristic of the Mowry shale—the apparently unusual abundance of fish scales—may be only an apparent peculiarity caused by its hardness. The writer has found fish scales equally abundant on fresh surfaces of shale in many other beds in the Graneros of the Black Hills region, and it is quite possible that scales are conspicuous in the Mowry shale simply because the rock disintegrates very slowly. As is pointed out in this paper, other characteristics of the Mowry shale, such as its association with bentonite, may also be indirectly related to its hardness.

[8] See Kindle, E. M., A proposed scale of hardness and cohesion for rocks: Researches in sedimentation in 1925–26, pp. 95–97, National Research Council, 1926.

[9] Collier, A. J., The Osage oil field, Weston County, Wyo.: U. S. Geol. Survey Bull. 736, p. 82, 1922.

[10] Hancock, E. T., The Mule Creek oil field, Wyoming: U. S. Geol. Survey Bull. 716, p. 42, 1920.

[11] Collier, A. J., op. cit., p. 83.

[12] Reeside, J. B., jr., personal communication.

[13] Collier, A. J., The Bowdoin dome, Mont.: U. S. Geol. Survey Bull. 661, p. 199, 1918. Geis, W. H., The origin of light oils in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 499–500, 1923. Reeves, Frank, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Mont.: U. S. Geol. Survey Bull. 751, p. 107, 1924.

[14] Shown by binder tests made by Bureau of Public Roads, Department of Agriculture, on samples collected by the writer. Comparison with tests on other shales of the Black Hills region suggests that the binder or cement is silica.

VARIATIONS IN HARDNESS

The hardness or silica content of the shale thus assumes an importance which led the writer during several seasons' work in the region to make observations that might suggest its cause.

The most obvious variation in hardness is a vertical one that extends throughout the member; the Mowry shale is softest in the lower part and hardens progressively upward. The lower part is so soft that mapping of the thin, soft Nefsy shale between the Mowry and Newcastle members had to be abandoned, for at only a few places could a satisfactory boundary be chosen between Mowry and Nefsy, and in most exposures the rather uniform increase in hardness upward showed the two members to be but parts of one lithologic unit.

A second relation observed is that the shale is harder immediately below interlaminated bentonite beds. This relation, though generally inconspicuous, was noticed in 1922 and tested at every later opportunity, and the writer is now convinced of its truth as a generalization. Hardening of beds adjacent to bentonite was noted also at several places in the Belle Fourche and Pierre shales of the same region. The most striking example of hardened strata near bentonite beds is a hard bed of partly altered tuff 1½ feet thick at the top of an 18-foot bentonite near the base of the Pierre in the vicinity of Pedro, Wyo. Microscopic examination and chemical analyses show that the only important difference between this tuff and the bentonite is the larger amount of very finely divided silica in the tuff. The writer has also noticed thin and very hard beds in bentonite in the Thermopolis shale near the Pryor Mountains, in south-central Montana; and hardened shale near bentonite beds is reported from Virginia, Kentucky, and Mexico.[15]

The combined effect of the two relations just mentioned is that the softest shale is in the lower part of the member, the hardest is just below the thick bentonite bed at the top, and the hardening upward is interrupted slightly at each intervening bed of bentonite. This stratigraphic distribution of hardness may be made clearer by a specific example. Chemical analyses show that the amount of contained silica varies with the hardness of samples, although doubtless a soft sandy layer might contain more silica than a hard shale. Analyses of samples collected near Thornton, Wyo., show a silica content of 84.14 per cent in a weathered sample from 5 to 10 feet below the top of the Mowry shale and of 75.62 per cent in a fresh fragment immediately below a thin bentonite about 25 feet below the top of the member. Rough crushing tests of these and other analyzed specimens and of other samples of the shale led the writer to estimate that at Thornton the silica content of the fresh shale in the lower few feet of the overlying Belle Fourche is 55 to 60 per cent, at the top of the Mowry 80 to 85 per cent, 75 feet below the top 65 or 70 per cent, and at the base of the Nefsy member about 55 per cent. This sequence is interrupted by increases of 5 per cent or more at the bases of other bentonite beds.

A third relation is an apparent geographic variation in the hardness of the Mowry shale. In the southeastern part of the Black Hills uplift, between Hermosa and Edgemont, S. Dak., the Mowry shale is inconspicuous or absent. As the member is recognized largely if not entirely by its hardness, its apparent absence to the southeast is probably the result of decreased hardness in that direction. Elsewhere about the Black Hills the Mowry shale seems to increase in hardness westward and to reach its maximum induration and topographic prominence near Upton and Thornton, Wyo. It is interesting to note that this direction of hardening coincides with the direction of the source of the bentonite at the top of the Mowry shale, as indicated by the thickening of the bed and the increase in size and amount of contained sand-sized particles. These sand-sized particles are essentially the phenocrysts which crystallized in the magma before the eruption of the volcanic ash that has been changed to bentonite. Like a decrease in the thickness of an ash bed and in the size of its constituent fragments away from the source, the decrease in amount of these crystalline particles is an index of distance from the volcanic vent, as shown by the ash erupted from Krakatoa.[16]

A fourth factor in the varying hardness of the Mowry shale appears to be the degree of weathering; the light-colored weathered chips seem to be more siliceous and brittle than the fresh rock. Silicification of exposed rock surfaces is said to be widespread and especially noticeable in the more arid climates. In the Black Hills region the writer has found evidence that the Minnelusa and Lakota sandstones, the Greenhorn limestone, and old terrace deposits have commonly undergone hardening of this type. Silicification at the outcrop has been explained as due to evaporation and secondary deposition of silica originally present in the rock and to concentration at the surface by leaching out of other constituents.[17] However, well cuttings show that the Mowry is harder than other Cretaceous shales even far underground, and it appears certain that the greater part of the silicification is unrelated to weathering.

A fifth but less definite observation is that the Mowry shale is hardest in its finest-grained portions. This generalization may not be valid, for differences in the size of grain of the Mowry shale are difficult to recognize in the field, and the somewhat softer, coarser beds were found well below the top of the member, where the finer-grained beds are also softer.

[15] Ross, C. S., personal communication.

[16] Murray, John, and Renard, A., On the microscopic characters of volcanic ashes and cosmic dust and their distribution in the deep-sea deposits: Roy. Soc. Edinburgh Proc., vol. 12, p. 486, 1884.

[17] Twenhofel, W. H., Treatise on sedimentation, p. 387, 1926.

It has been found that some shale formations are hardest where they are most folded or otherwise affected by regional metamorphism.[18] This possible factor was in mind during the field work, but no evidence indicating a relation of this sort was noted.

INFERENCES FROM FIELD RELATIONS AS TO ORIGIN OF SILICA IN MOWRY SHALE

The field observations thus show that the Mowry shale hardens progressively upward to its upper boundary and toward associated bentonite beds, also westward toward the probable source of the sediments in one of the associated bentonite beds; it probably hardens somewhat with weathering and increasing fineness of the shale. These relations suggest several possible explanations of the hardness or silica content and of other peculiarities of the Mowry shale.

The stratigraphic and geographic variations in hardness of the Mowry shale in the Black Hills region and confirmatory evidence in younger beds in the same region indicate strongly a relation to the occurrence of bentonite. The theory, suggested by Hewett,[19] that bentonite is an altered volcanic ash has been firmly established by the investigation of others. Ross and Shannon, who have studied bentonite exhaustively, recently defined it as "a rock composed essentially of a crystalline claylike mineral formed by devitrification and the accompanying chemical alteration of glassy igneous material, usually a tuff or volcanic ash."[20] In addition to these conclusions regarding bentonite in general, definite evidence of this origin is presented by the bentonite beds of the Black Hills region.

The field relations of the hardness of the shale to occurrences of bentonite first suggested to the writer that the Mowry shale may have been secondarily silicified by solutions derived from the bentonite. However, this hypothesis encounters many objections, and the relation can be explained by the presence of similar original material in both the bentonite and the harder shale. That is, the relation might be either original or secondary: the Mowry shale and the associated bentonites might be derived from a common source, or the Mowry may have been secondarily silicified. These possibilities will be discussed more fully after a consideration of the chemical and microscopic evidence.

It is possible that the relation of hardness to bentonite is merely fortuitous and that the hardness increases upward and westward as a result of lithologic variations only accidentally connected with occurrences of bentonite. One of the field relations suggests that size of grain may be the lithologic variation that causes variations in hardness. On this assumption the harder and finer-grained portions of the shale may have originally contained more silica (either finely divided clastic quartz or colloidal silica) than the coarser-grained portions, or precipitation of secondary silica may have been greater in the fine shale owing either to the capillary size of pore spaces or to the presence of substances that coagulate silica. However, other considerations make this hypothesis appear improbable. No evidence of progressive coarsening downward was observed, and in fact the clay in the Nefsy member appears finer than much of the Mowry. The hypothesis would call for a coarsening of the sediments after each ash fall, whereas finer sediments might more logically be expected. Moreover, the Mowry shale of the Black Hills does not appear to coarsen southeastward, as required by the hypothesis, and in Montana the sandiness is reported to increase westward.

The possibility that silicification resulted from the replacement of rock of some other type, such as a silty limestone, may be mentioned, but the absence elsewhere of any readily replaceable rock at this horizon and of replacement phenomena in the Mowry itself makes this method of silicification seem very improbable.

The abundance of fish scales, the relative scarcity of shells and bones, and the presence of volcanic ash and Radiolaria suggest as another possibility that the Mowry may be the result of extremely slow sedimentation, for teeth and other chemically resistant bony remains of fish are widespread, and volcanic ash and Radiolaria are common in several types of deep-sea deposits.[21] The known paleogeography at the time of deposition of the Mowry shale and the great thickness of the Aspen formation make it appear extremely improbable that the Mowry accumulated in abyssal depths, like the deposits described in the *Challenger* reports, but it is conceivable that comparable conditions of slow sedimentation may have existed at times in the center of the shallow Cretaceous sea of the Western Interior.

CHEMICAL COMPOSITION OF MOWRY SHALE AND RELATED DEPOSITS

Some of the analyses made by the chemists of the United States Geological Survey for the writer's forthcoming general report upon the Cretaceous and Eocene rocks on the northwest flank of the Black Hills have a bearing upon the origin of the Mowry shale.

[18] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Calif.: U. S. Geol. Survey Bull. 322, p. 46, 1907. Wilson, J. H. Lithologic character of shale as an index of metamorphism: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 625–633, 1926. Russell, W. L., Porosity and crushing strength as indices of regional alteration: Idem, pp. 939–952.

[19] Hewett, D. F., The origin of bentonite: Washington Acad. Sci. Jour., vol. 7, pp. 196–198, 1917.

[20] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, p. 79, 1926.

[21] Murray, John, and Renard, A. F., *Challenger* Rept., Deep-sea deposits, 1891.

Chemical analyses of Mowry shale and other rocks

	1 Mowry shale	2 Same as 3, "silicified"	3 Bentonite from Clay Spur, Wyo.	4 Average bentonite	5 Phenocrysts in Mowry bentonite	6 Rhyolite pumice	7 Average shale	8 "Monterey shale"
SiO_2	[b] 84.14	85.70	70.36	61.94	81.1	73.90	58.38	86.92
"Soluble" SiO_2 [a]			.62		Trace.			
Al_2O_3	[c] 5.79	5.74	11.47	15.97	8.5	11.93	15.47	4.27
P_2O_5				.07			.17	
Fe_2O_3	1.21	1.24	2.48	2.92		.15	4.03	
FeO	Probably absent		Probably absent.	.71		.87	2.46	
MgO	.41	.69	1.38	2.45	1.6	.13	2.45	Trace.
CaO	.13	.13	.26	1.72	.1	.34	3.12	1.60
Na_2O	.99	.84	1.69	1.61	.1	4.10	1.31	2.48
K_2O	.50	.38	.75	.29	7.6	4.62	3.25	
H_2O-	5.56	5.66	11.32	7.17			5.02	
H_2O+				3.95		4.00		
TiO_2	.22	.05	.10	.23			.65	
ZrO_2					Trace.			
CO_2	None.	None.	None.	.41			2.64	
SO_3				.15			.65	
S				.01				
MnO							Trace.	
BaO							.05	
Li_2O							Trace.	
F					Trace.			
C				.14			.81	
Ignition								5.13
Organic matter [d]	1.21							
	100.03	100.43	100.43	99.74	100.0	100.04	100.46	100.40

[a] By 5 per cent Na_2CO_3 solution.
[b] "Soluble" silica probably about 0.7 per cent, judged by analyses of similar material.
[c] P_2O_5 probably about 0.4 per cent, judged by analyses of similar material.
[d] Ignition less H_2O.

1. Weathered Mowry shale, sample collected by W. W. Rubey from upper part of member in sec. 7, T. 48 N., R. 65 W., near Thornton, Wyo. J. G. Fairchild, analyst.
2. Same as No. 3, "silicified" by arbitrarily increasing the proportion of silica so that the other constituents are diluted to just one-half.
3. Bentonite, complete sample collected by W. W. Rubey from quarry at Clay Spur, sec. 30, T. 47 N., R. 63 W., Wyo. J. G. Fairchild, analyst.
4. Average of seven bentonite samples. Spence, H. S., Bentonite, p. 14, Canada Dept. Mines, Mines Branch, 1924.
5. Phenocrysts in bentonite beds associated with Mowry shale, computed from microscopic data.
6. Rhyolite pumice from Sailles, Mont Doré, France. Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, p. 129, 1917.
7. Average analysis of 78 shales. Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 631, 1924.
8. "Monterey shale." Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Calif.: U. S. Geol. Survey Bull. 322, p. 45, 1907.

EXCESSIVE AMOUNT OF SILICA IN MOWRY SHALE

Comparison of an analysis of Mowry shale from a locality near Thornton, Wyo., with the average analysis of 78 shales [22] shows the Mowry to be exceptionally high in silica and low in the other constituents, especially ferrous iron and carbonates. (See Nos. 1 and 7 in table of analyses.) The excess of silica is striking, for even on the assumption that silicate minerals with the highest probable silica ratios are present (orthoclase, albite, montmorillonite,[23] and kaolin) computing the norms shows that at least 70 per cent of the rock is uncombined silica.

The high silica content of the Mowry shale may be explained by the presence of large amounts either of clastic silica or of silica that was chemically precipitated at the time of deposition of the rock or else later. Other facts also have suggested the possibility that the peculiar composition of the Mowry shale may be due to chemical precipitation of silica either at the time of deposition or later. Precipitation of such unusual amounts might be explained by an exceptional source of silica or by the presence of unusually effective coagulating agents in the shale or in waters at one time in contact with the shale, or these factors may have been jointly effective. An exceptional source of silica might be unusual amounts of it in the original sea water or in circulating ground waters. Such unusual amounts might be accounted for by any one of several suppositions, the relative probability of which can be most effectively considered after a discussion of the microscopic evidence. Chemical analyses in themselves throw light on the possible presence of coagulating agents.

[22] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 631, 1924.
[23] Chemical formula: $(Mg,Ca)O.Al_2O_3.5SiO_2.5\text{-}7H_2O$ (Ross, C. S., and Shannon, E. V., op. cit., pp. 87-89).

POSSIBLE PRECIPITANTS OF SILICA

If some substances that are especially effective in coagulating dissolved or colloidally suspended silica are found to be unusually abundant in the Mowry shale, the hypothesis of primary or secondary precipitation of silica will be strengthened. Substances likely to be present that are considered especially effective in precipitating silica are ammonium carbonate,[24] phosphates,[25] ferric oxides,[25] bicarbonates[26] in uncommonly siliceous waters,[27] and ions of lime and magnesia.[28]

The widespread occurrence of fish scales and bone fragments in the Mowry shale suggests that phosphates may have precipitated the silica. However, an analysis shows only 0.40 per cent of P_2O_5 in a sample of hard scale-bearing Mowry shale, which is practically the same amount as the 0.42 per cent found in a fragment of Belle Fourche shale chosen for comparison. The analysis of the Mowry shale (No. 1 in the table) shows that none of the other substances favorable to precipitation are unusually abundant. However, the sample contains a rather large proportion of organic matter (1.21 per cent by weight), and another specimen, from sec. 35, T. 57 N., R. 66 W., Crook County., Wyo., analyzed by the United States Bureau of Mines, contained 1.40 per cent of organic carbon, 0.14 per cent of organic hydrogen, and 0.05 per cent of nitrogen. The dark color suggests that a large part of the shale would contain even more organic matter. During the decay of this organic material carbon dioxide (and hence, in sea water, calcium and magnesium bicarbonates) and ammonium carbonate [29] were almost certainly abundant, and these compounds may have precipitated the silica at that time. Thus, before its complete burial, the Mowry shale, or rather the waters in contact with it, probably contained adequate coagulating agents.

One alternative supposition is that the precipitating agents were contained in later infiltrating ground water. On this assumption both the excess silica and the precipitant must have been brought in by ground water, and it is necessary to postulate a mixing of the two solutions. Even assuming that water could circulate freely through such fine and impermeable material, it would be difficult to explain why an interaction of this sort would be restricted to the horizon of the Mowry shale over so great an area. As this hypothesis of the mixture of two ground waters fails to account for the general and detailed association of the Mowry lithology with bentonite and as it also encounters other serious objections if carried further, it may be dismissed from consideration.

It is possible, however, that the silica may have been precipitated from exceptionally siliceous ground water by conditions of temperature or pressure in the shale rather than by the presence of precipitants. Another hypothesis of this physico-chemical type is that detrital grains undergoing compacting might go into solution at their points of contact and that silica might be precipitated in adjacent pore spaces.[30]

"SOLUBLE" SILICA

A further test of the general hypothesis of chemical precipitation, either primary or secondary, may be made by a determination of the percentage of "soluble" or amorphous silica now present in the rock. The occurrence of a considerable amount would strengthen the hypothesis, but its absence would have little significance, for, even though originally precipitated as a gel, the silica might have crystallized into the less soluble quartz or chalcedony.

This test yielded no conclusive evidence, for a typical sample of Mowry shale contained 0.73 per cent of "soluble" silica, and a sample of Belle Fourche shale, chosen for comparison, 0.70 per cent.

COMPOSITION OF ASSOCIATED BENTONITE

The field observations suggest that the excess silica in the Mowry shale is somehow related to associated bentonite beds. Chemical analyses bear out this suggestion, for a sample of the bentonite bed at the top of the Mowry, collected from the bentonite quarry at Clay Spur, Wyo., contains, like the shale itself, an unusually high percentage of silica (70.98 per cent; see analyses 3 and 4). This is not only far higher than the 53.50 per cent in a bentonite bed in the soft Belle Fourche shale, about 20 feet above the Mowry, sampled near by, but is also higher than the percentage in any of the 35 or 40 published analyses of bentonite seen by the writer.

A published analysis [31] of a bentonite said to have been collected in sec. 30, T. 47 N., R. 63 W., Wyo. (the same locality as the Clay Spur quarry), shows but 54.31 per cent of silica. Mr. Hewett, to whom the sample was sent for study and comparison with other Wyoming bentonites, informed the writer that this analysis represents the finer 92 per cent of the sample as separated by mechanical analysis. A new determination shows the gross sample to contain 57.1 per cent of silica. This is 14 per cent less than was

[24] Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ. Dept. Geology Bull., vol. 11, pp. 399–402, 1918. Ammonium carbonate is also commonly used in laboratories to precipitate dissolved silica.

[25] Wallace, R. C., The distribution of the colloidal products of rock weathering: Roy. Soc. Canada Proc. and Trans., 3d ser., vol. 17, sec. 4, p. 73, 1923.

[26] Cox, G. H., Dean, R. S., and Gottschalk, V. H., Studies on the origin of Missouri cherts and zinc ores: Missouri Univ. School of Mines and Metallurgy Bull., vol. 3, No. 2, pp. 7–12, 1916.

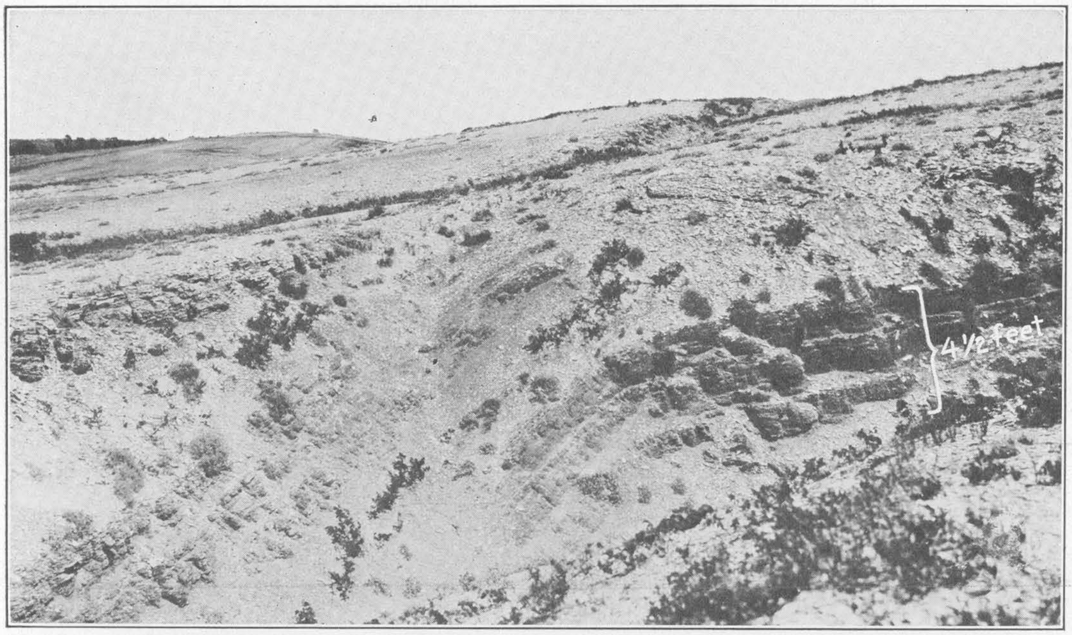
[27] Lovering, T. S., The leaching of iron protores; solution and precipitation of silica in cold water: Econ. Geology, vol. 18, pp. 537–538, 1923.

[28] Tarr, W. A., Origin of the chert in the Burlington limestone: Am. Jour. Sci., 4th ser., vol. 44, p. 436, 1917.

[29] Clarke, F. W., op. cit., pp. 123, 149.

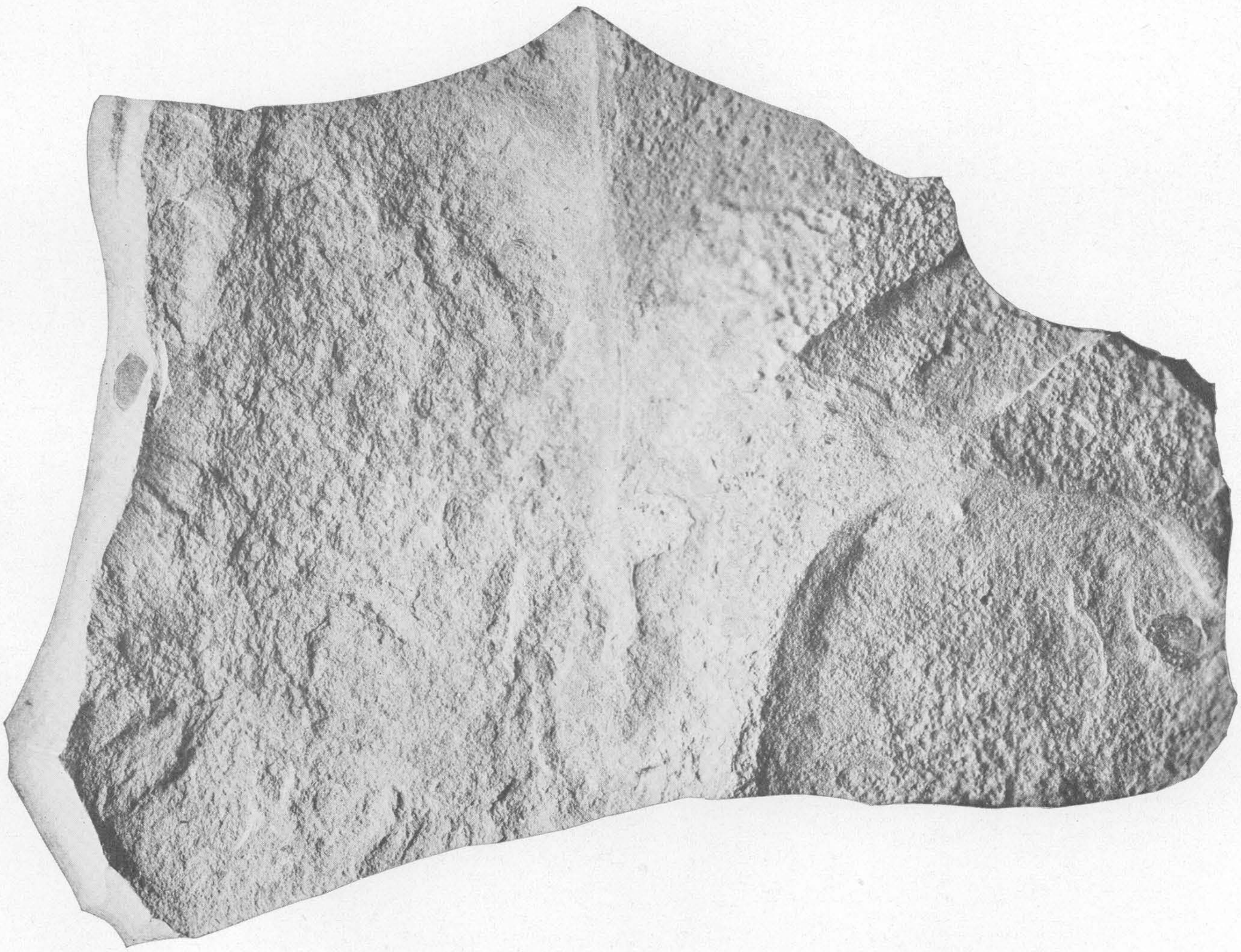
[30] Johnston, John, and Adams, L. H., On the effect of high pressures on the physical and chemical behavior of solids: Am. Jour. Sci., 4th ser., vol. 35, pp. 211, 215–217, 1913. Johnston, John, and Niggli, Paul, The general principles underlying metamorphic processes: Jour. Geology, vol. 21, pp. 499, 608–613, 1913.

[31] Hewett, D. F., Geology and oil and coal resources of the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles, Wyo.: U. S. Geol. Survey Prof. Paper 145, p. 56, 1926.



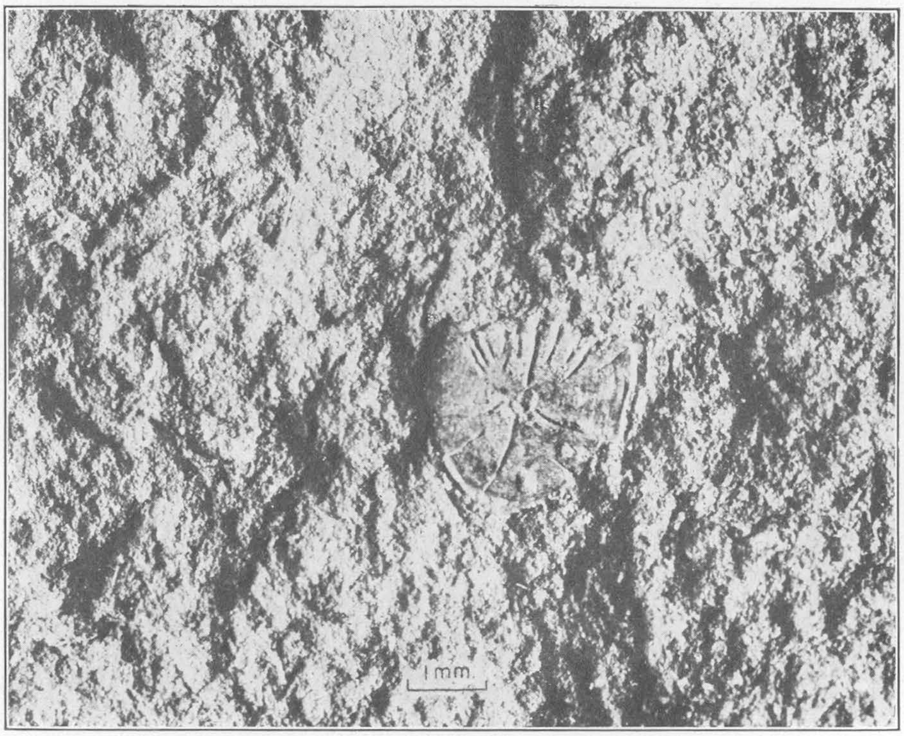
A. OUTCROP OF MOWRY SHALE ON THORNTON DOME, IN SEC. 7, T. 48 N., R. 65 W., WESTON COUNTY, WYOMING

Shows a small reverse fault; typical thin bedding of shale and alternation with thin beds of bentonite; and characteristic bare chip-covered ground. This outcrop differs from most others in not being heavily overgrown with pines



B. HAND SPECIMEN OF MOWRY SHALE COLLECTED NEAR NEWCASTLE, WESTON COUNTY, WYOMING, IN SEC. 25, T. 45 N., R. 62 W.

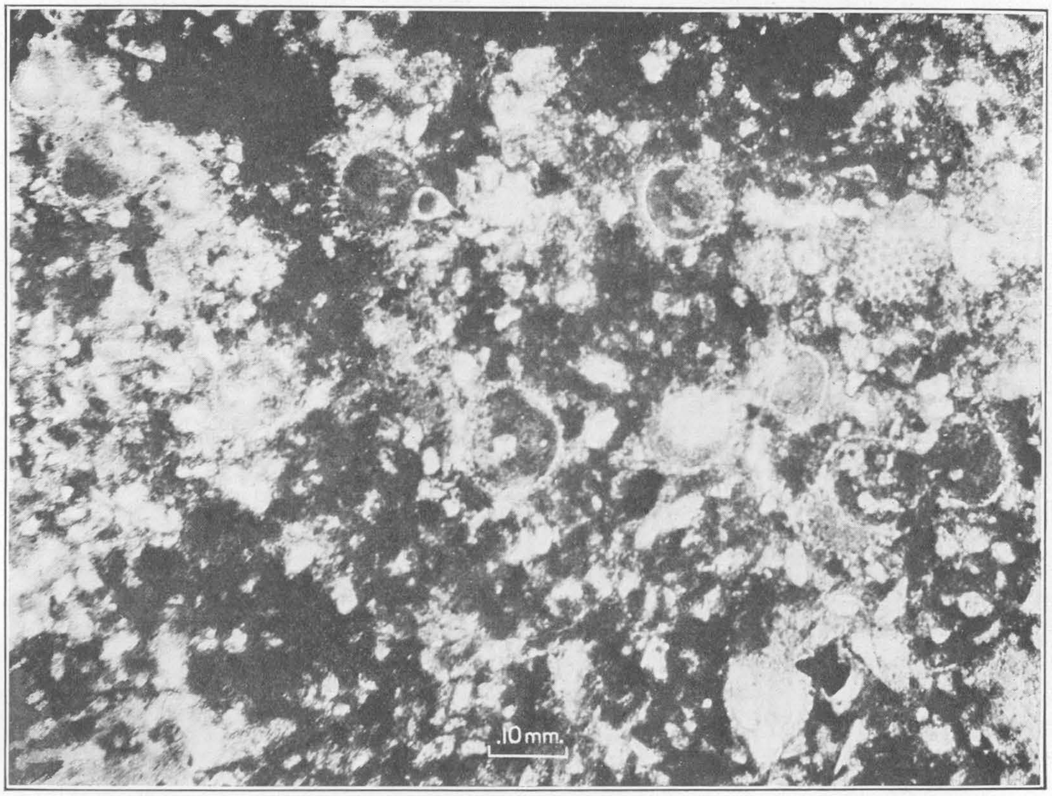
Shows typical distribution of fish scales and subconchoidal fracture. Natural size



A

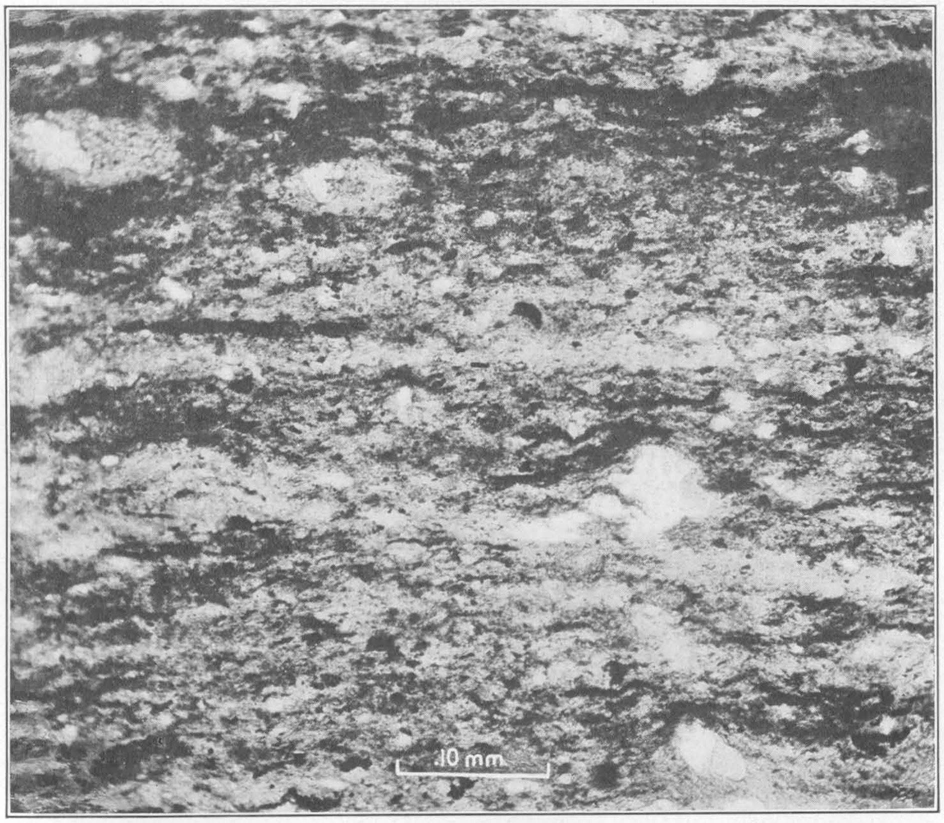
B

FISH SCALES IN MOWRY SHALE FROM SEC. 25, T. 45 N., R. 62 W., WYOMING



A. THIN SECTION OF MOWRY SHALE FROM SEC. 35, T. 57 N., R. 66 W., CROOK COUNTY, WYOMING

Shows an exceptionally large number of Radiolaria



B. THIN SECTION OF MOWRY SHALE FROM THORNTON DOME, WESTON COUNTY, WYOMING

The larger masses, unusually abundant in this section, are remnants of partly crystallized opal or glass found in the writer's sample from the Clay Spur quarry. It is, of course, possible that a bed of bentonite 4 feet thick may vary this much in chemical composition from one layer to another, but the lithology of the hand specimen and comparison of the silica content and the relative proportion of other constituents with other analyses make it seem more probable that the earlier sample was collected from a higher bed that crops out near the present Clay Spur quarry or from a quarry in another bed 12 miles distant.

The high silica content of the writer's sample of the bentonite from the Clay Spur quarry suggests that much detrital quartz may be present as an impurity, but other facts make this seem very improbable. This sample contained only 0.2 per cent of grains coarser than 0.07 millimeter in diameter (sand-sized particles of calcite, iron oxide, and clay aggregates being discarded). This is considerably less than the average percentage of grains larger than 0.07 millimeter found in 30 other samples of bentonite from the Black Hills of which the writer made mechanical analyses. Microscopic examination of the coarser particles revealed little obviously detrital material in any of the 30 samples. In the Clay Spur sample the largest grains were 0.25 millimeter in diameter, well above the lower limit of rounding, yet no evidence of abrasion indicating admixed detrital grains was noted. Furthermore, this coarser 0.2 per cent consisted largely of aluminum silicates (feldspar) rather than pure silica (quartz). That is to say, this unusually siliceous bentonite contains less than an average amount of sand-sized particles which might possibly be detrital, the few coarser grains which are present show no evidence of being other than phenocrysts, and they are not much more siliceous than the complete sample. These facts lead to the conclusion that the excess silica in this sample is present not as coarse detrital quartz but as very finely divided material. Small quantities of very finely divided or clay-sized quartz particles are doubtless formed by several natural agencies, but, considering the lower limits of abrasion and the ready solubility of the smallest fragments,[32] a large proportion of clay-sized clastic quartz grains in any rock would demand some very unusual geologic process of disintegration.

This evidence that the silica in the bentonite is very finely divided suggests that it may be a chemical or colloidal precipitate which was formed either during or after deposition of the ash. It seems improbable that silicification was later than deposition, for if the bentonite were thus secondarily silicified, its ability to swell when wetted would probably be considerably reduced.[33] However, of about 35 samples of bentonite from the Black Hills disintegrated by the writer, the Clay Spur sample was one of three that swelled most. Therefore it seems probable that the silica in the bentonite is an original chemical constituent of its finer portion. From this conclusion, the close association of the two rocks, and the similarity of their silica content, the inference could be drawn that the silica in the Mowry shale was likewise probably an original chemical constituent. This possibility will be considered more fully in the light of additional evidence.

Not only are the analyses of the two rocks similar in their high content of silica, but the relative proportions of the other compounds present are almost identical. By adding to the bentonite at Clay Spur an amount of silica equal to the total weight of the sample (that is, more than doubling the SiO_2 so that the other constituents are diluted to just one-half) the two analyses become strikingly similar. All the constituents except silica and organic matter are then within 0.3 per cent of the same in the two analyses, and the average difference, about 0.1 per cent, is only slightly greater than the probable error of the determinations. (See analyses 1 and 2.) This remarkable similarity between the two analyses suggests that the Mowry shale may be a silicified bentonite. Although the organic matter, structure, and other characteristics of the Mowry do not bear out this suggestion, there is a strong indication that the Mowry shale consists of approximately equal proportions of free silica and of the same material that altered into bentonite.

Another possible explanation of the similarity of the two analyses is that the silica content of the ash varied from time to time and that the more siliceous ash became a hard shale and the more normal ash altered to bentonite. Ross and Shannon think it "quite probable that glasses very high in silica are fairly stable and do not readily alter to bentonite."[34] However, no volcanic rocks of which analyses are available have a composition very similar to that of the Mowry shale analyzed, and the explanation calls for an utterly improbable repeated alternation in the percentage of one constituent in the original ash deposited. It seems much more probable, in view of the analyses, that any ash deposited in the Mowry shale had approximately the same composition as that in the associated bentonite beds.

The composition of the water in which the ash fell might have a strong influence on the type of decomposition and the resulting rock, but the sudden and repeated changes in composition of the water demanded in order thus to explain the differences between the Mowry shale and the bentonite seem quite as improbable as repeated changes in the silica content of the original ash.

A further possibility is suggested by the observation of Murray and Renard[35] that because of the order

[32] Galloway, J. J., The rounding of grains of sand by solution: Am. Jour. Sci., 4th ser., vol. 47, pp. 270-280, 1919.

[33] Ross, C. S., personal communication.

[34] Ross, C. S., and Shannon, E. V., op. cit., p. 84.

[35] Murray, John, and Renard, A., On the microscopic characters of volcanic ashes and cosmic dust and their distribution in the deep-sea deposits: Roy. Soc. Edinburgh Proc., vol. 12, p. 487, 1884.

of crystallization in a magma and the differences in specific gravity of the minerals, ash tends "to become more acid [siliceous] the farther it is removed from the center of eruption." That is, the minerals that crystallize first in a cooling magma are heavier and less siliceous than the magma itself, and in a volcanic eruption these minerals would fall nearest the source, leaving the uncrystallized and more siliceous portion to travel farther. Thus ash erupted over a long period of time might maintain the same composition at the volcanic vent, but variations in intensity of the explosions might cause variation in the composition of the ash deposited at any one distant point. However, this factor would not be effective in increasing the silica content of an ash after the heavier minerals had settled out, and, as the bentonite associated with the Mowry shale is in itself unusually siliceous, the extra silica in the Mowry shale is probably best explained by other means.

Silicification of the Mowry shale by the bentonite has been suggested by both field and chemical evidence. Ordinary bentonite contains a somewhat lower percentage of silica than the ash from which it was derived,[36] thus indicating that silica was given off during the alteration. Also the readiness with which particles of bentonite pass into an all but permanent suspension in water suggests that ground water might transport such material freely. However, this hypothesis calls for a free access of ground water to the bentonite, a difficult feat because of the intense swelling of bentonite when wetted. This supposition also makes it difficult to explain why the shale near all bentonite beds is not hardened. Furthermore, quantitative considerations greatly lessen the probability of this mode of origin of the silica in the Mowry. Although bentonite seems to be more abundant in the upper part of the Mowry shale than elsewhere throughout the Cretaceous rocks of northeastern Wyoming, it does not commonly constitute more than 10 per cent of the section, even in the upper 50 feet of that member. From the estimates of the silica content of the Mowry near Thornton, Wyo., it seems that the upper 50 feet contains about 20 per cent more silica than the adjacent softer shales, and hence the hypothesis demands that the bentonite beds furnish to the Mowry shale an amount of silica that is twice their own volume—that is, about twenty times as much silica as they would be expected to give off. It may be concluded, therefore, that bentonite is not an adequate source of all the excess silica in the Mowry shale.

On the other hand, the small portion of silica that causes local hardening near bentonite beds might conceivably be explained in this manner. Evidence indicating that in some places the alteration of ash to bentonite occurred after burial is cited in the conclusion to this paper, and, if this is true of the Mowry bentonites, siliceous water from the altering ash might have affected the underlying shale beds. However, the hypothesis seems unlikely in view of the close similarity between the decrease in hardness downward from any one bentonite bed and the decrease downward through the entire thickness of the Mowry shale, where as previously stated, the process seems quantitatively inadequate. Also the exceptionally high silica content of the bentonite certainly suggests that large quantities of silica can not have been leached from it. Furthermore, if local hardening of the Mowry shale near bentonite is caused by descending ground water, other Cretaceous bentonites in the same region should likewise be underlain by siliceous shale, whereas all other examples of hardened shale noted in the Black Hills region lie above instead of below the bentonite beds.

[36] Ross, C. S., and Shannon, E. V., op. cit., pp. 88-89. Ross, C. S., personal communication.

COMPOSITION OF ORIGINAL ASH

The conclusion that the Mowry shale consists in large part of the same material as that which altered into the bentonite makes it pertinent to consider the probable composition of the ash that formed the bentonite. In an examination of the sand-sized particles in bentonites from the Black Hills region, the writer estimated the proportions of different minerals present. An average of the counts of grains coarser than 0.07 millimeters in 21 samples of bentonite associated with the Mowry shale, after discarding clay aggregates, gypsum, iron oxides, and calcite, is as follows:

	Per cent.
Quartz	55
Orthoclase and sanidine	35
Biotite	8
Plagioclase (An_{35-40})	1
Zircon	Trace.
Glass	Trace.
Opal	Trace.
Apatite	Trace.

On the assumption that these fragments are phenocrysts, their mineralogic content indicates that the igneous rock in which they crystallized had the composition of a rhyolite that was very high in silica and low in plagioclase. In some of the samples a few rounded sand grains were noted, and these detrital grains make the average composition of the supposed igneous rock somewhat too high in quartz and, perhaps, in potash feldspars. If the figures given above are computed by norms into the form of a chemical analysis, it is seen that with the exception of the high percentage of K_2O the composition of the sand-sized material is similar to that of the Mowry shale and the bentonite at Clay Spur. (See analyses 5, 1, and 3.) Considering the facts that bentonite contains a somewhat lower percentage of silica than the ash from which it was derived and that the sand-sized particles in bentonite probably contain some detrital quartz, it is reasonable to assume that the original ash had a silica content intermediate between that of the bentonite and that of the sand-sized particles. The same relation should also hold for several other constituents.

The more acidic or siliceous varieties of rhyolite and other igneous rocks of similar composition contain from 70 to 80 per cent of SiO_2 and commonly from 1 to 7 per cent each of Na_2O and K_2O. An analysis that is fairly typical (though somewhat low in Fe_2O_3 and CaO) is that of a rhyolite pumice from Saillcs, Mont Doré, France (analysis 6). Comparison of the analyses of acidic rhyolites, the phenocrysts in Mowry bentonites, the bentonite at Clay Spur, and the Mowry shale indicates that the most soluble constituents, the alkalies, have been largely removed from the bentonite and shale. The conclusion therefore seems warranted that the original ash in the bentonite at Clay Spur and in the Mowry shale was of acidic composition and that during its alteration the alkalies were largely removed by solution.

SUMMARY OF CHEMICAL EVIDENCE

Analyses show that the Mowry shale contains an exceptionally large amount of uncombined silica. Consideration of chemical evidence leads to the conclusion that this silica may have been precipitated contemporaneously by the decay of organic matter or by substances in the sea water, it may have been deposited later during consolidation, or it may possibly be original very finely divided clastic material. It seems unlikely that the excess silica in the shale came from the bentonite. The composition of the Mowry shale and that of the associated bentonite are remarkably similar in the high percentage of silica and the relative proportions of the other constituents, strongly indicating that both contained the same original material. Analyses and phenocrysts in the bentonite indicate that this original material in both the bentonite and the shale was an acidic or siliceous ash from which the alkalies have been largely removed by solution.

MICROSCOPIC CHARACTERISTICS OF MOWRY SHALE

The Mowry shale is so fine grained and dark colored that microscopic study yields unsatisfactory results, yet much important evidence can be obtained in no other way. Both thin sections and crushed powders immersed in liquids of known refractive index were examined.

MATERIAL

Most of the thin sections of Mowry shale that were studied consist chiefly of clay-sized material. All but one of the Black Hills specimens contain less than 5 per cent of grains larger than about 0.005 millimeter in diameter (approximately the limiting diameter between silt and clay[37]). The coarser sample contains somewhat more than 50 per cent of these sand-sized and silt-sized grains. In every specimen the largest particle noted was between 0.15 and 0.20 millimeter across. The largest grains in the bentonites associated with the Mowry shale have diameters of 0.2 to 0.7 millimeter. The coarser material in the shale consists of angular grains of quartz, some fresh orthoclase and sanidine, and amorphous and finely crystalline particles. The finely crystalline particles include round and irregularly shaped masses of cryptocrystalline quartz and remnants of partly crystallized silica or glass that distort the bedding. (See pl. 16, *B*.) A few cuspate fragments of faintly brownish glass were recognized.

The fine portion is largely cryptocrystalline but contains some amorphous substances and appreciable amounts of very finely divided crystalline material, most of which is oriented essentially parallel to the bedding and shows a marked positive elongation (that is, the faster optic axis is approximately at right angles to the elongation of the particles). This fine crystalline material consists chiefly of quartz and an unknown clay mineral but contains also some potash feldspar, chalcedony, and biotite. In its birefringence, refractive indices, structure, and mode of occurrence[38] the clay mineral resembles montmorillonite, the common mineral of bentonite. The cryptocrystalline material appears from its indices of refraction to be chiefly quartz, with which are mixed organic matter and the clay mineral, but a large amount has refractive indices ranging between 1.51 and 1.545, and a little (very probably opal) has an index lower than 1.47. All stages in a complete gradation between the apparently amorphous material of low index and the cryptocrystalline aggregates of higher index may be found. A few apparently residual amorphous masses were seen. In some of the thin sections layers of cryptocrystalline quartz and some opal alternate with the more argillaceous material in very thin laminae. No evidence of secondary deposition such as veinlets or filled cavities was found.

A large amount of dark organic matter is present in all the specimens. It consists chiefly of small opaque fragments but contains also a few large transparent amber-colored masses of optically inactive material. The opaque organic matter is thoroughly disintegrated, and no plant or animal structure is visible. In many sections distinct, very thin bedding planes about 0.1 millimeter apart are marked by the organic matter. Some grains of iron oxide are also present.

NATURE OF FINE-GRAINED MATERIAL

The complete gradation between the cryptocrystalline material common in the groundmass and the

[37] Wentworth, C. K., A scale of grade and class terms for clastic sediments: Jour. Geology, vol. 30, pp. 377-392, 1922.

[38] Ross, C. S., personal communication.

amorphous material indicates that the former was derived from the latter. At least a part of the original amorphous material is opaline silica, but the analyses show pretty conclusively that most of it was of a more complex chemical composition. This complex original material may have been an isotropic colloid, but several lines of evidence indicate that a large amount of it may have been volcanic glass. Nearly all of the amorphous and cryptocrystalline material has refractive indices ranging between that of quartz and that of a glass with the composition of granite (1.51),[39] thus suggesting that the original substance from which the present material was derived was an acidic glass with a refractive index of about 1.51, rather than opal, which has an index of 1.46 or less. The small amounts of sodium and calcium shown in the analysis are not accounted for by the minerals recognized among the coarser grains (no plagioclase having been detected), thus indicating that these two elements are present in the finer portion, perhaps as an acidic volcanic glass. The clay mineral is similar to that characteristic of bentonite. It is true that only a few shards of glass were recognized and that those were among the coarser grains, but the glass in the associated bentonite has also lost these characteristic forms. The most definite evidence bearing on the identification of the amorphous matter as glass rather than opal is the fact that analyses, discussed elsewhere in this paper, show that the Mowry shale contains less than 1 per cent of opaline silica.

RELATIVE ABUNDANCE OF CONSTITUENTS

From the microscopic evidence and computations based on the chemical analyses, it is possible to make an approximate estimate of the constitution of a typical sample of Mowry shale of the Black Hills region. If Van Hise's definition of chert[40] as including "all forms of finely crystalline nonfragmental silica, including opaline, semicrystalline, and completely crystalline varieties," is adopted for the fine-grained silica in the Mowry shale the composition of a typical sample would be roughly as follows:

Very fine-grained sand and silt, chiefly quartz	4
Carbonaceous clay	20
Chert	35
More or less devitrified volcanic glass (?)	40
Iron oxide	1

SAMPLES OF MOWRY SHALE FROM LOCALITIES WEST OF THE BLACK HILLS

A sample of the Mowry shale collected near Winnett, Mont., about 250 miles northwest of the Black Hills region, by Frank Reeves, of the United States Geological Survey, was examined for comparison with the Black Hills material. In the hand specimen it consists of alternations of very hard dark-gray clay beds one-eighth inch thick, with light-gray, very fine-grained sandstone beds one-fourth inch thick. Fragments of fish scales and bones are abundant. According to Mr. Reeves, the thin-bedded alternation is typical of the Mowry of this region, but toward the west the sandy layers become thicker. Microscopic examination shows that the grains in the sandy layers are less than 0.2 millimeter in diameter and average about 0.04 or 0.05 millimeters. The sand grains consist of angular quartz (some of which show secondary enlargement) and fresh orthoclase (and sanidine?), nearly 1 per cent of rounded crystals of zircon, and some magnetite, hornblende (?), and cryptocrystalline material. The cement appears to be cryptocrystalline quartz. The clay beds contain a small percentage of fine sand and silt, and in every respect greatly resemble the Mowry shale of the Black Hills.

Near the Highwood Mountains, in northwestern Montana, about 350 miles northwest of the Black Hills region, a hard light-colored cherty volcanic ash occurs in the Colorado shale at a stratigraphic position near or perhaps somewhat below that of the Mowry shale.[41] This bed, about 30 feet thick, is "pale yellowish gray, weathering white. It resembles porcelain and is overlain by rock of similar character and appearance."[42] In one thin section examined by Johannsen the rock was seen to be "cryptocrystalline in texture. It is very slightly anisotropic, as a devitrified glass might be. There are a few irregular anisotropic patches which are too small to be determined. There is also a little brownish decomposed material." In another section the rock was "a very fine-grained, compact glass, consisting almost entirely of angular fragments very slightly devitrified, and a very few small, irregular grains, apparently of quartz, but too small to be determined. The rock is very homogeneous and uniform in appearance throughout the section."[43] Although this ash may not be an exact correlative of the Mowry shale, these descriptions indicate that it has several megascopic and microscopic characteristics in common with that member.

A thin section of a sample of the Mowry shale from Vermilion Creek, Colo., about 250 miles southwest of the Black Hills region, collected by W. H. Bradley, of the United States Geological Survey, was also examined. According to Mr. Bradley and other members of the Geological Survey, the Mowry shale in that region resembles hand specimens of the Mowry from the Black Hills and contains very little if any sandstone. Microscopically Mr. Bradley's sample is almost identical with specimens of the Black Hills Mowry. Less than 5 per cent of the grains have diameters greater than about 0.005 millimeter, and the largest

[39] Iddings, J. P., Rock minerals, p. 593, New York, 1911.
[40] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, p. 16, 1904.
[41] Reeves, Frank, personal communication.
[42] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, p. 37, 1909.
[43] Johannsen, Albert, in Fisher, C. A., idem, p. 37.

grain noted was 0.12 millimeter across. Much opal or glass is present, and cavities filled with microcrystalline chalcedony and round organisms similar to those in the Black Hills specimens were noted. There is also a large amount of dark organic matter.

Except for interlaminated sandy material in Mr. Reeves's specimen from Montana, the samples of Mowry shale from western localities closely resemble those from the Black Hills region. However, both the Montana and the Colorado specimens show some evidence of secondary silicification.

UNCERTAIN ORIGIN OF THE SAND, SILT, AND CLAY

The evidence is inconclusive as to whether the sand, silt, and clay that make up about one-fourth of the total weight of the Mowry shale are normal clastic sediments or derivatives from volcanic ash, but it seems probable that both sources have contributed.

The angularity, freshness, and small amount of the sand and silt in the Black Hills Mowry, the fairly uniform maximum diameter (0.2 millimeter) of the grains in all specimens, the sanidine and volcanic glass and the general association with altered volcanic ash suggest that the coarse material may be crystalline minerals from ash instead of ordinary clastic sand. The associated bentonite contains nearly as much crystalline material as the typical Mowry shale, and the sandy beds might be crystal tuff, which is reported to be a common product from acidic magmas.[44] Although the rounded form of the zircon crystals in Reeves's specimen may be the result of resorption in the magma,[45] abrasion seems a more probable explanation. This probable abrasion and the increase in amount of sandy material northwestward from the Black Hills suggest that a large part of the sand grains were normal clastic sediments.

The angularity and freshness of nearly all the sand and silt grains in the Mowry shale show that these grains have undergone very little abrasion and chemical weathering, and if they are not volcanic, they are difficult to explain. They may have been disintegrated in an arid or cold climate and deposited near by, thus escaping chemical decomposition and rounding, or they may have been broken from sea cliffs, protected from weathering by immediate submersion, and scattered widely in a shallow agitated sea. Admittedly neither alternative seems very satisfactory, but it is conceivable that the second one may explain the coarse material in the Mowry shale.

The determinable optical properties of the clay mineral and the striking similarity of the analyses suggest that the clay in the Mowry shale may be the bentonite mineral montmorillonite, derived from the alteration of ash. Yet the contained carbonaceous matter shows that the conditions of accumulation were different from those giving rise to bentonite and that at least some material other than ash was deposited. This evidence and the absence of the general characteristics of bentonite suggest that the clay in the Mowry may have been merely a normal mechanical sediment.

It seems probable that the sand, silt, and clay, estimated to make up about one-fourth of the Mowry shale of the Black Hills region, are partly more or less altered volcanic ash and partly normal clastic sediments. The writer sees no evidence indicating which of these two possible sources was most effective in the accumulation of this material.

SUMMARY OF MICROSCOPIC EVIDENCE

Microscopic examinations of the Mowry shale demonstrate the improbability of some of the explanations of its origin suggested by field relations and chemical analyses. It is seen, for example, that the siliceous character is not due to large quantities of quartz sand but that it has probably been derived from amorphous substances such as opal and volcanic ash. Approximately one-third of the rock is apparently cryptocrystalline quartz derived from opaline (chemically precipitated) silica. The remainder seems to be devitrified ash, carbonaceous clay, sand, and silt. The sand, silt, and clay, roughly one-fourth of the rock, may be partly volcanic and partly normal clastic material.

PREVIOUS INVESTIGATIONS

SUGGESTIONS AS TO ORIGIN OF MOWRY SHALE

Several theories of the origin of the Mowry shale have been proposed. Billingsley,[46] discussing especially the Mowry of Montana, interpreted the member as simply a fine-grained sandstone deposited during a sudden shoaling of the sea. Reeves,[47] likewise considering the Mowry of Montana, came to the similar conclusion that it is a very fine-grained sandstone "probably washed in a shallow sea and widely distributed by wave and current action."

Washburne,[48] in discussing a paper by Rae,[49] cites the Mowry as an "impure shaly chert" containing "a few spicules of Radiolaria but no diatoms" and formed by the "primary precipitation on the sea bottom of colloidal silica with much organic matter and other sediment." Rae, noting the relation between the amount of organic matter and free silica in river waters, had suggested that the source material

[44] Pirsson, L. V., The microscopical characters of volcanic tuffs: Am. Jour. Sci., 4th ser., vol. 40, p. 199, 1915.

[45] Armstrong, P., Zircon as criterion of igneous or sedimentary metamorphics: Am. Jour. Sci., 5th ser., vol. 4, pp 391-395, 1922.

[46] Kemp, J. F., and Billingsley, Paul, Sweet Grass Hills, Mont.: Geol. Soc. America Bull., vol. 32, pp. 473-475, 1921.

[47] Reeves, Frank, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Mont.: U. S. Geol. Survey Bull. 751, p. 89, 1924.

[48] Washburne, C. W., Am. Assoc. Petroleum Geologists Bull., vol. 7, p. 441, 1923.

[49] Rae, C. C., Organic material of carbonaceous shales: Am. Assoc. Petroleum Geologists Bull., vol. 6, pp. 333-341, 1922; A possible origin of oil: Am. Inst. Min. and Met. Eng. Trans., vol. 68, pp. 1112-1120, 1923.

of oil may have been precipitated chemically by sea water. Washburne suggests that the siliceous character of the Mowry and its association with oil in Wyoming may be explained by Rae's theory. Cunningham,[50] in a paper developing Rae's theory of the origin of oil in California, suggested that the great number of fish scales in the Mowry shale might be explained by a high mortality among fishes due to the poisonous effect of decomposing organic material upon the sea floor.

Geis,[51] who studied the Mowry shale in several areas, found that the weathered surface is "composed largely of the remains of organisms, especially of diatoms and Foraminifera," and that at several localities "volcanic ash forms a minor portion of the mass." He recognized a sandy phase of the member and noted a relation between the amount of sand in the Mowry and the quality of the oil produced in a region. From this relation, the fact that the geographic distribution of the Mowry shale and the light oil fields of the Rocky Mountain region coincide, and the stratigraphic distribution of Wyoming oil fields, he concluded that the Mowry shale was an important source of oil. It is of interest to observe in this connection that Estabrook [52] found that on the average the gravity of Wyoming oil increases both upward and downward from the horizon of the Mowry shale. In discussing the origin of the Mowry, Geis does not mention the hardness of the shale, although it seems that he may attribute it to the presence of sand and siliceous tests of diatoms. He interprets the Mowry simply as a normal shale rich in organic matter.

Macfarlane,[53] endeavoring to prove that oil is derived from fish remains, contends that essentially all oil in the Cretaceous rocks of western North America came from fishes, which were abundant during the deposition of the Mowry shale and were killed and preserved by numerous falls of volcanic ash. Henderson [54] criticizes this contention sharply and points out that the fishes were thoroughly decomposed and their scales scattered before burial. He also suggests that the general scarcity of calcareous shells and bones in the Mowry may be due to the presence of organic acids produced by the decomposition of algae in the water in which the shale was deposited.

Hewett [55] noted that the Mowry shale of the Big Horn Basin "probably contains considerable volcanic glass."

The explanation of the origin of the Mowry shale suggested by Billingsley and Reeves, although possibly satisfactory for the sandy Montana phase, does not account for the unusual character of the fine-grained shale of Wyoming. The organic content of the shale and its relation to occurrences of oil, as noted by Washburne and Geis, are in themselves not adequate explanations of the peculiarities of the Mowry. Cunningham's suggested explanation of the abundance of fish scales seems improbable, for unless the poisons were introduced suddenly and repeatedly it is difficult to account for the repeatedly renewed supply of fishes over so large an area. Siliceous organisms, if commonly present in such abundance as the diatoms found by Geis, might possibly be a satisfactory source of the silica. However, the writer's investigations indicate that in other places only a small number of either diatoms or radiolarians occur in the formation.

It seems unnecessary to assume, as Henderson has, that in order to dissolve out the carbonates the sea water must have contained acids derived from plant decay, for merely slow sedimentation would account for the solution of these carbonates. The solubility of calcium carbonate in sea water depends almost entirely upon the carbon dioxide content of the water. This carbon dioxide content, in turn, depends upon the amount of carbon dioxide available in the adjacent atmosphere and on the sea floor and upon the temperature of the water.[56] The colder the water the greater the quantity of carbon dioxide the water can contain, and the greater the carbon dioxide content the more calcium carbonate the water is capable of dissolving. Careful determinations indicate that, considering the temperature, the carbon dioxide content of the surface water of the ocean in tropical and temperate climates is approximately in equilibrium with the atmosphere, and that this surface water is essentially saturated with calcium carbonate.[57] If more calcium carbonate were somehow added it would be precipitated.

Sea water normally becomes colder with increasing depth, and hence the deeper water is capable of holding more carbonate in solution than the warmer surface water. This means that the deeper colder water would dissolve additional calcium carbonate if any was available until it became saturated. Calcium carbonate precipitated in the surface waters by whatever agencies and falling into the deeper water would be redissolved unless quickly buried. The effectiveness of the thermal gradient of sea water in causing solution of carbonates on the bottom of the ocean is shown by the local saturation of water in contact with the bottom [58] and

[50] Cunningham, G. M., Were diatoms the chief source of California oil?: Am. Assoc. Petroleum Geologists Bull., vol. 10, p. 714, 1926.

[51] Geis, W. H., The origin of light oils in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 499-504, 1923.

[52] Estabrook, E. L., Occurrences of oil and gas in Wyoming: Am. Assoc. Petroleum Geologists Bull., vol. 8, 515, 1924.

[53] Macfarlane, J. M., Fishes the source of petroleum, pp. 223-256, New York, Macmillan Co., 1923.

[54] Henderson, Junius, Sources of material from which petroleum may have been derived: California Acad. Sci. Proc., vol. 15, pp. 273-275, 1926.

[55] Hewett, D. F., Geology and oil and coal resources of the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles, Wyo.: U. S. Geol. Survey Prof. Paper 145, p. 54, 1926.

[56] Wells, R. C., The solubility of calcite in water in contact with the atmosphere and its variation with temperature: Washington Acad. Sci. Jour., vol. 5, pp. 617-622, 1915. Johnston, John, and Williamson, E. D., The rôle of inorganic agencies in the deposition of calcium carbonate: Jour. Geology, vol. 24, pp. 729-750, 1916.

[57] Johnston, John, and Williamson, E. D., op. cit., pp. 734-735.

[58] Wells, R. C., New determinations of carbon dioxide in water of the Gulf of Mexico: U. S. Geol. Survey Prof. Paper 120, p. 11, 1919.

by the corrosion and re-solution of shells collected from deep water.[59] If the rate of burial of the calcareous material on the bottom is rapid, or if circulation and diffusion are so slow that the bottom waters become and remain saturated, carbonates could accumulate. However, regardless of circulation, if the rate of sedimentation were sufficiently slow, calcium carbonate would be dissolved from the sea floor. Especially would this be true where, as during the deposition of the Mowry shale, abundant carbon dioxide was evolved by decaying organic matter on the sea bottom. As is discussed somewhat more fully under the heading "Conclusions," the thickness of the laminations, the condition of the organic matter, and other evidence indicate that the Mowry shale accumulated very slowly. It thus seems simplest and most in accord with the facts to attribute the absence of carbonates in the Mowry shale to a slow rate of sedimentation.

Washburne's theory that the silica was deposited colloidally on the sea floor is of these suggestions the only direct attempt to explain the high silica content of the Mowry shale. This theory, expanded to include Rae's proposed explanation of the origin of oil, is a fairly comprehensive interpretation of the origin of the Mowry shale. However, it does not adequately account for the observed relation of the shale to altered volcanic ash. Also most of the organic matter is in distinct if decayed fragments, and only a small part has a structure such as might result from colloidal precipitation, and it therefore seems that very little if any of this organic matter was precipitated as colloids.

THEORIES OF ORIGIN OF OTHER SILICEOUS FORMATIONS, INCLUDING "MONTEREY SHALE" OF CALIFORNIA

An imposingly large, controversial literature on the origin of chert might be cited for suggestions as to the origin of the silica in the Mowry shale. These various theories of the deposition of silica fall into two major groups, in one of which it is regarded as contemporaneous with and in the other as subsequent to sedimentation. Each group is further subdivided into classes of special theories. The contemporaneous or syngenetic group postulates normal clastic, biochemical, magmatic, or direct chemical deposition of the silica. The so-called pene-contemporaneous theory, which is more or less intermediate between the two major groups, assumes that the precipitation occurred later than sedimentation but before consolidation of the inclosing rocks. The subsequent or epigenetic group comprises two general types of theories—that the silica was deposited while the rock was in the zone of cementation and that it was deposited while it was in the zone of weathering.

Most theories of the origin of chert have been developed to explain nodular masses in calcareous rocks, a type of occurrence of silica very different from that in the Mowry shale. However, nearly all the theories have at some time been applied to bedded cherts, a type of occurrence in some respects similar to that in the Mowry shale. A few examples of bedded cherts that have been rather thoroughly studied will be cited.

Several geologists have discussed the origin of the "Monterey shale" of California, a widespread thick series of hard siliceous shale forming the major part of the Monterey group of current nomenclature, the distribution of which closely coincides with occurrences of oil. The Monterey group contains flinty chert, limestone, sandstone, diatomaceous earth and acidic tuff, but the predominant lithologic type is a siliceous shale in which diatoms and fish scales are common and Foraminifera, Radiolaria, and bone fragments occur. Under the microscope the rock seems to be made up of amorphous and microcrystalline silica surrounding angular quartz grains.[60] In its dominant lithologic character, wide distribution, association with occurrences of oil and volcanic ash, microscopic appearance, chemical composition (see analysis 8), and content of fish scales and some Radiolaria the "Monterey shale" resembles the Mowry. However, in many other respects the two are dissimilar.

From the abundance of organisms in certain portions of the series, the "Monterey shale" had been thought to be made up of the siliceous remains of diatoms, radiolarians, and sponges. Lawson,[61] thinking this explanation inadequate, noted that the small amount of crystalline material in the shale is fresh and angular, that these minerals are those of an acidic volcanic rock, and that the chemical composition of the shale corresponds to that of a very acidic soda rhyolite. He therefore suggested tentatively that the shale was derived largely from volcanic glass dissolved by sea water and chemically precipitated as pulverulent or gelatinous silica. This hypothesis seems to have been disregarded by later writers. Fairbanks [62] suggested that the "Monterey shale" was formed by the crystallization of diatomaceous shale. Arnold and Anderson,[63] noting that diatoms probably constitute less than 10 per cent of the rock in even the most fossiliferous shales and that these most fossiliferous shales are the least siliceous, concluded that the chief agents in hardening were infiltrated siliceous waters. Davis [64]

[59] Murray, John, and Renard, A. F., *Challenger* Rept., Deep-sea deposits, pp. 276–280, 1891. Willis, Bailey, Conditions of sedimentary deposition: Jour. Geology, vol. 1, pp. 504-507, 1893. Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 132, 1924.

[60] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Calif.: U. S. Geol. Survey Bull. 322, pp. 33–47, 1907. For a review of the stratigraphy of the Monterey group see Louderback, G. D., The Monterey series in California: California Univ. Dept. Geology Bull., vol. 7, pp. 177–241, 1913.

[61] Lawson, A. C., The geology of Carmelo Bay: California Univ. Dept. Geology Bull., vol. 1, pp. 24–28, 1893.

[62] Fairbanks, H. W., U. S. Geol. Survey Geol. Atlas, San Luis folio (No. 101), p. 4, 1904.

[63] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 46–47.

[64] Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ. Dept. Geology Bull., vol. 11, p. 298, 1918.

considered secondary silicification but dismissed it as untenable and concluded that the siliceous portions of the "Monterey shale" were deposited originally as gelatinous silica that was derived from some source other than the diatoms. Heim [65] ascribes the absence of lime, the abundance of diatoms, the regularity of stratification, and the scarcity of sand to sedimentation in a cold longshore current on a rather deep ocean floor. Rae [66] cited the siliceous and bituminous shales of California as possible examples of his theory that silica and the mother substance of oil are precipitated colloidally by sea water, and this idea has been developed further by Cunningham.[67] English [68] considered the diatoms an inadequate source of the silica and suggested that an original siliceous mud, derived clastically and chemically from the decay of a rhyolitic land mass, would account for it. He also mentioned the possibility that its siliceous character might be due to the presence of fine ash. At a symposium on "Siliceous shale and the origin of oil in California" held by the Cordilleran section of the Geological Society of America in January, 1926,[69] Hoyt S. Gale suggested that the volcanic material in the shale made the sea water rich in silica and thus furnished a favorable habitat for the diatoms.

Though different from the Mowry shale in many respects, the radiolarian cherts of the Franciscan also repay consideration, because of the careful attempts that have been made to interpret their origin. In addition to the radiolarian cherts, the Franciscan, which like the Monterey is restricted to California, contains sandstone, limestone, pillow basalts, and schist.

The Franciscan cherts had long been considered metamorphic rocks, but Ransome,[70] discovering the presence of radiolarians, concluded that the rocks are sedimentary deposits which are siliceous because of the contained organisms. Lawson [71] considered the silica an amorphous chemical precipitate formed on the ocean floor and concluded that siliceous springs were most probably the source of this silica. In an exhaustive study, including an extensive review of the literature of radiolarian cherts, Davis [72] considered many possible explanations and concluded that Lawson's suggestion, despite certain criticisms that had been made of it, appeared most probable.

[65] Heim, Arnold, Notes on the Tertiary of southern Lower California (Mexico): Geol. Mag., vol. 59, p. 539, 1922; Über submarine Denudation und chemische Sedimente: Geol. Rundschau, Band 15, p. 35, 1924.

[66] Rae, C. C., A possible origin of oil: Am. Inst. Min. and Met. Eng. Trans., vol. 68, pp. 1118–1119, 1923.

[67] Cunningham, G. M., op. cit., pp. 709–719.

[68] English, W. A., Geology and oil resources of the Puente Hills region, southern California: U. S. Geol. Survey Bull. 768, pp. 31–33, 1926.

[69] Heald, K. C., Annual meeting of the Cordilleran branch of the Geological Society of America: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 449–450, 926.

[70] Ransome, F. L., The geology of Angel Island: California Univ. Dept. Geology Bull., vol. 1, pp. 199–200, 1894.

[71] Lawson, A. C., Sketch of the geology of the San Francisco Peninsula: U. S. Geol. Survey Fifteenth Ann. Rept., pp. 425–426, 1895.

[72] Davis, E. F., op. cit., pp. 235–432.

In a recent discussion of the origin of a bedded radiolarian chert associated with pillow lavas and acidic tuffs, Sampson [73] emphasized the widespread and intimate association of cherts with pillow lavas and tuffs as recorded in the literature. He concluded that the chert he studied was formed largely by the inorganic precipitation of silica which came from submarine springs.

Honess [74] found that at least a part of the Arkansas novaculite, a thick series of hard siliceous rocks similar to chert, is silicified and devitrified volcanic ash.

Cathcart [75] has recently found that a very thick series of Triassic (?) cherts in Nevada show all stages of gradation into fine-grained volcanic tuffs. Some of his hand specimens and thin sections of this material were examined by the writer and found to bear rather striking resemblances to samples of the Mowry shale. This series of Triassic (?) cherts may be the same as a series of siliceous rocks exposed about 50 miles to the southeast which Hill [76] found to be largely volcanic tuffs.

CONCLUSIONS AS TO PROBABLE ORIGIN OF MOWRY SHALE

The field, chemical, and microscopic evidence converge in indicating that the Mowry shale of the Black Hills region is somehow related to altered volcanic ash. This conclusion is strengthened by the common association of bedded siliceous rocks elsewhere with volcanic materials. The evidence indicates that the Mowry shale consists of volcanic ash, clay, silt, sand, and organic matter and a large amount of chemically precipitated silica. The most probable causes of deposition of this silica that have emerged from the foregoing discussions account for it as either (1) secondary, having been deposited after the accumulation of the mechanical sediments by (*a*) weathering at the outcrop or (*b*) consolidation—solution at the contacts of glass particles and deposition in pore spaces; or (2) contemporaneous, having been deposited with the clastic sediments, from sea water rich in silica, by the decay of organic matter or by other precipitating agents in the sea.

SECONDARY DEPOSITION OF SILICA

The absence of unusual precipitating agents in the Mowry shale and the conclusion that silicification by bentonite or by the interaction of two ground waters was unlikely have apparently reduced the probable methods of secondary deposition to two:

Weathering at the outcrop.—Without going into a detailed discussion of solution and deposition of silica

[73] Sampson, Edward, The ferruginous chert formations of Notre Dame Bay, Newfoundland: Jour. Geology, vol. 31, pp. 571–598, 1923.

[74] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 121–139, 1923.

[75] Ferguson, H. G., and Cathcart, S. H., Hawthorne quadrangle, Nevada: U. S. Geol. Survey Prof. Paper (in preparation).

[76] Hill, J. M., Some mining districts in northeastern California and northwestern Nevada: U. S. Geol. Survey Bull. 594, pp. 172–174, 1915.

by evaporation and leaching of other constituents of a rock, it is sufficient to note that without some outside source this method of silicification can be effective only in a rock already high in silica. There is no suggestion of an adequate source of silica near the Mowry shale, and the problem is no nearer solution if it is assumed that the shale was rich in silica before weathering. Furthermore, well cuttings show that even far underground the formation is more siliceous than the adjacent shales. Field evidence indicates that some silicification takes place at the outcrop, but other considerations apparently prove it to be only a minor factor.

Consolidation—solution at the contacts of glass particles and deposition in pore spaces.—If the writer's estimate is correct that less than one-half of the Mowry shale is precipitated silica, secondary deposition is within the bounds of possibility, for an accumulation of small highly angular fragments of glass might have a porosity of 50 per cent or even more. As the accumulation became more deeply buried, solution at the contacts of sharp edges and precipitation in the pores would be expected. However, according to this hypothesis, the ash was extremely angular at the time of deposition, and the precipitation of cement should have preserved the original surfaces of the glass particles next to the pores. The fact that very few such sharp margins were found but that on the contrary a few apparently residual masses of opal were seen considerably weakens the hypothesis. The uncrushed condition of the delicate radiolarian test (see pl. 16, *A*) indicates that the shale has undergone much less compacting than this hypothesis seems to demand. If this explanation were correct the precipitated material should consist of the less soluble constituents of the glass, chiefly alumina and silica, but analyses and microscopic evidence indicate that the added material is silica without appreciable amounts of alumina. Moreover, the hypothesis does not explain the alternation of the layers of microcrystalline quartz and more argillaceous material. Nor does it account for the physical differences between the Mowry shale and bentonite; as both were presumably derived from the same ash, the purer ash beds should by this hypothesis have formed harder rock instead of bentonite. Although this method of consolidation may have been a factor in the silicification of the Mowry shale, it seems extremely unlikely that it was more than a very minor one.

CONTEMPORANEOUS ORIGIN OF SILICA

The most probable hypotheses of contemporaneous origin call for a sea water that contained an adequate supply of silica and substances that would cause the precipitation of silica. The silica originally in the sea water might have come from river waters rich in silica,[77] from submarine springs, or from the solution of a siliceous volcanic ash. Siliceous organisms are not considered a likely source because they are very uncommon in the specimens examined by the writer and because their excellent state of preservation (see pl. 16, *A*) would be very difficult to explain had the cryptocrystalline matrix also been derived from siliceous organisms. Moreover, such organisms merely use silica already present.

The precipitation of silica might have been brought about by silica-secreting organisms, by electrolytes in the sea water, or by compounds derived from the decay of nitrogenous organic matter (animals and microscopic plants). Siliceous organisms obtain the material for their tests from suspended clay particles in the sea rather than from dissolved silica,[78] and water that contained large quantities of suspended silicates and siliceous organisms might deposit much silica biochemically. Under certain conditions the remains of these tests might be dissolved on the sea floor and precipitated as amorphous silica. However, as mentioned in the preceding paragraph, the excellent state of preservation of the Radiolaria in the Mowry shale makes it seem extremely improbable that any such process of solution and deposition acted upon siliceous tests to form the cryptocrystalline matrix. Organic precipitation seems improbable, but electrolytes present in normal sea water are capable of precipitating silica [79] and ammonium carbonate, a compound especially effective in coagulating silica, and bicarbonates were almost certainly abundant while the organic matter now present in the Mowry shale decayed.

It has been concluded in the foregoing discussions that the original ash in the Mowry shale and that in the associated bentonite beds were nearly identical in composition and that the presence in the Mowry of the clay, silt, and especially the organic matter and precipitated silica constitutes the only important difference in the composition of the two rocks. These associated materials, therefore, might be expected to explain why some of the ash formed siliceous shale and and some altered to bentonite.

Beds of bentonite that are nearly free from organic or other impurities probably represent individual ash falls. Organic matter of any sort is very uncommon in bentonite. The writer found no fossils in the bentonite beds associated with the Mowry shale, and the sole occurrence of fossils in any bentonite bed known to him consists of some invertebrate remains in a persistent bed of fairly pure bentonite in the middle of the Belle Fourche member of the Graneros shale. Here, in the W. ½ sec. 19, T. 57 N., R. 66 W., Crook County, Wyo., the writer found abundant shells of a smooth simple form of *Ostrea* and some crustacean fragments [80] in a 1-inch layer of prismatic and cone-

[77] Tarr, W. A., Origin of the chert in the Burlington limestone: Am. Jour. Sci., 4th ser., vol. 44, pp. 428-432, 1917.

[78] Murray, John, and Irvine, Robert, On silica and the siliceous remains of organisms in modern seas: Roy. Soc. Edinburgh Proc., vol. 18, pp. 244-250, 1891.

[79] Tarr, W. A., op. cit., pp. 434-437.

[80] Identification by J. B. Reeside, jr.

in-cone calcium carbonate in the upper part of a bentonite bed 4 feet thick. The very small amount of organic matter in most bentonite beds suggests, though it by no means proves, that the original ash accumulated so rapidly that the organisms were obscured by the large proportion of contemporaneous sediments.

This possibilty of a relatively rapid rather than a gradual accumulation of the ash that formed bentonite is considerably strengthened by examinations of the sand-sized material in bentonites from the Black Hills region. Wherry [81] found a marked decrease upward in the amount of feldspar, biotite, and magnetite in a bed of bentonite near the base of the Pierre shale in southwestern South Dakota. He explained this decrease by the difference between the settling velocities of these crystalline minerals and the extremely angular bubble-filled particles of volcanic glass. The bentonite bed at the top of the Mowry shale also shows this distribution of the crystalline minerals, for the present writer found a fairly uniform decrease upward in the percentage of sand-sized material in seven samples constituting a vertical section of the bed near Upton, Wyo. This distribution indicates that the thick bed of bentonite at the top of the Mowry represents the deposit of a single ash fall. Furthermore, the small amount of obviously detrital sand grains in most bentonites and particularly in those associated with the Mowry shale tends to support the assumption of relatively rapid deposition.

Unlike the associated bentonite, the Mowry shale itself contains much organic material. The large amount of this material suggests that it required a long time to accumulate. The disintegrated condition of the organic matter, the abundance of the chemically resistant fish scales, and the absence of easily soluble carbonates indicate that this débris was long exposed to decay and submarine solution. If, as seems a reasonable assumption, the thin laminae in the shale are annual layers,[82] the Mowry shale accumulated in about half a million years. This would mean that the ash that formed the bentonite was deposited several thousand times as rapidly as the material that formed the shale. These several lines of evidence make it seem justifiable to assume that the shale with its contained ash accumulated very slowly and that this ash, unlike that which altered to bentonite, lay for a long time on the sea floor in contact with water. This suggested difference in the length of time the ash in the two rocks lay exposed to sea water affords a possible clue to the origin of the Mowry shale.

Another minor but perhaps significant difference between the two rocks is the greater size of the original ash particles in the bentonite, as indicated by the maximum diameters of the unaltered crystalline material.

PROPOSED INTERPRETATION OF ORIGIN OF MOWRY SHALE

An acidic volcanic dust contains an unusually large proportion of the most soluble constituents in igneous rocks—the alkalies, sodium and potassium—and as the small size and extreme angularity of its particles facilitate solution, water immediately in contact with the dust would become alkaline. Silica, the chief constituent of volcanic dust, though slightly soluble in pure water, is much more so in alkaline solutions.[83] The particles of ash would therefore be attacked by the locally alkaline water; the glass particles, if unusually small and not soon buried by later sediments, would be partly dissolved; and the water on the sea floor would become rich in silica. Ammonium carbonate from decaying organic matter or electrolytes in the sea water would probably precipitate a portion of this silica as a gel.

That some such subaqueous decomposition of volcanic glass into amorphous silica takes place is indicated by experimental and observational data. Cushman [84] found that powders of rock that contain alkalies, especially the powders of noncrystalline materials such as artificial glass, when immersed in water give an alkaline reaction and are decomposed, with blurring of the outlines of fragments and the formation of colloidal silica or silicates. Dimbleby and Turner [85] showed that the chemical instability of artifical glasses in water increases with an increase in the proportion of Na_2O in the glass. The presence of hydrated silica associated with glass in volcanic muds on the sea floor [86] indicates that a similar decomposition occurs in nature.

Though both electrolytes and decaying organic matter might have precipitated the silica, the details of the relation between the hardness of the Mowry shale and bentonite beds suggest that decaying organic matter was the more effective. The proportion of electrolytes in sea water would be essentially unaltered by an ash fall, and if electrolytes were the principal coagulating agents, hardened shale would be expected just above even the thickest bentonite beds, for the top of the ash bed would have been long exposed to the chemical action of electrolytes. On the contrary, the Mowry shale is hardest just below each bentonite bed and quite unsilicified above the last and thickest one.

[81] Wherry, E. T., Clay derived from volcanic dust in the Pierre in South Dakota: Washington Acad. Sci. Jour., vol. 7, pp. 579, 582, 1917.

[82] Rubey, W. W., manuscript report on the lithologic character, rate of deposition, and organic content of Cretaceous shales from the Black Hills region (to be published by U. S. Geol. Survey); Possible varves in marine Cretaceous shale in Wyoming [abstract]: Washington Acad. Sci. Jour., vol. 18, pp. 260-262, 1928.

[83] Lovering, T. S., The leaching of iron protores; solution and precipitation of silica in cold water: Econ. Geology, vol. 18, pp. 524-533, 1923. Also common laboratory practice is based on this fact.

[84] Cushman, A. S., The effect of water on rock powders: U. S. Dept. Agr. Bur. Chemistry Bull. 92, pp. 5-24, 1905.

[85] Dimbleby, Violet, and Turner, W. E. S., The relationship between chemical composition and the resistance of glasses to the action of chemical reagents: Soc. Glass Technology Jour., vol. 10, pp. 304-358, 1926.

[86] Murray, John, and Renard, A. F., *Challenger* Rept., Deep-sea deposits, pp. 243-244, 1891.

This relation might be explained by assuming that the organic débris on the sea floor was quickly buried by the ash falls, that many organisms were killed by each fall, that between eruptions they recovered slowly to their former abundance, and that the final, largest fall virtually exterminated them. A further objection to the general idea of precipitation by electrolytes, raised by Dean,[87] is that the electroylytes would be the principal material adsorbed by the silica and hence form the chief impurity in the siliceous rock.

Other factors than the effect of ash falls upon organisms must also have contributed to bring about the upward increase in silica content of the Mowry shale and the change in conditions of sedimentation from Mowry to Belle Fourche time. There is some evidence in the stratigraphic distribution of bentonite beds in the Mowry shale that ash falls became progressively more frequent or that there was less and less normal sedimentation between large ash falls until the end of Mowry deposition. Therefore the progressive upward increase in silica content may be in large part due to greater quantities of highly siliceous ash or to longer exposure to decomposition by sea water. It is also possible that a small amount of the excess silica in the shale just below bentonite beds may be due to secondary silicification, even though this process could not account for all the excess silica at these horizons.

The theory that the Mowry shale was formed on the sea floor by the chemical decomposition of slowly accumulated, very fine grained, highly siliceous volcanic ash in the presence of decaying organic matter appears to account satisfactorily for the present physical differences between the shale and the bentonite, despite the fact that the exact changes involved in the alteration of ash to bentonite are not known. Large ash falls would accumulate very rapidly and perhaps contain larger particles, thus preventing much solution of silica,[88] and, as organic remains would be practically absent, little silica would be precipitated. Between the more violent explosions small eruptions might occur frequently enough to distribute widely a small amount of fine volcanic dust, or ash from earlier falls might be washed into the sea and the finer fragments widely distributed. Altered by long exposure to the action of sea water and decaying organic matter and embedded with silica gel, this dust would form a rock quite different from bentonite.

It does not seem necessary to call upon river waters or submarine springs as a source of the silica, for an acidic volcanic ash would furnish an unusual amount, far from shore, and concentrated upon the sea floor more readily than diffusion and currents in water, and none of the evidence suggests local deposition near submarine springs.

The occurrence and excellent state of preservation of the Radiolaria may perhaps be explained by the unusually favorable conditions for the preservation of these incidental fossils.

It is consistent with this theory to interpret the thickening of the Mowry shale and its correlatives southwestward as evidence that the volcanoes from which the ash in the shale and bentonite was blown were situated near southwestern Wyoming. If this interpretation is correct, individual bentonite beds should likewise thicken southwestward toward the supposed source of the ash, but near-shore deposits might mask a portion of an ash deposit or split it with partings into thinner beds. In other ways also the thickness of a bentonite bed is not a reliable indication of the thickness of the original ash, for there were probably volumetric changes depending upon the degree of alteration and compacting. A more satisfactory test of the location of the volcanic vents would be the size of the included tuffaceous fragments.

The fine sand which thickens northwestward may be partly a normal clastic deposit derived from some source in central western Montana.

SIGNIFICANCE OF RESULTS

The evidence seems overwhelming that the origin of the Mowry shale is intimately connected with the occurrence of altered volcanic ash, and whether or not the proposed explanation of the silica in the shale is correct this occurrence of ash suggests possible applications to other problems.

Acidic tuffs may have been the source of silica in other siliceous formations, and this hypothesis seems worthy of consideration in further studies of the origin of chert and of such formations as the "Monterey shale" of California.

If it is true that the Mowry shale is a source of much oil, the interesting problem of the relation between the formation of oil and the conditions of deposition of the tuffaceous material is raised.

A most interesting application is stratigraphic. According to current correlations the deposition of the thicker Aspen formation of southwestern Wyoming began earlier than the Mowry epoch and continued through but not beyond it. This interpretation that the lower part of the Aspen is older than the lower part of the Mowry is based partly upon the greater thickness of the Aspen and partly upon the assumption that the top of the Bear River formation, which underlies the Aspen, is equivalent to the top of the Dakota sandstone, which in many places lies several hundred feet below the base of the Mowry. However, the presence of large quantities of volcanic ash in the original Mowry sediments makes it seem much more probable

[87] Dean, R. S., The formation of Missouri cherts: Am. Jour. Sci., 4th ser., vol. 45, p. 412, 1918.

[88] This is consistent with the findings of Miser and Ross (Miser, H. D., and Ross, C. S., Volcanic rocks in the Upper Cretaceous of southwestern Arkansas and southeastern Oklahoma: Am. Jour. Sci., 4th ser., vol. 19, p. 120, 1925; Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154, pp. 175 et seq., 1929), who found calcite concretions that contained unaltered tuff in bentonite beds and concluded that the alteration to bentonite was subsequent to the burial of the ash.

to the writer that the Mowry shale is the time equivalent of the Aspen formation. The greater thickness of the Aspen formation can be explained as due simply to thicker contemporaneous deposits near the source of the ash. This assumption could probably be tested, for tracing of individual bentonite beds—the most exact time markers available to stratigraphers—would show whether or not the limits of the Mowry shale vary sensibly from place to place. In southwestern Wyoming the Aspen formation is underlain by the Bear River formation, a thick unit of sandstone and shale carrying a fresh-water fauna.[89] The exact age of the Bear River is unknown, as the paleontologic and stratigraphic evidence indicates merely that it is somewhat older than part of the Benton, but from its lithologic character and general stratigraphic position the formation has been tentatively correlated with the Dakota sandstone. In the absence of paleontologic evidence to the contrary, it seems more logical to correlate the volcanic débris of the Mowry and Aspen formations than the sandy material of the Dakota and Bear River formations, as has been done heretofore.

If the Mowry and Aspen formations can be considered strictly contemporaneous, they are valuable aids in interpreting the Cretaceous history of the Western Interior, for they can be used as a horizon marker in that part of the Cretaceous system which yields little paleontologic basis for long-distance correlation.

The Dakota sandstone has long been referred to as a typical transgressing formation, yet, as it cuts across no reliable faunal zones, this interpretation is based solely upon its varying stratigraphic position with respect to other lithologic units, all of which may be in turn transgressive. If correct, the revised correlation here proposed would mean that the sandstone facies at the base of the Cretaceous called the Dakota sandstone transgresses upward and westward across Wyoming, as, from other evidence, it is generally thought to transgress upward and southward across the Great Plains.

The upper sandstone of the Dakota of northeastern Colorado, the Muddy sand of southeastern and central Wyoming, and the Newcastle sandstone of the Black Hills region have commonly been considered equivalents,[90] despite the fact that in Wyoming these sandstones occur well above the base of beds classified as Benton. As the Mowry shale almost immediately overlies these sandstones in Wyoming, it seems that a microscopic search for volcanic ash at the horizon of the Mowry in Colorado might be rewarded by new and definite evidence as to the equivalence of these sandstone beds throughout the general region.

89 Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 98–115, 1892.

90 Stanton, T. W., Some problems connected with the Dakota sandstone: Geol. Soc. America Bull., vol. 33, pp. 264–269, 1922. Lee, W. T., Continuity of some oil-bearing sands of Colorado and Wyoming: U. S. Geol. Survey Bull. 751, pp. 1–22, 1925.

OIL SHALE IN A PRODUCING OIL FIELD IN CALIFORNIA

By H. W. Hoots

General features.—A considerable thickness of oil shale has been penetrated by a well drilled in the southwest corner of sec. 22, T. 11 N., R. 20 W., on the north flank of Wheeler Ridge, at the south end of San Joaquin Valley, Calif. This shale is similar to oil shale found in some of our Rocky Mountain States in that it contains no free oil but includes much detrital carbonaceous material, which when heated yields oil. Nearly continuous cores of this shale and associated fine sandstone and sandy shale were taken from depths of 1,869 to 4,090 feet, a range that represents a stratigraphic thickness of about 1,400 feet. The cores were 4 inches in diameter. In 1924, just before the well was abandoned, the writer was permitted by officials of the Midland Oilfields Co. (Ltd.), of Fellows, Calif., to sample these cores for later examination.

Shale in some of the samples taken is dark brownish gray to black, has the appearance of hard rubber, and is finely laminated throughout. Dark carbonaceous laminae alternate with others of light buff-gray color, which are commonly calcareous. Small calcareous nodules from one-eighth to one-half inch in diameter are abundant in some of the samples. In other samples, not so rich in hydrocarbons, shale either alternates with laminae and thin beds of fine gray sand or is splotched irregularly with ¼-inch to ½-inch patches of sand not so fine in texture.

The dense brown rubberlike appearance of some of the shale suggested its bituminous character. Upon heating small crushed samples in test tubes it was found that different quantities of dark-brown oil were driven off, and that some samples, it was estimated, yielded as much as 25 per cent by volume of volatile hydrocarbons that condensed to oil. None of the samples, when crushed and subjected to the solvent action of carbon tetrachloride, ether, or chloroform, were found to contain free oil. Miss Taisia Stadnichenko, of the National Research Council, made additional tests with various solvents and obtained the same results. These tests, however, were applied to only about a dozen small samples taken from the 1,400 feet of shale penetrated by the well, and they do not prove that free oil is not associated with bituminous material in much of the shale. Free oil and oil residues are known to be associated with bituminous shale in other parts of California.

Microscopic character and richness.—An accurate statement of the character and richness of the entire rock thickness penetrated by this well can not be given. Cores were taken from only part of the well. At the time of sampling the presence of oil shale was not suspected, and the 82 collected samples, an average of one sample for every 27 feet of depth, may not contain representatives of the best oil shale penetrated by the drill.

Thin sections were made from some of the samples that appeared richest and were submitted to David White for examination. His statements concerning the character and content of these shales appear below.

> The carbonaceous shales found at different depths in the well have been examined by means of thin sections cut both vertical and parallel to the bedding. All these sections show much organic matter, including a rather large amount of débris that consists largely of the outer coats of algae, which were more or less cutinized or fatty, together with a few spores of different kinds and some miscellaneous débris. In general aspect, character, and arrangement of débris and "ulmic" colloidal matter all the specimens belong to the normal laminated type of oil shale, whether it be as old as the Devonian or as young as the Tertiary. In short, these shales are charactertistic bituminous or oil shales, in which, in general, only the somewhat decay-resistant organic structures are preserved.
>
> Estimation from the thin sections of the possible yield of the shale is difficult, but I am inclined to hazard the forecast that shale like the thin layers from which some of the sections were cut would probably yield as much as 30 gallons of distillate to the ton of rock.

In addition to the algae, spores, and other organic remains noted by Mr. White, some thin sections show distinct outlines of calcareous Foraminifera, which, according to D. D. Hughes,[1] belong to the genera *Bolivina*, *Bulimina*, and *Buliminella*. Dr. Paul P. Goudkoff[2] found these same forms to be common in comminuted samples of cores taken from depths below 3,040 feet. Higher in the well, between depths of 1,900 and 3,040 feet, Foraminifera contained in the cores, according to Doctor Goudkoff, are entirely arenaceous forms. He found that remains of diatoms are either entirely absent or scarce in all samples examined. This statement applies equally well to the thin sections.

In hand specimens amber-colored fish scales were noted to be abundant throughout practically all the cores. In one sample the crushed partial skeleton of a fish was preserved along the bedding plane of compact, finely laminated dark-brown shale.

[1] Oral communication.

[2] Letter dated Dec. 22, 1926.

Of the available small samples having indications of at least moderately high content of carbonaceous material, those large enough for partial distillation tests were tested by the United States Bureau of Mines. Unfortunately, before the distillation tests were made the original small samples had been twice reduced in size for micropaleontologic studies, and as a result some of the best samples, including some of those examined by Mr. White and heated in test tubes by the writer were too small for distillation tests. Yields of oil from the tested samples are listed below.

Results of distillation tests on oil shale from Wheeler Ridge, Calif.

Depth (feet)	Oil yield (gallons to the ton)
2, 646–2, 651	3. 07
3, 040	2. 04
3, 196	3. 28
3, 352–3, 358	4. 73
3, 491–3, 496	2. 40
3, 536–3, 538	9. 27

Specific gravity of oil from last sample, 0.9490. Not sufficient oil produced for complete distillation.

The accompanying photomicrograph (pl. 17, *A*) of one of the thin sections, cut normal to the bedding of a small sample taken from a depth between 3,475 and 3,480 feet, illustrates the microscopic character of some of the best samples examined. Dark portions of this photograph appear in the thin section as dark-brown lamellae of carbonaceous material, which are intercalated with irregular stringers of a pale-brown (nearly colorless) substance, some of which is isotropic with an index of refraction less than 1.54. This substance is syngenetic and appears to be silica in the form of opal and incipient chalcedony. Minute grains of quartz and feldspar are abundant, and the outline and inner structure of a foraminifer appear in the upper right quadrant of the picture. According to W. H. Bradley, of the United States Geological Survey, this and other slides appear to compare favorably in content of carbonaceous material to fairly good oil shales from the Green River formation of the Rocky Mountain region. The previously mentioned estimate, based on heating of test-tube portions, that some samples yield as much as 25 per cent by volume of volatile hydrocarbons that condense to form oil (about 30 gallons to the ton of rock) may be considered an approximation to the potential oil content of the best samples.

Age of the oil shale.—The Midland well was drilled on the outcrop of rocks considered as belonging to the Pliocene Etchegoin formation. The arenaceous Foraminifera found in the upper 1,000 feet of the cores, between depths of 2,000 and 3,040 feet, are reported by Doctor Goudkoff to be the same as those found in strata mapped by Arnold and Anderson [3] as the Santa Margarita formation (upper Miocene) of the Pyramid Hills and Big Tar Canyon, in the Coalinga district. The calcareous Foraminifera found below 3,040 feet in depth are considered by Doctor Goudkoff to belong to the Maricopa shale (upper and middle Miocene). It is fairly certain that most, if not all, of the oil shale at Wheeler Ridge is of Miocene age.

Stratigraphic relation of oil shale to oil-producing zone.—Many shows of oil and of oil and gas were obtained in the Midland well, and they were all confined to that portion of the well in which oil shale is common. (See pl. 17, *B*.) This striking relation may be due in part to the fact that the Miocene "brown shale" strata, in which oil shale occurs, are the only beds that were cored and examined carefully for oil content. Nevertheless it is noteworthy that a column of rock containing considerable oil shale also yields strong shows of petroleum. This relation is substantiated and becomes even more striking when it is noted, as shown in Plate 17, *B*, that this same stratigraphic interval corresponds to most of the producing zone of the Wheeler Ridge oil field, only 1,100 feet south of the Midland well.

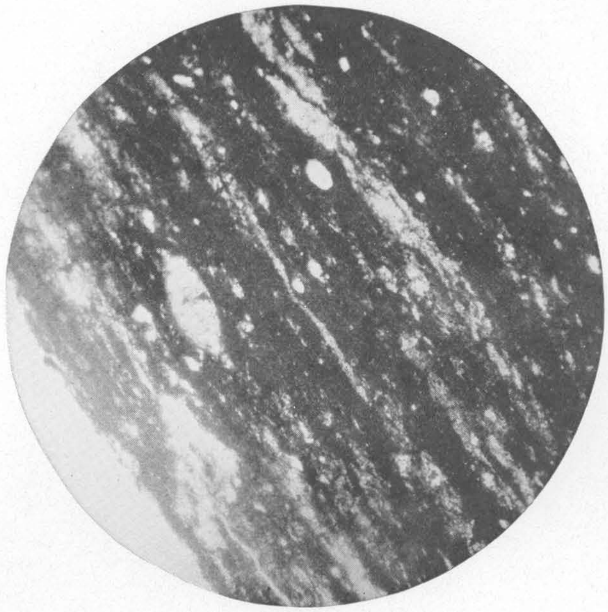
Significance of the stratigraphic relation.—Has the oil now being produced from porous strata in the Wheeler Ridge field been derived from the abundant and varied detrital organic material of intercalated oil shale, or has it originated, according to the more commonly accepted theory for California oil, in deeper and possibly also more distant shale deposits, which may be composed largely of diatoms and their remains? The available evidence provides no answer to this question. According to experiments conducted by McCoy [4] and Trager,[5] oil shale when subjected to pressure will yield free oil; but even though this fact and the close stratigraphic relation between oil shale and petroleum production in Wheeler Ridge are certainly suggestive, the possibility must be considered that this relation is entirely accidental and that the Wheeler Ridge oil has been derived from another source. On the assumption that oil shale will yield petroleum under natural conditions resulting from deep burial and pronounced deformation, it must be conceded that there is field evidence at Wheeler Ridge that supports a plausible theory for the origin of oil at this locality—a theory that is ideal in simplicity and that avoids the difficulties encountered by assuming migration of oil generated in deeper or more distant strata. Diatoms and Foraminifera associated with the oil shale may also have contributed oil to intercalated petroliferous beds, but from their apparent scarcity in the oil-producing strata of this area it appears probable that they are of minor importance as source material.

Is typical oil shale, such as this at Wheeler Ridge, more common in fields that are producing oil than is

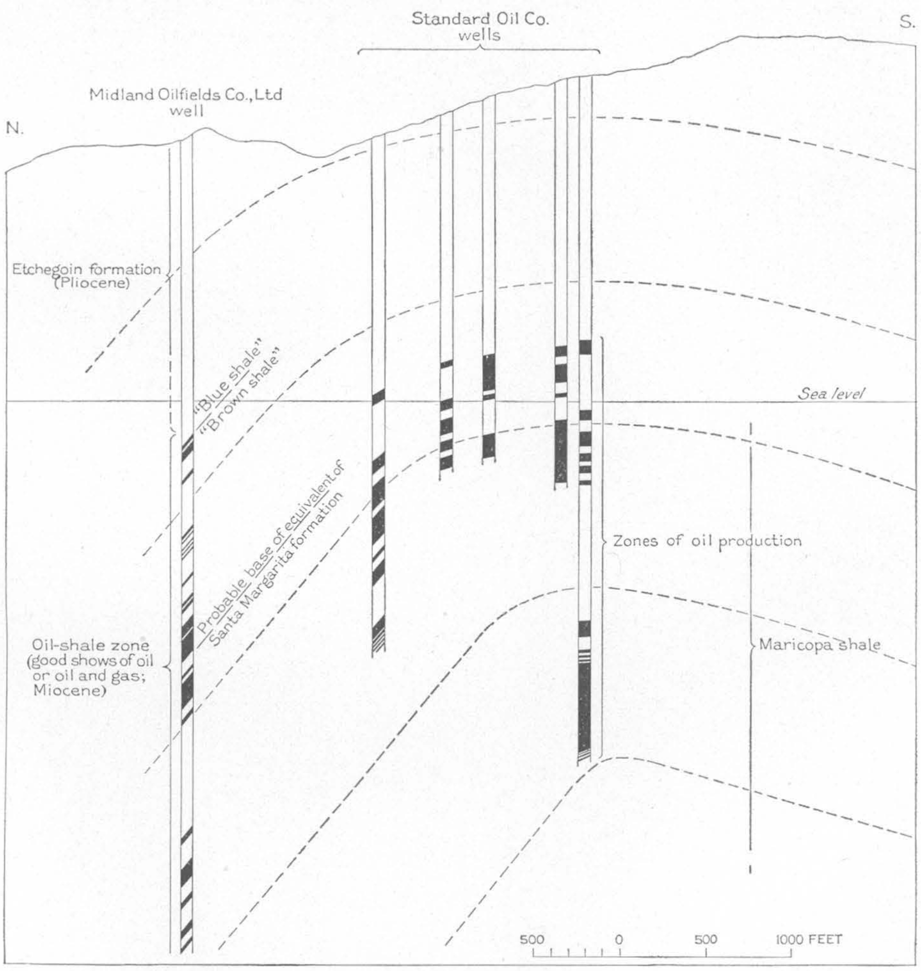
[3] Arnold, Ralph, and Anderson, Robert, Geology and oil resurces of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, Pl. I, 1910.

[4] McCoy, A. W., Notes on the principles of oil accumulation: Jour. Geology, vol. 27, pp. 252-262, 1919.

[5] Trager, E. A., Kerogen and its relation to the origin of oil: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 301-311, 1924.



A. PHOTOMICROGRAPH OF A THIN SECTION OF OIL SHALE FROM WHEELER RIDGE, CALIFORNIA



B. NORTH-SOUTH SECTION ACROSS AXIAL PART OF WHEELER RIDGE ANTICLINE CALIFORNIA, SHOWING STRATIGRAPHIC RELATION OF OIL SHALE TO BEDS PRODUCING OIL now generally recognized? Such oil shale may be of common occurrence in Pliocene as well as Miocene oil-yielding strata of California.

It will be noted from the photomicrograph (pl. 17, *A*) that unmistakable marine Foraminifera occur embedded within the fine laminations of rich carbonaceous material. These fragile forms are unbroken and show no evidence of having been reworked; they appear to prove that the oil shale is of marine origin. In this way the Wheeler Ridge shale is similar to the Devonian oil shales of Kentucky and Indiana but differs from the extensive Eocene deposits of oil shale in the Rocky Mountain region, which, according to Bradley,[6] were formed from organic sediments deposited in large inland lakes.

It would appear that if typical oil shale will yield petroleum under natural conditions which have prevailed since its deposition, any stratigraphic zone of oil shale or other highly organic rock, whether of marine or lacustrine origin and even though entirely devoid of recognizable fossils, should be considered an adequate source for petroleum deposits in areas where overburden has been great or where deformation has been intense. At Wheeler Ridge the oil-shale beds, together with about 4,000 feet of overlying Pliocene sediments, have been folded into an asymmetric anticline whose limbs dip 20° and 50°.

[6] Bradley, W. H., Shore phases of the Green River formation in northern Sweetwater County, Wyo.: U. S. Geol. Survey Prof. Paper 140, pp. 127–128, 1926.

WATER-LAID VOLCANIC ROCKS OF EARLY UPPER CRETACEOUS AGE IN SOUTHWESTERN ARKANSAS, SOUTHEASTERN OKLAHOMA, AND NORTHEASTERN TEXAS

By Clarence S. Ross, Hugh D. Miser, and Lloyd W. Stephenson

INTRODUCTION

Very few persons associate volcanoes with the flat land of the Gulf Coastal Plain of southwestern Arkansas, but for a number of years geologists have known that the "roots" of old volcanoes were present near Murfreesboro, in Pike County. They found here not only the rocks that once composed the craters of these volcanoes, but also the decomposed material filling their necks, which carries diamonds and is almost identical with the diamond-bearing earth of the great Kimberley mine of South Africa. Much of the material ejected by these volcanoes was in the form of volcanic ash, sand, and lapilli, which were thrown out by violent explosions and then widely distributed by wind and water.

The present paper deals with these and other volcanoes in Arkansas and with recent discoveries of material that was ejected from them. From the character of this material it has been possible to determine the geologic period in which the explosions occurred, the localities in Arkansas whence the material came, and the agencies by which it was distributed.

DISCOVERY OF ROCKS OF VOLCANIC ORIGIN IN THE WOODBINE AND TOKIO FORMATIONS

The igneous rocks of Arkansas were for many years believed to have been formed near the end of Cretaceous time.[1] Later evidence placed their time of intrusion between the Comanche (Lower Cretaceous) and Gulf (Upper Cretaceous) epochs.[2] The occurrence in the basal Gulf rocks in Arkansas of water-laid materials that have been derived from igneous rocks has been described by several geologists.[3] Recently discovered evidence indicates that volcanic eruptions accompanied by violent explosions took place near Murfreesboro, Ark., early in Gulf time.[4] The diamond deposits near Murfreesboro occur in the necks of the Cretaceous volcanoes. Yet the discovery of unquestionable volcanic ash and tuff in the Gulf series of southwestern Arkansas was not made until 1923. This discovery has led to the conclusion that much if not all of the water-laid igneous material previously found in the rocks of Gulf age was originally fragmental material that was ejected from volcanic vents.

The volcanic material was identified by Clarence S. Ross in the spring of 1923 during the examination of specimens submitted to the United States Geological Survey by J. N. Garner, of Nashville, Ark. In October, 1923, Miser studied deposits of volcanic material in the Gulf series of southeastern Oklahoma; in November and December, 1923, Ross and Miser made a field investigation of similar deposits in Arkansas; in 1924–1926 L. W. Stephenson studied them in Red River, Lamar, and Fannin Counties in northeastern Texas; in 1925 Miser, Stephenson, and C. H. Dane visited many exposures of the volcanic material in Arkansas, and later in 1926 they visited several exposures of it in northeastern Texas.

To Mr. Dane the authors of the present report extend their thanks for his cooperation and assistance both in the field and in the office. To Mr. J. N. Garner they wish to express their sincere appreciation of his cooperation in the field. He personally guided them to exposures of volcanic rocks in Arkansas that he had discovered both before and after he had sent the first specimens to the Geological Survey for identification.

In Arkansas and Oklahoma volcanic rocks of Cretaceous age are so far as known confined to the Woodbine and Tokio formations, but in Texas they are found in the Woodbine sand, Eagle Ford clay, Austin chalk, Taylor marl, and Navarro formation. The Woodbine formation is the basal formation of the Gulf series in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas. In Arkansas and in McCurtain County, Okla., it forms the lower part

[1] Branner, J. C., and Brackett, R. N., The peridotite of Pike County, Ark.: Am. Jour. Sci., 3d ser., vol. 38, pp. 50–59, 1889. Williams, J. F., The igneous rocks of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 2, p. 3, 1891.

[2] Glenn, L. C., Arkansas diamond-bearing peridotite (abstract): Geol. Soc. America Bull., vol. 23, p. 726, 1912. Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: U. S. Geol. Survey Bull. 540, pp. 541–545, 1914.

[3] Sterrett, D. B., [Diamonds in] Arkansas: U. S. Geol. Survey Mineral Resources for 1909, pt. 2, pp. 757–759, 1910. Miser, H. D., op. cit. Miser, H. D., and Purdue, A. H., Gravel deposits of the Caddo Gap and De Queen quadrangles, Ark.: U. S. Geol. Survey Bull. 690, pp. 22–24, 1918; Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Ark.: U. S. Geol. Survey Bull. 735, pp. 291–292, 1923.

[4] Miser, H. D., and Ross, C. S., op. cit., pp. 310–312; Econ. Geology, vol. 17, pp. 662–674, 1922; Smithsonian Inst. Ann. Rept. for 1923, pp. 261–272, 1925. Mitchell, G. J., Diamond deposits in Arkansas: Eng. and Min. Jour.-Press, vol. 116, pp. 285–287, 1923.

of the "Bingen sand" of Veatch, and the Tokio formation is the upper part of the "Bingen." In Arkansas and Oklahoma the Gulf series is separated from the Comanche series by a marked unconformity, and in places in Arkansas the Gulf series rests upon the truncated edges of steeply dipping Paleozoic rocks.

A short preliminary paper on the volcanic rocks in the "Bingen formation" of Arkansas and Oklahoma was recently published[5] and a brief description of the igneous rocks in the De Queen and Caddo Gap quadrangles, Arkansas and Oklahoma, is given in a report now in press.[6]

DISTRIBUTION OF THE VOLCANIC ROCKS

The volcanic rocks here described are exposed in an east-west belt of country about 150 miles long that lies near the northern margin of the Gulf Coastal Plain, in Texas, Oklahoma, and Arkansas. The exposures in Arkansas and in McCurtain County, Okla., occur in a strip of high land lying only a few miles south of the north boundary of the Coastal Plain. This strip is a southward-sloping cuesta to which Veatch[7] has applied the name "Lockesburg," from Lockesburg, Sevier County, Ark. (Veatch used the term "wold" instead of "cuesta," but of these two terms cuesta is in more general use at present.) The Lockesburg cuesta owes its form and altitude to the resistant character of the southward-dipping beds of gravel, tuff, and sand of the Woodbine and Tokio formations, and it is in general coextensive with the outcrops of these formations as shown on Plate 20. It ranges in width from several to many miles and extends from a point near Delight, Ark., west by south across Pike, Hempstead, Howard, Sevier, and Little River Counties into Oklahoma, where it descends into the bottom lands of Red River west of Idabel, McCurtain County. Within this distance of about 100 miles the cuesta is not continuous but is trenched by the wide alluvial valleys of Little, Cossatot, Saline, and Little Missouri Rivers, which run in a general southeasterly direction, and by the valleys of the small southward-flowing streams between the wide valleys. Owing to the extensive dissection of the cuesta by streams, its surface is rolling to hilly, and there are no large tracts of level country.

The north edge of the cuesta culminates at 600 to 700 feet above sea level, and its northward-facing escarpment is conspicuous, especially in Arkansas, where it rises 100 to 200 feet above the land at its foot.

[5] Miser, H. D., and Ross, C. S., Volcanic rocks in the Upper Cretaceous of southwestern Arkansas and southeastern Oklahoma: Am. Jour. Sci., 5th ser., vol. 9, pp. 113-126, 1925.

[6] Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles, Arkansas and Oklahoma: U.S. Geol. Survey Bull. 808, pp. 99-115, 1929.

[7] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 14-15, 1906.

The country that is underlain by the volcanic rocks of the Woodbine formation is known as "red-land" country and lies along the northern edge of the Lockesburg cuesta. (See pl. 18, *A*). On it in Arkansas are situated Highland, Corinth, Centerpoint, Horatio, and Cerro Gordo; in Oklahoma, Jadie, Goodwater, Odell, Shults, and Idabel.

The red-land country received its name from the prevailing bright-red color of its clayey soil and subsoil. In spite of its poor appearance the soil produces good crops, especially of peaches and other fruits. The red clay is derived by weathering from volcanic tuff and owes its fertility to the potash and other mineral ingredients supplied by the tuff.

In northeastern Texas the rocks containing the volcanic material occur in the northern parts of Red River and Lamar Counties, in a belt having a maximum width of 5 miles, and in the northwestern part of Fannin County. The Woodbine sand, of which these rocks are a part, does not form a cuesta here, for the rocks have been planed off by the terrace-forming processes operating in the valley of Red River. Most of the exposures occur in bluffs along Red River beneath a covering of terrace materials or along the sides of tributary valleys whose streams have cut down through the terrace covering.

ROCKS ASSOCIATED WITH THE VOLCANIC MATERIAL

GENERAL FEATURES

Most of the rocks in which the volcanic material is exposed are sedimentary, but some are of igneous origin. The igneous rocks include the four bodies of diamond-bearing peridotite near Murfreesboro, Ark.; a dike of ouachitite of possible Cretaceous age 7 miles east of Gillham, Ark.,[8] a diorite sill of Ordovician (?) age 4 miles north of Glover, in northern McCurtain County, Okla.[9]; quartz-orthoclase pegmatites of Carboniferous age, also in northern McCurtain County[9]; and granite of pre-Cambrian age on the west border of the mapped area (pl. 20) southwest of Atoka, Okla. Beds of volcanic ash and tuff found a short distance north of the Coastal Plain are of Silurian,[10] Devonian,[11] and Carboniferous age.[12]

The sedimentary rocks in the country adjoining the Coastal Plain on the north are of Paleozoic age, ranging from Cambrian to Carboniferous, though thin beds of Quaternary gravel and alluvium are found in places, especially along the streams. (See pl. 20.)

[8] Mitchell, G. J., Antimony in southwestern Arkansas: Eng. and Min. Jour.-Press, vol. 114, pp. 455-456, 1922; also letter dated Sept. 7, 1923.

[9] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 39-40, 48-49, 64-66, 210-212, 1923.

[10] Honess, C. W., op. cit., pp. 107-109.

[11] Idem, pp. 121-139.

[12] Miser, H. D., Mississippian tuff in the Ouachita Mountain region [abstract]: Geol. Soc. America Bull. vol. 31, pp. 125-126, 1920. Honess, C. W., The Stanley shale: Am. Jour. Sci., 5th ser., vol. 1, pp. 63-80, 1921; Oklahoma Geol. Survey Bull. 32, pp. 179-202, 1923.

The Paleozoic rocks consist mainly of shale, sandstone, limestone, novaculite, and chert and have a total thickness in west-central Arkansas and southeastern Oklahoma of about 25,000 feet. They were compressed into close westward-trending folds and were broken by many faults near the end of Pennsylvanian time, so that the dips are various but generally at high angles.

The sedimentary rocks of the part of the Coastal Plain in which the volcanic rocks here described occur are of Comanche (Lower Cretaceous), Gulf (Upper Cretaceous), and Quaternary age. They have been grouped into several formations, but only the Woodbine, Eagle Ford, and Tokio formations, which contain the volcanic deposits, are here briefly described. (See fig. 16.)

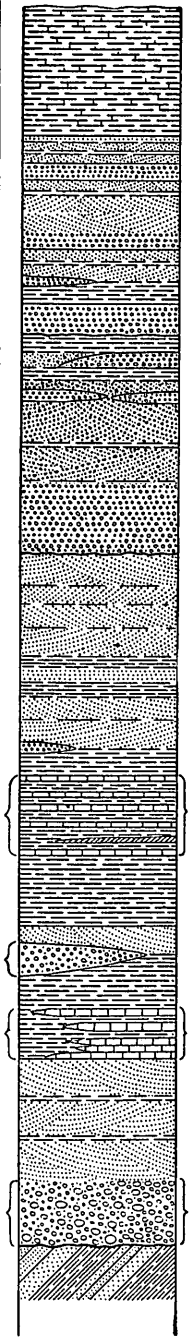
System	Series	Formation and member	Section	Thickness in feet	Character of rocks	Character of topography and soil
Cretaceous	Gulf (Upper Cretaceous)	Brownstown marl.		100±	Fossiliferous blue or gray calcareous clay.	Gently rolling area. Fertile black waxy soil.
		Tokio formation (upper part of "Bingen sand" of Veatch).		(100-300+)	Gravel; gray cross-bedded quartz sand; lignitic material; volcanic ash, light-colored and dark clays, some of which contain fossil plants.	Hilly areas. Gray sandy and gravelly soil; suitable for general farming and fruit culture.
		Unconformity				
		Woodbine formation (lower part of "Bingen sand" of Veatch).		0-350	Gravel; greenish volcanic tuff; red clay; and dark plant-bearing clay.	Rolling southward-sloping plateau. Gravelly clay soil suitable for general farming and fruit culture.
		Unconformity				
	Comanche (Lower Cretaceous)					All soils mentioned below are suitable for genera farming if they are fertilized and properly cared for.
					Gray cross-bedded sand in heavy beds; some clay.	Poor gray sandy soil
		Trinity formation. De Queen limestone member.		(60-72)	Fossiliferous limestone and an equal or greater amount of green clay. Gypsum and celestite near base.	Usually a yellowish-brown clay soil; in some areas fertile but in others poor.
				70-1,000+	Variegated clays.	
		Ultima Thule gravel lentil.		(0-40)	Pebbles less than an inch in diameter.	Dissected southward-sloping upland. Gravelly soi suitable for fruit culture
					Variegated clays.	
		Dierks limestone lentil.		(0-40)	Fossiliferous limestone and a smaller amount of green clay.	Fertile black clay soil.
					Gray cross-bedded sand in heavy beds; some clay.	Sandy gray soil.
		Pike gravel member.		(0-100)	Irregularly bedded pebbles and cobbles as much as 10 inches in diameter.	Dissected southward-sloping upland. Gravelly soil suitable for fruit culture.
		Unconformity				
Carboniferous		Atoka formation, Jackfork sandstone, and Stanley shale.			Shale and sandstone.	

FIGURE 16.—Generalized section of the oldest Cretaceous rocks exposed in Howard, Pike, and Sevier Counties, Ark.

Stratigraphic relations of Woodbine and Tokio formations in northeastern Texas, southeastern Oklahoma, and southwestern Arkansas to adjacent formations of Cretaceous age

[For a graphic representation of relations of some of the rocks see section on pl. 20]

Northeastern Texas	Southeastern Oklahoma	Southwestern Arkansas
Brownstown marl.	Brownstown marl. Present in McCurtain County but not exposed.	Brownstown marl (restricted).
		Unconformity
Blossom sand.	Tokio formation. Present in McCurtain County.	Tokio formation.[a]
Bonham clay.		
	Unconformity?	Unconformity
Ector tongue of Austin chalk; basal part is shaly clay and sand with "fish-bed conglomerate" at base. Thins out toward northeast in Fannin County.	Not present.	Not present.
Unconformity		
Eagle Ford clay. Thins out toward east in Lamar and Red River Counties.	Eagle Ford shale present only in Bryan County.	Not present.
Unconformity	Unconformity	
Woodbine sand.[a]	Woodbine sand[a] in Bryan and Choctaw Counties. / Woodbine formation[a] in McCurtain County.	Woodbine formation.[a] Thins out toward east.
Unconformity	Unconformity	Unconformity
Washita group.	Washita group. Thins toward east.	Washita group. Thins out toward east.
Fredericksburg group.	Goodland limestone.	Goodland limestone. Thins out toward east.
Trinity sand.	Trinity sand. Thins toward west by overlap of younger beds of formation over older beds of formation.	Trinity formation. Thins out toward east owing to unconformity at base of Woodbine and Tokio formations.

[a] Contains water-laid volcanic rocks.

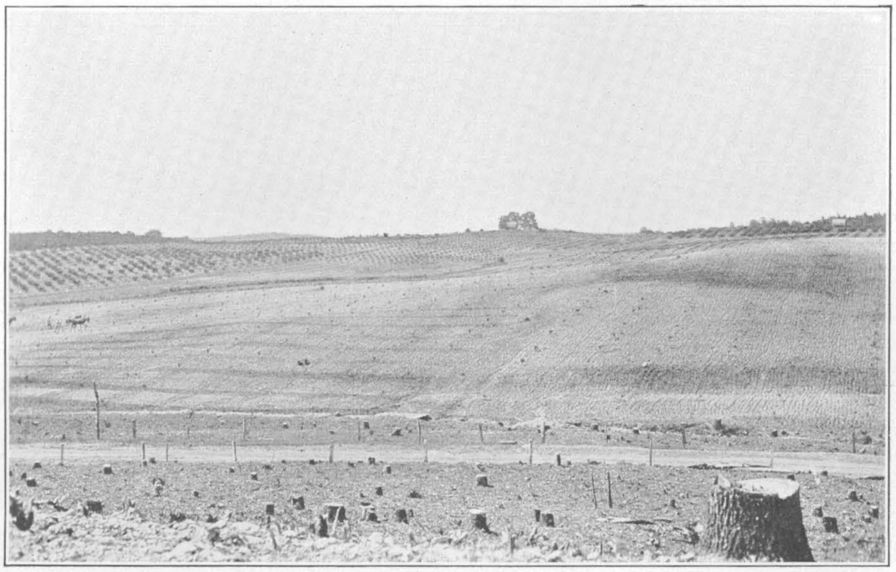
WOODBINE FORMATION

The Woodbine formation of the Gulf series (Upper Cretaceous) received its name from the village of Woodbine, in Cooke County, Tex. The formation consists mainly of quartz sand in northeastern Texas and in Bryan and Choctaw Counties, Okla., where it is appropriately called the Woodbine sand. Water-laid volcanic material is present in the Woodbine but increases in quantity toward the east in Texas, Oklahoma, and Arkansas and comprises a large part of the formation in McCurtain County, Okla., and in southwestern Arkansas, where the term formation is more suitable than the term sand. In Arkansas the Woodbine comprises the lower part of the "Bingen sand" of Veatch and later authors, and in McCurtain County, Okla., it comprises the lower part of the "Bingen formation" as shown on the geologic map of the State published in 1926 by the United States Geological Survey.

The area of outcrop is a belt extending from the valley of Little Missouri River in Pike County, Ark., west by south to the Oklahoma line, thence westward through the southern part of McCurtain, Choctaw, and Bryan Counties, Okla., and the northern parts of Red River, Lamar, Fannin, and Grayson Counties, Tex., and thence southward for many miles through central Texas. (See pl. 20.) In both southwestern Arkansas and McCurtain County, Okla., the Woodbine and the gravel and sand of the younger Tokio formation produce the southward-sloping Lockesburg cuesta, which is described on page 176.

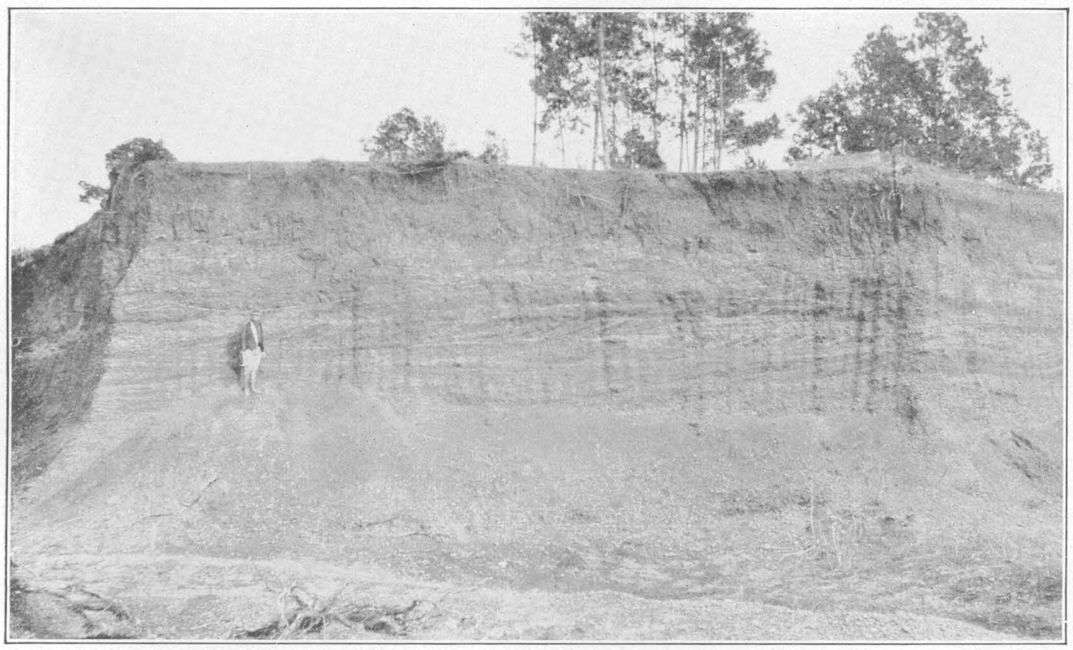
The formation has an estimated thickness of about 500 feet in southern Bryan and Choctaw Counties, Okla., and an apparent thickness of 625 feet in Fannin County, Tex., but it thins toward the east so that the thickness at most places in Arkansas is between 250 and 350 feet. It thins out on the west side of the valley of Little Missouri River, in Arkansas, and is not present east of this stream.

The formation has a southerly dip of perhaps 50 feet to the mile in most of the area shown on the accompanying map, though near the west end of the area it has been bent into a low anticline called the Preston anticline, whose axis extends southeastward through



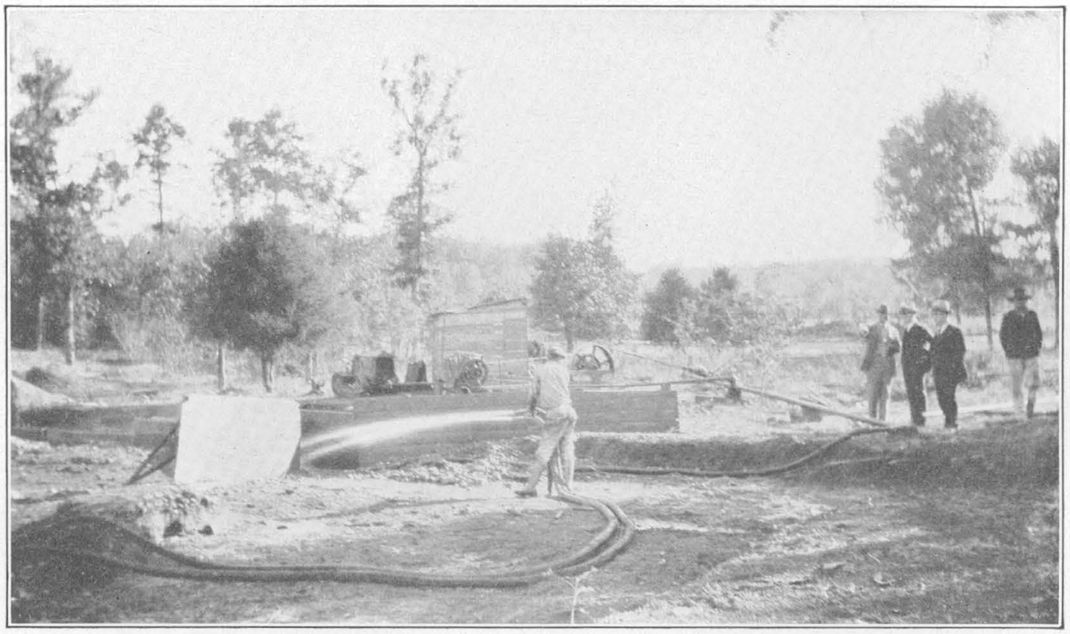
A. ROLLING "RED-LAND" COUNTRY ON LOCKESBURG CUESTA NEAR CORINTH, HOWARD COUNTY, ARK.

Underlain by gravel and tuff in the Woodbine and Tokio formations. Such country is especially adapted to growing peaches and other fruits. Photograph furnished by J. N. Garner

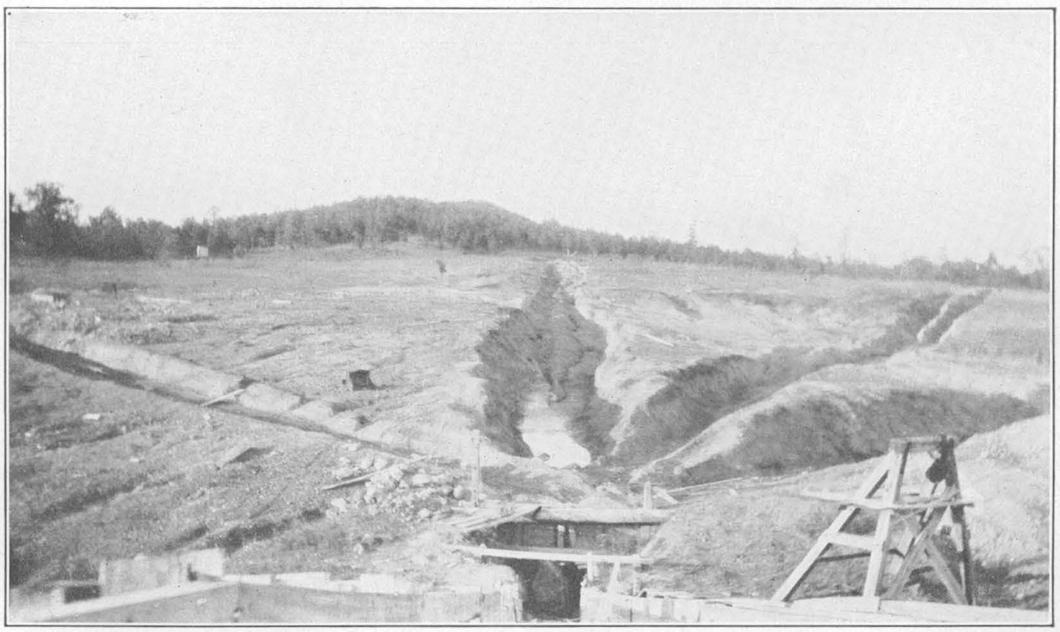


B. BASAL GRAVEL OF WOODBINE FORMATION IN GRAVEL PIT NEAR HORATIO, SEVIER COUNTY, ARK.

Cross bedding is conspicuous. Photograph by P. D. Torrey



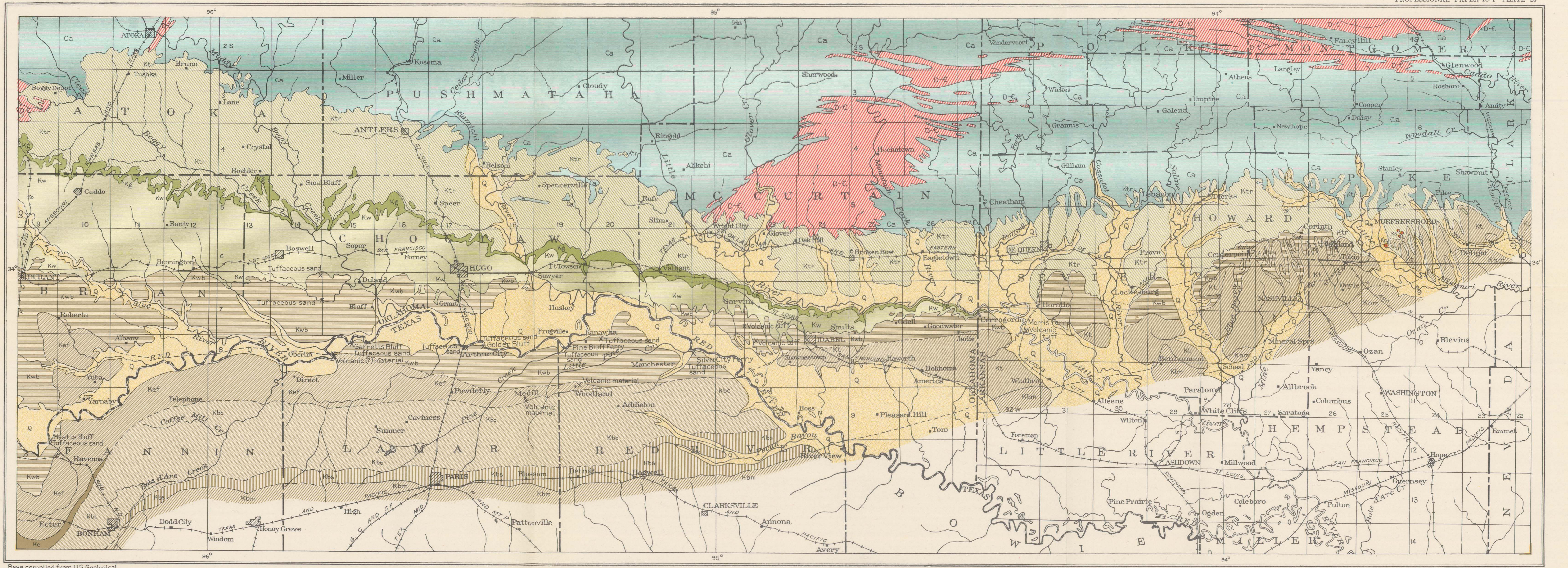
A



B

WEATHERED PERIDOTITE BRECCIA IN NECK OF CRETACEOUS VOLCANO NEAR MURFREESBORO, PIKE COUNTY, ARK.

Contains diamonds. *A* shows diamonds being mined by hydraulicking. In *B* the hill in the distance is partly capped by a mass of Paleozoic sandstone that was lifted and carried upward during volcanic activity



Base compiled from U.S.Geological Survey 1:500,000 maps

Geology compiled by authors from published and unpublished maps

A.Hoen & Co. Balto.

GEOLOGIC MAP OF PARTS OF ARKANSAS, OKLAHOMA, AND TEXAS,

WITH GENERALIZED STRUCTURE SECTION SHOWING THE RELATIONS OF THE COMANCHE SERIES AND THE LOWER PART OF THE GULF SERIES AND THE RELATIONS OF THE IGNEOUS AND VOLCANIC ROCKS

Scale 1:500,000

0 10 20 30 40 50 MILES

EXPLANATION

QUATERNARY

Q — Flood-plain and terrace deposits (*Partly represented*)

CRETACEOUS

Gulf series (Upper Cretaceous)

Kbm — Brownstown marl

Kbs — Blossom sand

Kbc — Bonham clay

Kt — Tokio formation (*Contains water-laid volcanic material in Arkansas*)

Ke — Ector tongue of Austin chalk

Kef — Eagle Ford clay

Kwb — Woodbine formation (*Consists mainly of quartz sand in northeastern Texas and Bryan and Choctaw Counties, Okla., but volcanic material in Woodbine in these areas increases in quantity toward east and comprises large part of formation in McCurtain County, Okla., and southwestern Arkansas. Best exposures of volcanic material in Texas and Oklahoma are shown on map.*)

Kp — Peridotite (tuff, breccia, and intrusive rock) in volcanic necks (*Near Murfreesboro, Ark.*)

Comanche series (Lower Cretaceous)

Kw — Washita group

Kg — Goodland limestone

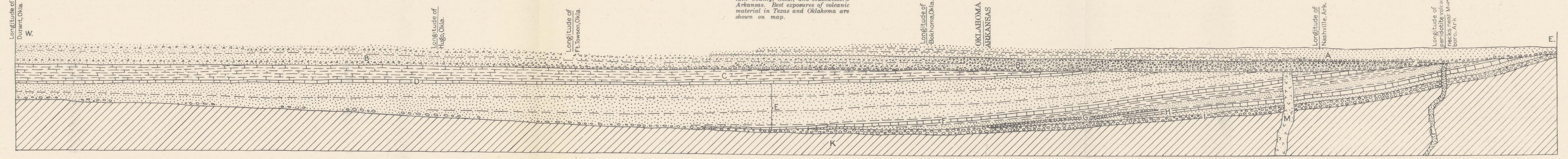
Ktr — Trinity formation

CARBONIFEROUS

Ca — Atoka formation, Jackfork sandstone, and Stanley shale (*Includes in northwest corner of area other formations of Carboniferous age*)

PRE-CARBONIFEROUS

D-Є — Devonian to Cambrian rocks (*Includes pre-Cambrian granite southwest of Atoka*)

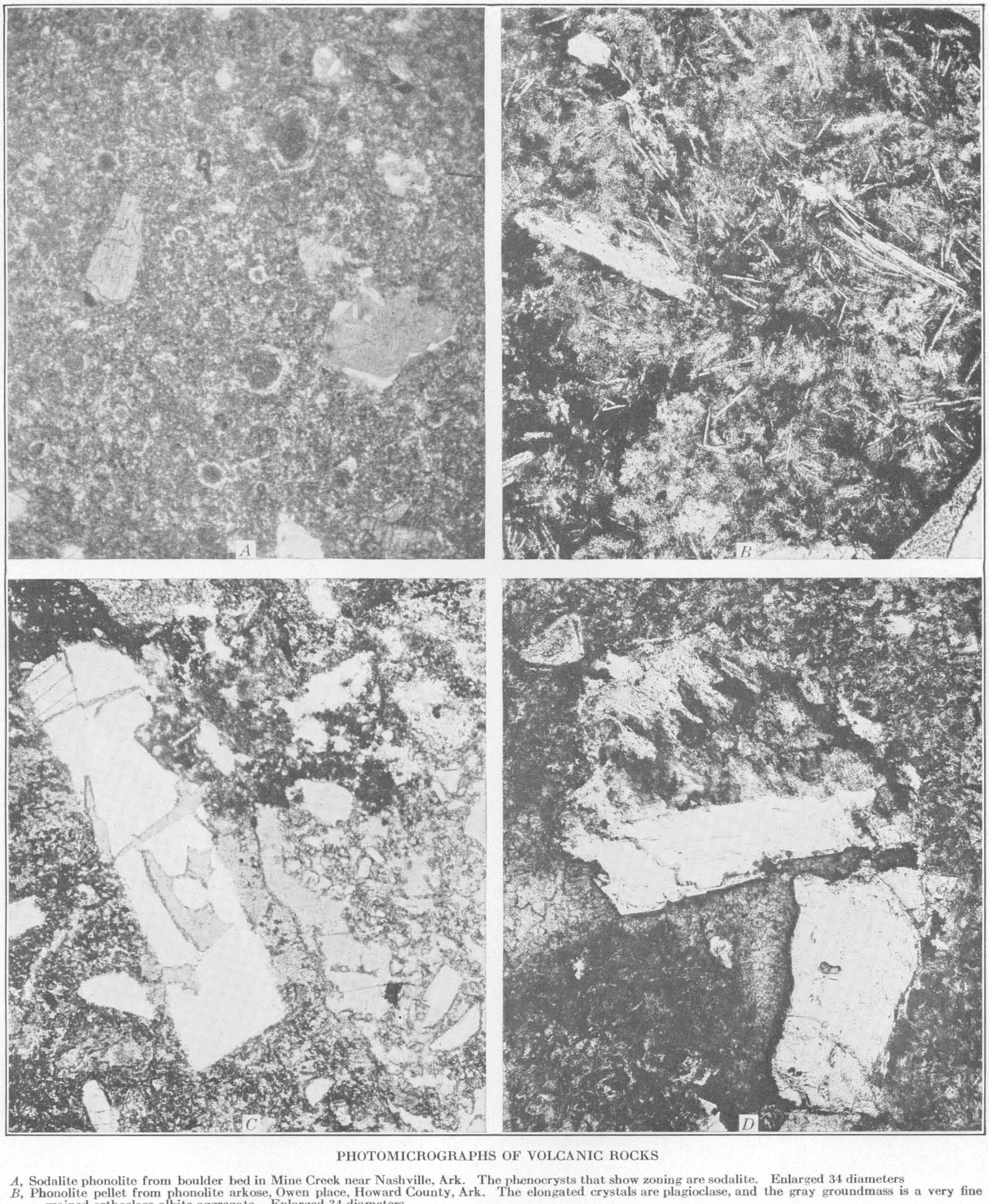


A Tokio formation, Upper Cretaceous; contains some water-laid volcanic tuff (indicated by triangular pattern)
B Woodbine formation, Upper Cretaceous; contains much water-laid volcanic tuff
C Washita group, Lower Cretaceous
D Goodland limestone, Lower Cretaceous
E Trinity formation, Lower Cretaceous:
F DeQueen limestone member
G Ultima Thule gravel lentil
H Dierks limestone lentil
I Pike gravel member
K Devonian, Silurian, Ordovician, Cambrian, and pre-Cambrian rocks
L Peridotite intruded in early Upper Cretaceous time
M Trachytic rock in supposed volcanic neck a few miles northwest of Nashville, Ark.

Vertical scale

0 1,000 5,000 FEET

Horizontal scale is same as that of map



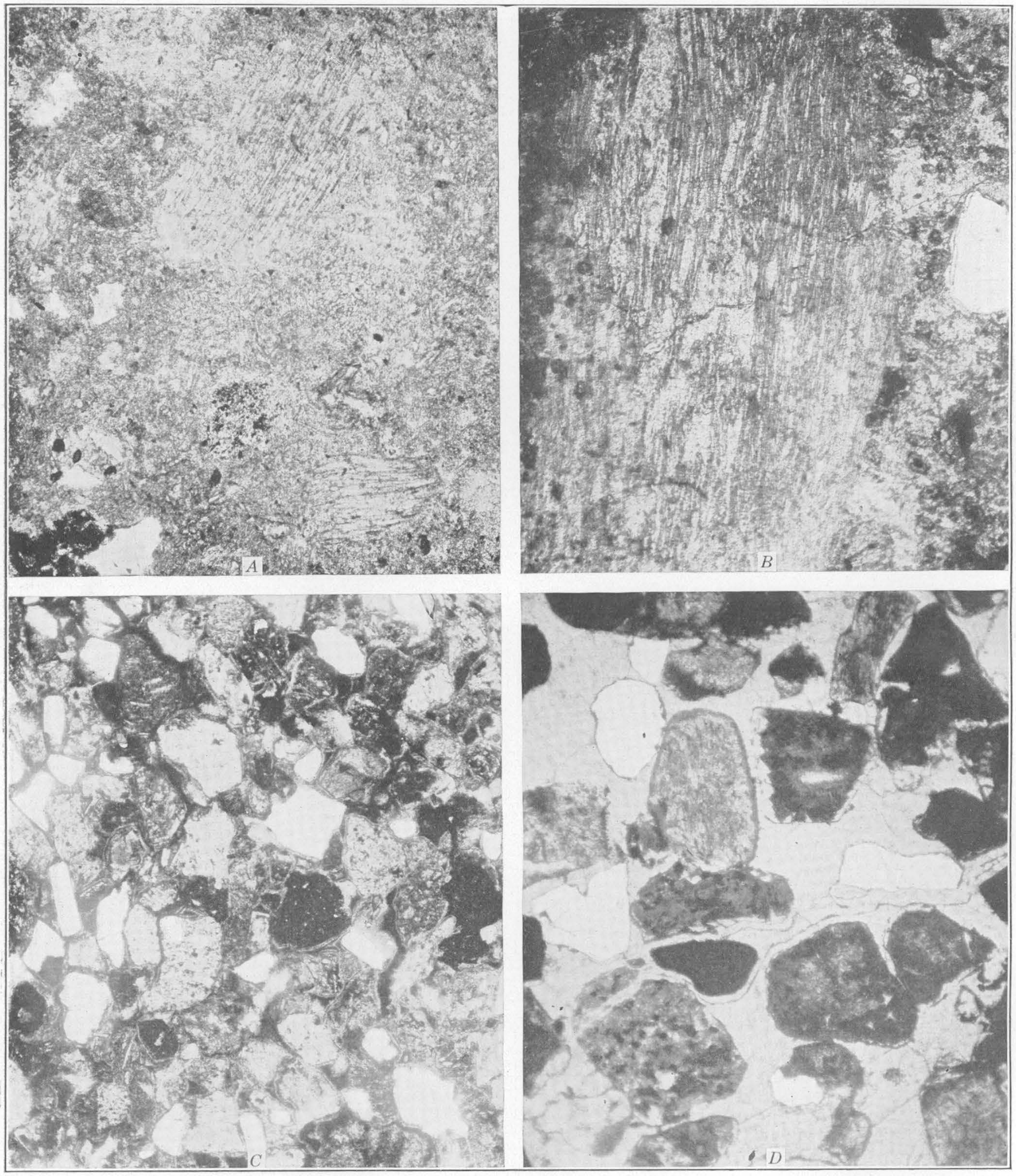
PHOTOMICROGRAPHS OF VOLCANIC ROCKS

A, Sodalite phonolite from boulder bed in Mine Creek near Nashville, Ark. The phenocrysts that show zoning are sodalite. Enlarged 34 diameters

B, Phonolite pellet from phonolite arkose, Owen place, Howard County, Ark. The elongated crystals are plagioclase, and the gray groundmass is a very fine grained orthoclase-albite aggregate. Enlarged 34 diameters

C, Orthoclase crystal partly replaced by calcite, Owen place, Howard County, Ark. Enlarged 48 diameters

D, Orthoclase crystal partly replaced by calcite, Owen place, Howard County, Ark. The area with fingerlike extensions has the same optical orientation as the white central mass, and the dark area between is calcite. Enlarged 28 diameters



PHOTOMICROGRAPHS OF VOLCANIC ROCKS

A, Volcanic tuff entirely replaced by calcite but preserving the structure of glassy pumice, Owen place, Howard County, Ark. Enlarged 54 diameters
B, Part of a large glassy pumice fragment entirely replaced by calcite, Owen place, Howard County, Ark.
C, Phonolite tuff from Prothro dome, Bienville Parish, La. Pure white areas are feldspar; light spotted ones are quartz or novaculite, and darker ones with white elongated inclusions are phonolite. The interstitial material is glauconite. Enlarged 33 diameters
D, Phonolite tuff from Prothro dome, Bienville Parish, La. White angular areas are feldspar; rounded one, quartz; gray ones, phonolite pellets and partly replaced augite grains above and to the right of the center. Groundmass calcite. Enlarged 54 diameters

the village of Ector, Fannin County, Tex., and it has also been bent into a syncline whose axis runs northwestward through Yuba, Bryan County, Okla.

The Woodbine rests upon the truncated edges of all the Comanche formations—the youngest subjacent formations to the west and the oldest to the east—and at the east edge of the area shown on the map (pl. 20) it rests upon steeply dipping beds of sandstone and shale of Carboniferous age. A marked angular unconformity therefore separates the Gulf series from the Comanche series in southwestern Arkansas and southeastern Oklahoma. (See section on pl. 20.)

The water-laid volcanic material in the Woodbine consists of tuffaceous sand in northeastern Texas and in Bryan and Choctaw Counties, Okla., and of tuff in McCurtain County, Okla., and in southwestern Arkansas. The sand and tuff, which are described in detail on pages 180 to 200, occur in widespread beds that attain a thickness of 125 feet or more. These materials are mostly cross-bedded, soft, grayish and olive-gray, are composed of coarse and fine grains of volcanic rocks, and are for the most part unconsolidated but in places cemented by calcite. The calcite-cemented masses are lenticular or spherical.

Besides tuffaceous sand the Woodbine of northeastern Texas and of Bryan and Choctaw Counties, Okla., includes irregularly bedded quartz sand, which was deposited in shallow marine and brackish water. Interbedded with the sand are films, lenses, and layers of clay, which in places attain a thickness of 25 feet or more.

In Arkansas and in McCurtain County, Okla., there is a bed of gravel at the base of the formation and beds and lenses of gravel higher in the formation. (See pl. 18, *B*.) The gravel beds are thickest and most extensive in Arkansas, where the basal bed is continuous and attains a thickness of about 60 feet. The beds of gravel consist mostly of pebbles of novaculite, but in addition there are in Arkansas rather extensive deposits of pebbles of igneous rocks in the tuff, which overlies the basal gravel. Some of the larger igneous pebbles occur in the thick bed of gravel at the base of the formation, but most of them occur in thin beds and lenses of gravel interstratified in the tuff. Many small pebbles are, however, disseminated through the tuff. Clay is found at some places in beds many feet thick interbedded with the volcanic tuff. It is gray to brown, is laminated, and contains at places fossil leaves, some of which were collected at a locality on Mine Creek 4 miles north of Nashville, Ark.

EAGLE FORD CLAY

In western Lamar County and in Fannin County, Tex., the Woodbine sand is overlain, probably unconformably, by the Eagle Ford clay, which consists typically of 300 or 400 feet of dark, more or less bituminous clay carrying calcium carbonate concretions, in part septarian, some of which are fossiliferous.

The Eagle Ford is represented on Plate 20 as extending as a rapidly narrowing band eastward from Lamar County into Red River County in the vicinity of Woodland, but the beds thus mapped are not typical of the Eagle Ford clay. They consist of 50 or 60 feet of fine to coarse marine sand, a central band of which contains a small percentage of water-laid volcanic material. At the base of this sand just north of Woodland is a bed of conglomeratic sand, 1½ feet thick, containing many waterworn pebbles of novaculite reaching a diameter of 1 inch and reworked chunks of soft reddish sandstone. The Eagle Ford age of the sands near Woodland has not been satisfactorily established, and indeed there is some question as to whether they may not represent the basal part of the deposits of Austin age (Bonham clay) which overlie them within a mile south of Woodland. (See pp. 196–197.) The beds exposed within 4 or 5 miles north of Woodland are mostly sand and sandstone and are of Woodbine aspect, but future studies may show that they are in part of Eagle Ford age.

TOKIO FORMATION

The Tokio formation takes its name from the village of Tokio, at the northern edge of Hempstead County, Ark. The deposits when first defined by Miser and Purdue were described as the "Tokio sand member of the Bingen formation." Recent field work by Stephenson and Dane, in which Miser cooperated for short periods, has shown that an unconformity occurs at the base of a thick gravel bed immediately underneath the "Tokio sand member of the Bingen." It has also shown that the part of the "Bingen" below this gravel bed represents the Woodbine sand of Texas. As a result of this work and of a study of the fossils by Stephenson, the following changes in names have been made: The name "Bingen" has been discontinued; the lower part of the "Bingen"—the part below the unconformity—is called the Woodbine formation; and the "Tokio sand member of the Bingen" is now called the Tokio formation, though the lower limit of the new formation is extended so as to include the thick gravel at whose base there is an unconformity. The Tokio formation as thus defined has a basal gravel like the Woodbine, and each formation has an unconformity at its base. The formation in Arkansas rests upon lower and lower rocks toward the east—first upon the truncated edge of the Woodbine formation, then upon successive parts of the Trinity formation, and next upon the steeply dipping rocks of Paleozoic age. (See structure section on pl. 20.)

The Tokio formation is exposed in a belt extending west by south across several counties in southwestern

Arkansas and thence into McCurtain County, Okla., at whose southern border the belt of exposure is terminated by alluvium and terrace deposits of Quaternary age along Red River. The belt of exposure is not continuous but is broken by bands of alluvium and terrace gravel along Little Missouri, Saline, Cossatot, and Little Rivers and other streams that cross it. The belt ranges in width from a few miles to about 12 miles and narrows eastward in consequence of the apparent thinning of the formation in this direction. The thickness is about 300 feet in the area west of Nashville, Ark., and is less east of Nashville.

The formation contains water-laid igneous materials near Murfreesboro, Pike County, Ark. These include thin beds that appear to be peridotite tuff and also include beds of kaolin that is apparently altered volcanic dust. These volcanic materials are described on pages 186 and 187. The formation is, however, composed largely of light to dark gray clay and gray sand that weathers yellowish and reddish. In addition there is much gravel in Arkansas, the thickest bed of which is at the base. The gravel is composed of well-rounded pebbles consisting of quartz and novaculite of many colors and ranging in size from that of a pea to a diameter of about 6 inches. The dark clay contains many invertebrate fossils, and some of it contains identifiable fossil plants. The proportions of clay and sand change both vertically and horizontally in the formation.

CHARACTER OF VOLCANIC ROCKS

GENERAL FEATURES

Most of the tuff occurs in the Woodbine formation. The main bed of volcanic material overlies the basal gravel of the formation and attains a thickness of 125 feet or more in the area lying between Center Point and Nashville, Ark. It consists of mineral grains, rock fragments, and pebbles in a claylike matrix.

The best exposures of volcanic material in Arkansas are on and near Mine Creek, Blue Bayou, and other streams near Center Point and Nashville. (See fig. 17.) Near Blue Bayou Church, 4 miles south of Center Point, the principal mineral in the sand bars of Blue Bayou is orthoclase in glistening transparent grains that have been derived from near-by exposures of tuff. The best exposures in Oklahoma are near Odell and Garvin; there the tuff is characterized by the occurrence of "black sand" and limonitic "buckshot" in the gullies. In Arkansas and Texas these minerals are not abundant enough to be conspicuous in gullies.

In northeastern Texas water-laid tuffaceous material, the westward extension of the tuffaceous beds of the Woodbine of Arkansas, forms a considerable part of the sand of the Woodbine formation, especially in the upper beds.

Coarse tuffaceous sand containing notable amounts of volcanic materials has been examined at six localities (pl. 20), which are alined in an approximate east-west direction in the northern parts of Red River and Lamar Counties, as follows: At Silver City Ferry, 17 miles north of Clarksville, at a locality 2 miles east of Kanawha, and at Pine Bluff Ferry, 4½ miles north of Woodland, in Red River County; at Golden Bluff, 3 miles east of Arthur City, at the bluff near Arthur City, and at Garretts Bluff, 13 miles west of Arthur City, in Lamar County. Similar coarse tuffaceous sand in approximately the same stratigraphic position has been observed at Hyatts Bluff, 5 miles northwest of Ravenna, Fannin County. The locality east of Kanawha in Red River County has yielded large typical specimens of *Ostrea soleniscus* Meek, a characteristic Woodbine species. Smaller, less typical specimens, probably belonging to the same species, occur at Golden Bluff, in Lamar County, at a horizon 30 feet above the top of the main bed of tuffaceous sand. (See pls. 25–27.)

Volcanic material makes up a small percentage of a sandstone of questionable Eagle Ford age in the vicinity of Woodland, in the northwestern part of Red River County, and a similar slightly tuffaceous sandstone occurs at Medill, in the northeastern part of Lamar County. These localities are between 4 and 5 miles south of the main east-west belt of tuffaceous sandstone, and on the assumption that the regional dip of the beds toward the south is not less than 50 feet to the mile, this upper tuffaceous bed should be 200 feet or more stratigraphically above the main tuffaceous bed. Other beds of tuffaceous material may occur between the main bed and the uppermost bed, but this has not yet been demonstrated. At Woodland and Medill the tuffaceous sandstone is immediately overlain by the Bonham clay, which belongs stratigraphically above the Eagle Ford clay.

A sandstone containing a small percentage of tuffaceous material was observed in a bluff on Red River, 1½ miles north of Ragtown, in the northwestern part of Lamar County. This sandstone lies near the top of the Woodbine formation about 12 feet stratigraphically below the base of the Eagle Ford clay, which is well developed in this area.

The tuffs and tuffaceous sands of southwestern Arkansas, southeastern Oklahoma, and northeastern Texas were for the most part deposited in shallow water and under the influence of strong currents. They are mixed in various proportions with detrital material derived from the Paleozoic rocks on the north, and parts of the tuffs themselves were reworked and redeposited. All this has resulted in a very intimate mixing of the various types of volcanic and detrital materials and an obscuring of the volcanic history. The geologic study is still further complicated by an intense alteration of the glassy tuffs, which has left them in the form of clay beds. Nevertheless some layers in the tuffs, especially in the vicinity of Nashville, Ark., are composed of volcanic débris that shows little mixing of the volcanic rocks, and this has made possible a recognition of the principal rock types and rock textures that have contributed to the formation of the volcanic beds of the region.

The volcanic material that occurs in greatest volume and with the widest distribution is in the form of are probably a finely crystalline phase derived from the same magma that formed the glassy tuff. Accompanying these materials are crystal grains, which represent the phenocrysts that were ejected along with the tuff.

LITHIC PHONOLITE TUFF AND SAND

The most widely distributed volcanic material occurs in the form of small rounded rock pellets that average

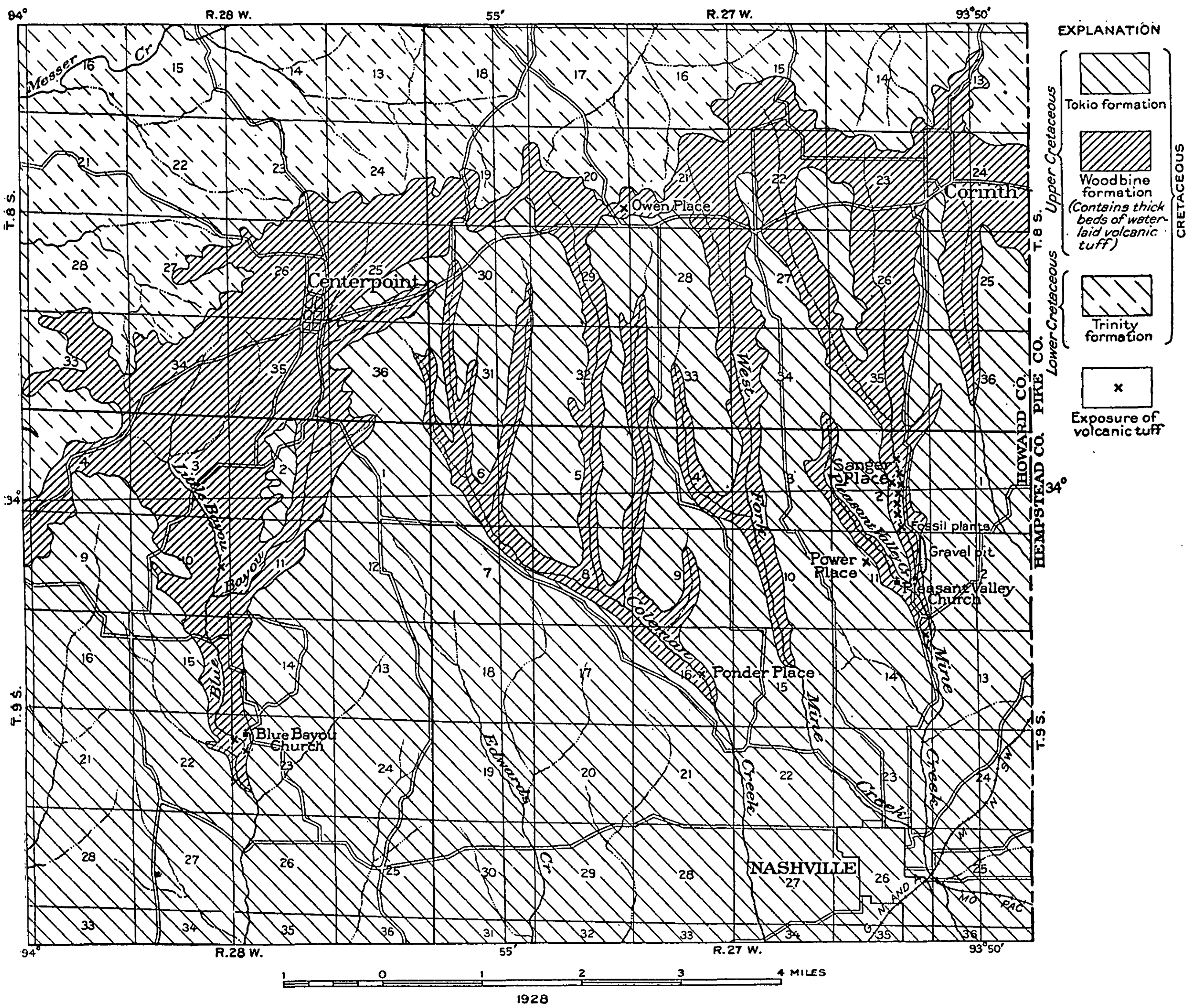


FIGURE 17.—Map of part of Howard County, Ark., showing the surface distribution of the volcanic deposits of the Woodbine formation

rounded lithic rock grains that average between 0.5 and 1 millimeter in diameter. Interbedded with the tuff are beds of gravel and boulders, which are composed predominantly of quartz and novaculite but which locally contain well-rounded boulders of the same volcanic rock types as the material in the lithic tuff.

Near Nashville are extensive beds of material that was originally glassy pumiceous tuff. Associated with this are angular lithic tuff and rock fragments that

0.5 to 1 millimeter in diameter. The color of the unweathered rock is dark olive-green to dark gray-green. On weathering the material assumes various shades of yellow and brownish red. Beds made up almost wholly of fragments of volcanic rock have been recognized in a few localities, and this material may be called lithic tuff, but more commonly the fragments of volcanic rock are mixed with some grains of quartz and novaculite, and this material is more correctly described as tuffaceous sand. (See pl. 22, *C*, *D*.)

The volcanic rock structure is clearly recognizable in all thin sections, even in the rocks that have completely lost their original minerals through kaolinization. The rounded rock pellets are characterized by a single volcanic rock type, and the only difference is a slight one in texture and mineral proportions. (See pl. 21, *B*.) They all show a trachytic structure, and many have a parallel arrangement of the slender plagioclase crystals of the ground mass. The rock of the pellets is all of very fine grain, and the crystals of the groundmass range from 0.02 to 0.3 millimeter in greatest length. Anhedral orthoclase is abundant, and nephelite is often recognizable despite the fineness of grain. The rock grains rarely carry phenocrysts, as these were not abundant and were usually set free by the explosive violence that pulverized the rock.

The mineral grains associated with the lithic phonolite tuff and sand are orthoclase, plagioclase, augite, hornblende, zircon, apatite, and magnetite. Titanite, biotite, and black spinel are found in some beds, but it seems probable that these minerals were derived from the admixed pumice tuff and not from the phonolite. Brown tourmaline, garnet, and staurolite, which are characteristic of metamorphic rocks, are present in small amounts and are associated with the typical minerals of igneous rocks in the tuff. Secondary minerals that have developed in the beds after their deposition are siderite, calcite, pyrite, glauconite and phosphatic granules.

PHONOLITE COBBLES

Well-rounded cobbles and pebbles are found locally in the beds and lenses of gravel associated with the tuff and are especially abundant on Mine Creek, near Nashville, Ark. (See fig. 17.) Few pebbles in the tuff are more than 2 or 3 inches in diameter, but the cobbles in the gravel reach 9 or 10 inches in diameter.

The rock type that makes up 75 per cent or more of the cobbles is the same as that forming the phonolite pellets and is represented by the analysis on page 187. The rock structure is shown in Plate 21, *B*. The rock is dark gray with a very fine grained groundmass and phenocrysts of sodic plagioclase and orthoclase forming less than 5 per cent of the mass. Augite is still rarer and is seldom seen in a hand specimen. The microscope shows a rock with trachytic structure and groundmass crystals which range from 0.02 to 0.3 millimeter in length and many of which have a common orientation. The range in mineral composition of the phonolite is as follows:

Mineral composition of phonolite

	Per cent
Plagioclase	50–65
Orthoclase	30–40
Nephelite	5–15
Pyroxene or hornblende	2–15
Magnetite	3
Apatite	0.5

The orthoclase forms anhedral crystals between the euhedral plagioclase crystals. The nephelite is in part anhedral and in part euhedral and forms very small interstitial crystals. Augite occurs as phenocrysts and in the groundmass, but forms less than 3 per cent of the rock in the predominant type of phonolite. In a few specimens it is more abundant and may reach 15 per cent. Green or brown hornblende is a rare constituent. One specimen examined was similar to the predominant type of rock but contained a small proportion of sodalite. (See pl. 21, *A*.)

Nearly all the phonolite from the gravel and most of the rock pellets in the tuff are very fine grained and commonly show flow structure or orientation of the feldspar grains and so have a structure characteristic of volcanic rocks, but a rare rock type that occurs in the boulders has the texture of an intrusive. This is a fourchite with abundant augite and nephelite.

PUMICE TUFF

In the vicinity of Nashville, Ark., are extensive beds composed partly or almost wholly of materials that originally formed a tuffaceous volcanic pumice. This pumice has completely lost its glassy texture and is most commonly represented by bentonitic claylike material, but locally concretionary calcium carbonate has cemented the pumice fragments into boulderlike forms that have escaped this type of alteration.

The predominant color in the claylike material is gray to light blue-gray where unweathered; after oxidation it is yellow. The boulders with calcite cement are pale buff. The pumice fragments differ widely in size, ranging from 0.1 to 50 millimeters in diameter. The pumice has a fibrous structure that resulted from the presence of very fine, closely spaced elongated or flattened vesicles separated by very thin glass walls. In the claylike beds consolidation has slightly compressed and flattened the altered pumice fragments and eliminated the vesicles, but the fiberlike pumiceous texture has been perfectly retained. (See pl. 22, *B*.) In hand specimens the clay has little resemblance to tuff, but thin sections exhibit the tuff structure as perfectly as the original glass.

The pumice beds contain mineral grains representing phenocrysts that were set free from their glassy matrix by the explosive force of the eruptions that produced the pumice itself. Most of these crystals are euhedral or have one end perfect and the other fractured, but in some beds the crystals are strongly etched, though none of them are well rounded by transportation and abrasion.

The minerals are orthoclase, biotite, titanite, magnetite, zircon, apatite, and black spinel. Augite and hornblende possibly occur in very small amount but are probably derived from the phonolite and not from the trachyte. Orthoclase is very abundant and may form as much as 25 per cent of the rock, but the other minerals are rare and form less than 1 per cent. The metamorphic rock minerals tourmaline, garnet, and staurolite occur in small proportions in tuff of all types. Phosphatic grains and glauconite were probably formed during deposition, and siderite, calcite, and pyrite have developed after deposition.

LITHIC TRACHYTE ROCK FRAGMENTS

Crystalline rock fragments are associated with the pumice tuff and in some localities form as much as 50 per cent of the material. The pumice and the trachyte always occur together and carry the same minerals, and it seems evident that one is the glassy and the other the crystalline phase of the same igneous magma. They show little sorting, large and small rock fragments occurring together. In this they differ from the phonolite rock fragments, which are well rounded and usually well sorted. The pumice and orthoclase trachyte show much less mixing with foreign material than the phonolite, and some beds are composed of pure igneous material.

The orthoclase trachyte rock fragments range from 1 to 20 millimeters in diameter and are angular or knotted. They are white or light gray and are composed of phenocrysts of orthoclase in a groundmass that is a very fine grained aggregate of anhedral feldspar. Euhedral orthoclase phenocrysts are abundant in some fragments and nearly absent in others. Biotite, titanite, and black spinel in fine euhedral crystals are very sparsely present.

DETAILED DESCRIPTION OF MINERALS

IGNEOUS ROCK MINERALS

Orthoclase.—The pumice and lithic tuff of trachytic composition contain abundant orthoclase, and the lithic phonolite tuff and sand contain small proportions. The orthoclase crystals range from 0.3 to 3 millimeters in diameter but average about 1.5 millimeters. Most of the crystals have been fractured, probably by the explosive eruptions, but most of them show one or more perfect crystal faces, and Carlsbad, Manebach, and Beveno twins are not rare. Some crystals have been etched, as described on page 185 and pictured in Plate 21, *C, D*, and there is practically no rounding of the fragments of tuff near Nashville, Ark., but in other areas there is slight rounding of some of the crystals. Nearly all the crystals show great clearness, but a few have inclusions of glass. The optical axial angle is small in most crystals and nearly uniaxial in many, and these characters indicate that the mineral is the sanidine variety of orthoclase.

Augite.—In the phonolite tuff augite is the second most abundant mineral, but in the pumice and trachyte tuff it is rare or absent. Most of the crystals are pale bottle-green in millimeter-sized grains and colorless in thin section, but a few are faintly lavender in thin section. Nearly all have the peculiar cockscomb termination shown in Plate 24, *A*. The origin of these forms is discussed on page 184.

Biotite.—Dark-brown euhedral flakes of biotite are present in the pumice and trachyte tuff but form less than 1 per cent of the rock.

Hornblende.—Many separations of heavy minerals have been made by means of heavy solutions, and slender hornblende crystals are always present, but they form only a fraction of 1 per cent of the tuff. They are brilliant black in millimeter-sized grains and usually olive-green in thin section, but a few have the reddish-brown color of basaltic hornblende. The crystals reach 3 or 4 millimeters in length and most of them are euhedral, but some of those separated from the tuffaceous sand of Oklahoma and Texas are slightly rounded by abrasion, although none of them show etching.

Titanite.—All the igneous rocks of the region contain titanite, but it is especially abundant in the pumice and trachyte tuff. It forms brilliant golden-yellow crystals that average less than 1 millimeter in diameter. Most of them are perfectly euhedral and show almost no fracturing or rounding by attrition, but a few are slightly etched.

Magnetite and spinel.—Magnetite is present in all the tuffs, and black spinel is most abundant in the pumice and trachyte tuff. Both have very sharp euhedral faces, but the crystals are usually pitted or incompletely developed. The magnetite can be separated from the spinel with a hand magnet, and then it is noticed that the spinel has much more brilliant black faces than the magnetite. The spinel is opaque except in exceedingly fine grains.

Apatite and zircon.—Apatite and zircon are present in all the heavy minerals that have been separated. The apatite is usually colorless, but a few grains are a fine blue. The zircon is colorless to deep lavender-pink.

SECONDARY MINERALS

Siderite.—Small grains of siderite have been formed in most of the tuff beds, probably before the calcite, for small crystals of siderite are completely inclosed in calcite. Siderite is found in the calcite concretions in the phonolite, in uncemented phonolite tuff and tuffaceous sand, and in the bentonitic material derived from the pumice. It most generally forms small euhedral rhombs, but also some knotlike pellets and a few well-rounded radially fibrous grains similar to grains of sphaerosiderite. A few boulder-like masses several inches in diameter are composed almost entirely of siderite. The color is yellow to reddish brown, and the index of refraction indicates that much of the material is nearly pure iron carbonate.

The siderite grains weather out of the tuff and become oxidized to limonite. These grains become concentrated by flowing water and form accumulations of shotlike grains in the steam beds throughout the region.

Calcite.—The tuff and tuffaceous sand of Arkansas contain concretions cemented with calcite that reach a maximum diameter of several feet. In the Texas and Oklahoma areas some beds are completely cemented with calcite, and the same relation is shown in the Louisiana localities that contain tuff identical in character with that of Arkansas, Oklahoma, and Texas. The calcite commonly forms large crystals, some of them 4 to 5 centimeters in diameter, that inclose large numbers of mineral and rock grains.

Pyrite.—Small rounded crystalline aggregates and octahedrons of pyrite have been formed abundantly in some of the tuff beds subsequent to their deposition.

Phosphatic grains.—Small rounded grains of phosphatic material were probably formed together with the marine type of glauconite on the sea bottom during the deposition of the beds.

Glauconite.—The tuff in some localities, especially that from the Prothro salt dome, Bienville Parish, La., contains rounded glauconite grains. These are bluish green, are composed of the usual aggregate of overlapping crystal plates, and were probably formed on the sea bottom. Most of the tuff beds of the phonolite type contain some proportion of a yellowish-green mineral, with a habit entirely dissimilar to that of the normal glauconite. This mineral has developed in the tuff since its deposition, as it has replaced augite and phonolite grains with various degrees of completeness and has slightly replaced calcite. It forms narrow zones around all mineral and rock grains in many beds of the phonolite tuff and is the cause of the green color in most of these beds. It forms radial zones of a micaceous mineral with a high birefringence and a mean index of refraction of about 1.62. Qualitative chemical tests show the presence of essential potash and indicate that the material is glauconite or possibly celadonite.

MINERALS CHARACTERISTIC OF METAMORPHIC ROCKS

Nearly all crops of heavy minerals separated from the tuff contain very small proportions of minerals that are characteristic of metamorphic rocks. The most generally distributed of these is brown tourmaline, but pale-pink garnet and staurolite are occasionally seen. Some fragments of these minerals are rounded, but many are sharply angular, and much of the tourmaline is euhedral. There is no direct evidence as to the source of these minerals, but it is possible that deeply buried metamorphic rocks were shattered and small quantities of their mineral components carried to the surface together with the normal volcanic material by the violence of the volcanic eruptions. This supposition is supported by the presence at the diamond mines near Murfreesboro, Pike County, Ark., of rather large blocks of Paleozoic sandstone that are believed to have been blasted from their position and carried to the surface, and fragments of norite that must have been derived from some deep-seated source have also been recognized in rock from the same locality. (See pl. 19.)

REPLACEMENT OF MINERALS SUBSEQUENT TO SEDIMENTARY DEPOSITION

The augite grains from all the tuff beds show multiple terminating pyramids that produce the cockscomb-like habit shown in Plate 24, *A*. Calcite-cemented concretions have been formed in the tuff bedsof Arkansas subsequent to their deposition, and in parts of Texas and at the Prothro salt dome, La., the beds are completely cemented by calcite. Thin sections of tuff from the Owen place, Ark. (fig. 17), and the Prothro dome give a clue to the mode of formation of the augite crystals with the cockscomb habit. In many localities of the region a film of glauconitic material was deposited around each grain of rock or mineral soon after its deposition. Thus the original form of the augite crystals was preserved. Later the augite was partly replaced by calcite or etched by solutions that permeated the beds. In their present form the augite grains show each a dark zone of glauconitic material that marks the original boundary of the crystal; within that is a zone of calcite that represents replaced augite; and the core is perfectly fresh augite with cockscomb habit. (See pl. 23, *C*.) Not uncommonly the replacement has progressed so far that two or more completely isolated augite areas that are in uniform optical orientation have developed from a single original grain, as shown in Plate 23, *B*. The multiple terminations were not present on the original augite grains and have developed entirely as a result of secondary processes. Most of the tuff beds in the Arkansas area do not have an interstitial cement of calcite, but in these the augite grains also show the cockscomb habit. It is evident that carbonate-bearing waters were present in all the beds of the Woodbine formation, and it seems probable that these were capable of corroding and etching augite. In many of the Texas and Oklahoma localities the replacement of augite is complete, and the characteristic form of the replaced crystal is all that remains to indicate that augite was once present. The pyroxene has been altered to glauconite after partial replacement by calcite, and interstitial glauconite and films of glauconite around mineral grains are characteristic of several localities. One of these grains is pictured in Plate 24, *D*. All these changes took place only after the deposition of the material, and they present abundant evidence that glauconite is not necessarily formed on the sea bottom but can result from the replacement of preexisting minerals.

Augite crystals with the cockscomb habit have been observed in material from northern New Mexico and Montana and are illustrated in Plate 24, *B*, *C*. Those from Montana were slightly rounded before the secondary crystal faces were developed.

Most of the orthoclase crystals show euhedral faces, but a few have been embayed and replaced by calcite, as shown in Plate 21, *C*, *D*.

All the other minerals of igneous rocks are unaltered and unreplaced by calcite. Hornblende is unetched, and the original crystal faces are often brilliant and perfect. Thus it is evident that augite was not stable under the conditions that controlled the deposition of these sedimentary beds and was subject to solution or replacement, whereas under the same conditions hornblende was stable.

ALTERATION AND WEATHERING OF TUFFS

The volcanic tuffs throughout the region are composed largely of materials that were not stable under the physical conditions that promoted solution and hydration (in the zone of katamorphism) and so have undergone very extensive alteration. Some of these changes were produced by ordinary weathering, but others are more profound.

Fresh phonolite tuff and tuffaceous sand are greenish gray or dull olive-green. They are very porous, and their easy permeability has resulted in rather deep weathering in much of the region. Where weathering is complete they have assumed a red or reddish-brown color, but the less deeply weathered material is rusty brown.

The crystalline materials have resisted alteration much more than those with glassy texture, and so many of the individual phonolite grains are little affected by even the more intense alteration processes. In some beds, however, the feldspar of some of the rock fragments has been kaolinized and the original minerals have been more or less replaced by secondary ones.

As the phonolite cobbles are all very well rounded they must have been transported and eroded prior to deposition in their present situation. Many of them have been weathered and show an outer kaolinized zone an inch or more in thickness. Fresh and weathered pebbles are found side by side, in places below the permanent water level of the creek beds. This indicates that the kaolinization of the pebbles took place before deposition. As the glassy tuff was altered to bentonite after deposition, kaolinization and the formation of bentonite are two processes that took place at different times and probably under different conditions.

BENTONITE

Throughout most of the Arkansas area the glassy pumiceous tuff of the Woodbine formation has been altered to a bentonite that contains a large proportion of igneous-rock phenocrysts and detrital rock fragments, but locally calcite concretions have formed in the pumice tuff soon after deposition and prevented the formation of bentonite.

Bentonite is a rock composed predominantly of clay and formed by the alteration and devitrification of glassy volcanic material, usually a tuff. It generally contains differing porportions of igneous-rock phenocrysts and admixed detrital débris. Most bentonites contain montmorillonite as their characteristic clay mineral, but the bentonite of southwestern Arkansas is composed of beidellite.[13] This mineral has been found in one other sample of bentonite [14] and in gouge clays from mineral veins,[15] and it is an abundant soil and clay forming mineral, which has the chemical formula $(Al_2O_3, Fe_2O_3).3SiO_2.nH_2O$, where n is about 4. The mineral is plastic and has a micaceous habit and high birefringence. An analysis of Arkansas bentonite has been made by Earl V. Shannon, of the United States National Museum, who, together with C. S. Ross, has been engaged in a study of bentonite. The igneous rock from which the Arkansas bentonite has been derived has been analyzed by George Steiger, of the Geological Survey.

The conditions that promote the change of volcanic glass to bentonite have not been well known, but mineral relations in the Arkansas area permit some deductions as to the physical environment that favored the change. The development of bentonite was not due to surface weathering but to causes that affected all glassy materials at all observable depths, and in the same beds feldspar, all ferromagnesian minerals, and fragments of lithic tuff are commonly unaltered. The lime concretions that were formed in the tuff beds have preserved very delicate pumice fragments with uncollapsed bubble walls, as shown in Plate 22, *A*, *B*, and evidently the infiltrating calcium carbonate was introduced before the formation of the bentonite. The calcium was no doubt transported as bicarbonate, and it is quite probable that the water was bicarbonate bearing throughout the period of alteration. The ash fell in a marine embayment, and the entrapped water may have remained saline during alteration, but it

[13] Larsen, E. S., and Wherry, E. T., Leverrierite from Colorado: Washington Acad. Sci. Jour., vol. 7, pp. 208-217, 1917; Beidellite, a new mineral name: Idem, vol. 15, pp. 465-466, 1925. Ross, C. S., and Shannon, E. V., The chemical composition and optical properties of beidellite: Washington Acad. Sci. Jour., vol. 15, pp. 467-468, 1925; The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, pp. 77-96, 1926.

[14] Ross, C. S., and Shannon, E. V., Am. Ceramic Soc. Jour., vol. 9, pp. 77-96, 1926.

[15] Larsen, E. S., and Wherry, E. T., Leverrierite from Colorado: Washington Acad. Sci. Jour., vol. 7, pp. 208-217, 1917.

is impossible to determine the degree of dilution with fresh water. The ash fell in water, and calcite concretions were present when the alteration took place, and therefore volcanic gases and acids stronger than the dissolved carbon dioxide were not present and could have had no part in the alteration. It seems equally certain that organic or so-called humic acids were absent, for no extensive plant remains are associated with the beds, and a very great thickness of material has been affected by the processes of alteration.

The known factors of the alteration were the absence of oxidizing conditions, the presence of water for hydration, the removal of excess chemical constituents, and the probable presence of bicarbonates, sodium chloride, and possibly of magnesium salts from the sea water. Calcium carbonate and iron carbonate leave a record of their transportation probably as bicarbonates, but soluble alkaline bicarbonates would leave no such record and so may or may not have been present. The absence of sulphate minerals like gypsum indicates that sulphates were absent or practically absent from the solutions. No other factors suggest themselves that are likely to have contributed to the formation of bentonite. Thus it seems improbable that the alteration of volcanic glass to bentonitic clay was brought about by unusual chemical conditions. On the other hand, it seems to have been the result of hydration and solution of an unstable glass that was perhaps more or less aided by the presence of chlorides and bicarbonates, the latter probably in very weak concentration.

Analyses of the trachyte that is believed to have approximately the same composition as the pumice, of the bentonite from Mine Creek, and of other related clay minerals are given in the following table:

Analyses of trachyte, bentonitic clay from Mine Creek, Howard County, Ark., and related clays

	1	2	3	4
SiO_2	62.97	45.12	47.28	48.80
Al_2O_3	19.00	28.24	20.27	21.08
Fe_2O_3	1.13	4.12	8.68	.92
FeO				
MgO	.26	2.32	.70	4.84
CaO	.54	.88	2.75	1.36
Na_2O	2.86		.97	(a)
K_2O	10.80		Trace	
H_2O-	.72	18.72	19.72	20.92
H_2O+	1.26			
TiO_2	.26			
P_2O_5	.10			
	99.90	99.40	100.37	97.92

a About 2 per cent alkalies.

1. Trachyte, Coleman Creek, Howard County, Ark. George Steiger, analyst.

2. Bentonitic mineral concentrated from bentonite derived from trachytic pumice, Mine Creek, Howard County, Ark. Earl V. Shannon, analyst.

3. Clay mineral from Beidell, Colo. Edgar T. Wherry, analyst. Larsen, E. S., and Wherry, E. T., Washington Acad. Sci. Jour., vol. 7, p. 213, 1917.

4. Bentonitic mineral concentrated from bentonite, Ardmore, Nebr. Earl V. Shannon, analyst.

The analyses given above show the chemical relations of the bentonitic mineral to the rock from which it was derived. Analysis 1 represents the porphyritic trachyte with a very fine crystalline groundmass, but the relation of pumice to trachyte and the identity of the associated phenocrysts indicate that one was the glassy and the other the crystalline phase derived from the same magma. The norm of the trachyte given on page 187 shows that it was a highly alkalic rock with less than 4 per cent of quartz and indicates that the Arkansas bentonite was derived from a rock low in quartz and high in alkalies. No analyses have previously been available of material that was known to have altered to bentonite, but the presence of the igneous rock minerals has led to the belief that bentonite was derived from glassy rocks high in alkalies and less silicic than normal rhyolites.[16]

Analyses 1 and 2 show the chemical changes involved in the alteration of glass to bentonite. It is probable that there has been little addition or abstraction of Al_2O_3 during the alteration of the glass, but the alkalies have been almost completely abstracted. This indicates that it has taken about 1½ parts of the trachyte pumice to produce each part of the resulting bentonite, which would require the removal of about half the original silica to give a final product with 47.23 per cent of silica. There appears to have been a moderate addition of iron, and a rather large addition of magnesium was probably derived from the sea water that was present during alteration. The other great change was the addition of water and the production of hydrated minerals.

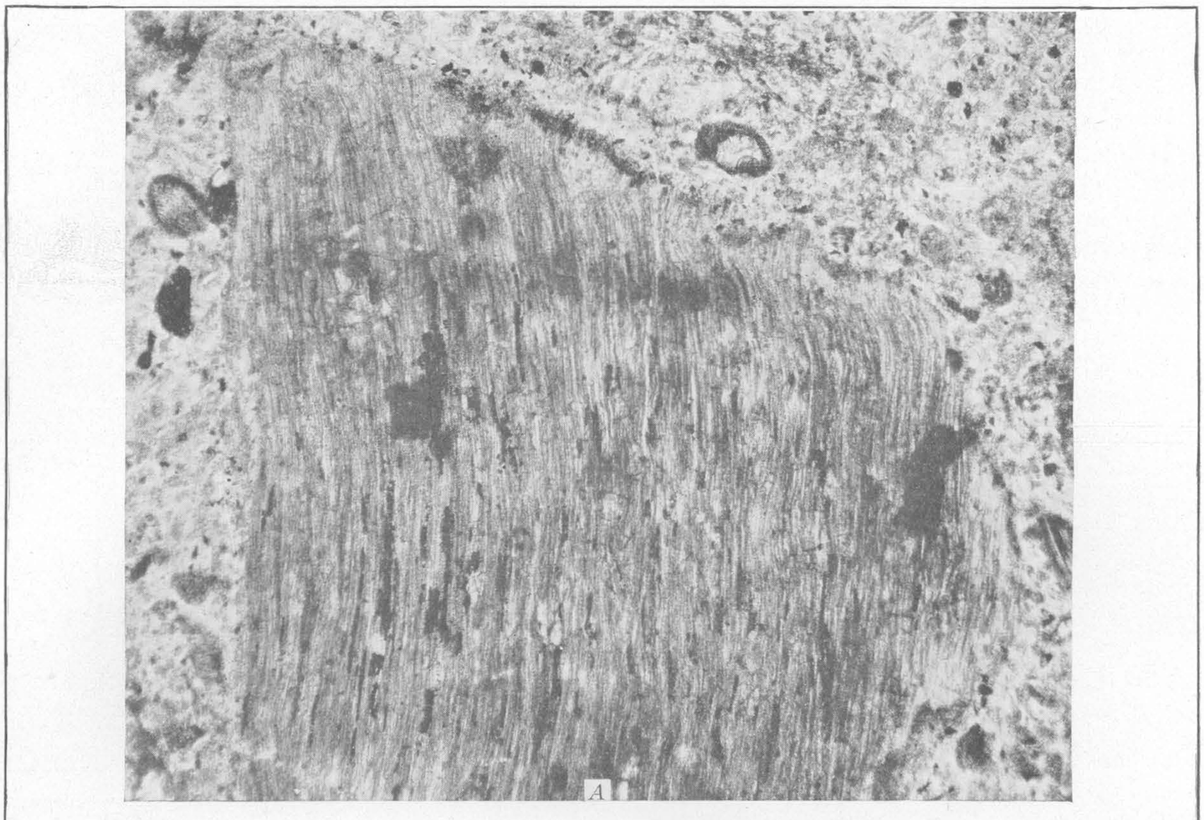
KAOLINIZED VOLCANIC MATERIAL

One or more beds of kaolinized volcanic material having a thickness of 5 feet occur in the Tokio formation between Murfreesboro and Delight, Ark. (See pl. 20.) The material is chalky white to creamy, but the lowest layer of one bed has a lavender color. It is nonplastic, is very fine grained, and breaks with a conchoidal fracture. The volcanic material is known locally as kaolin and has been so designated by all geologists[17] who have heretofore written on the region. A description of the kaolin deposits and a discussion of their economic value are given on pages 201 and 202.

The altered volcanic material is very pure clay, and microscopic studies indicate that it is composed of pellet-like fragments, the largest of which are less than 1 millimeter in diameter. The internal structure of the pellets resembles that of altered feldspar, but the same structure seems to be characteristic of some clay minerals. The structure therefore does not give clear evidence of the origin of the kaolin. Kaolin is a

[16] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, p. 84, 1926.

[17] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, pp. 147-153, 1908. Miser, H. D., and Purdue, A. H., Gravel deposits of the Caddo Gap and De Queen quadrangles, Ark.: U. S. Geol. Survey Bull. 690, p. 24, 1918.

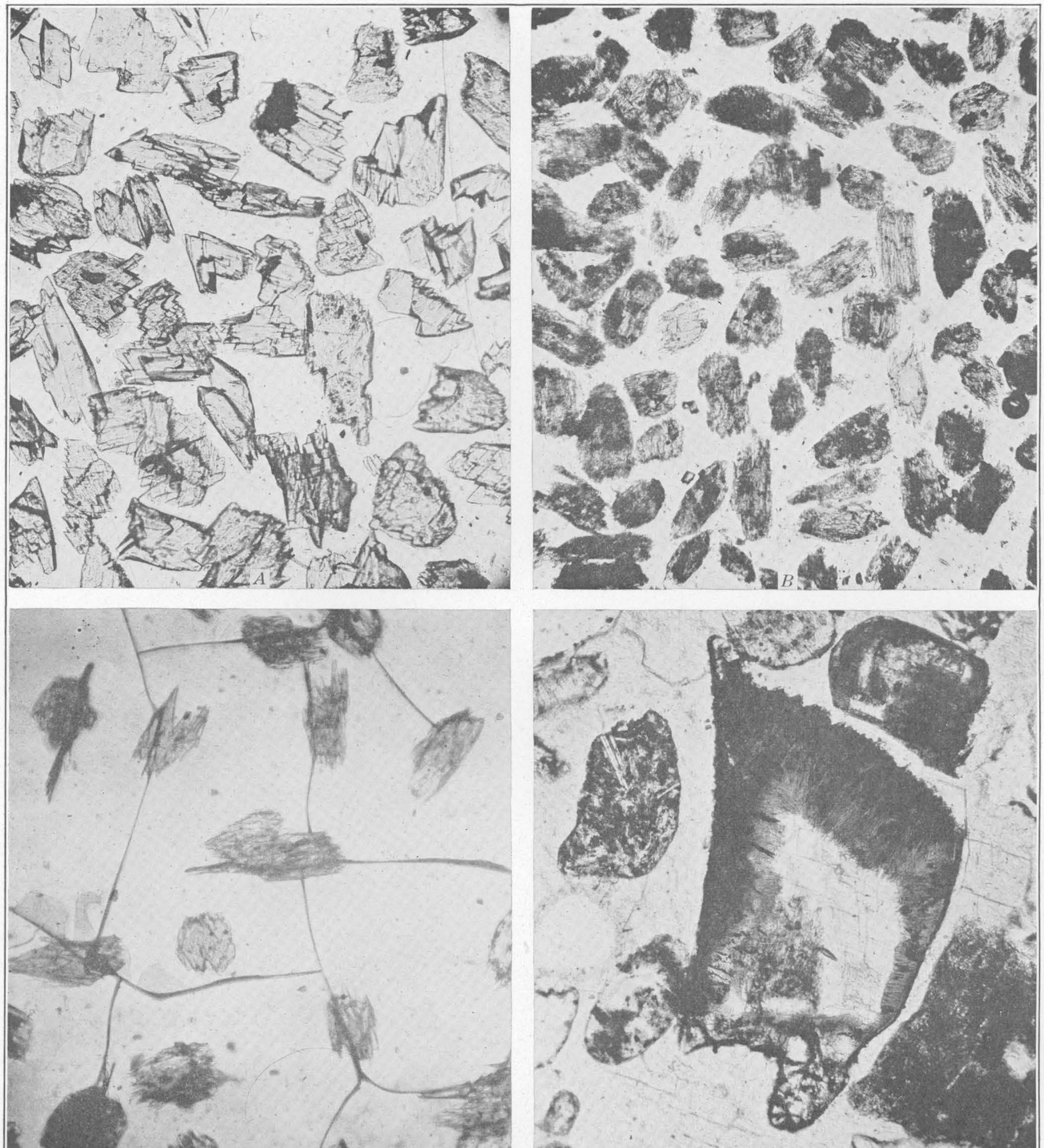


PHOTOMICROGRAPHS OF VOLCANIC ROCKS

A, Thin section of bentonitic volcanic tuff from Coleman Creek near Nashville, Ark. The large fragment was originally glassy pumice of orthoclase trachyte composition but is now completely altered to the clay mineral beidellite. Groundmass is fine-grained material of the same type. Enlarged 62 diameters

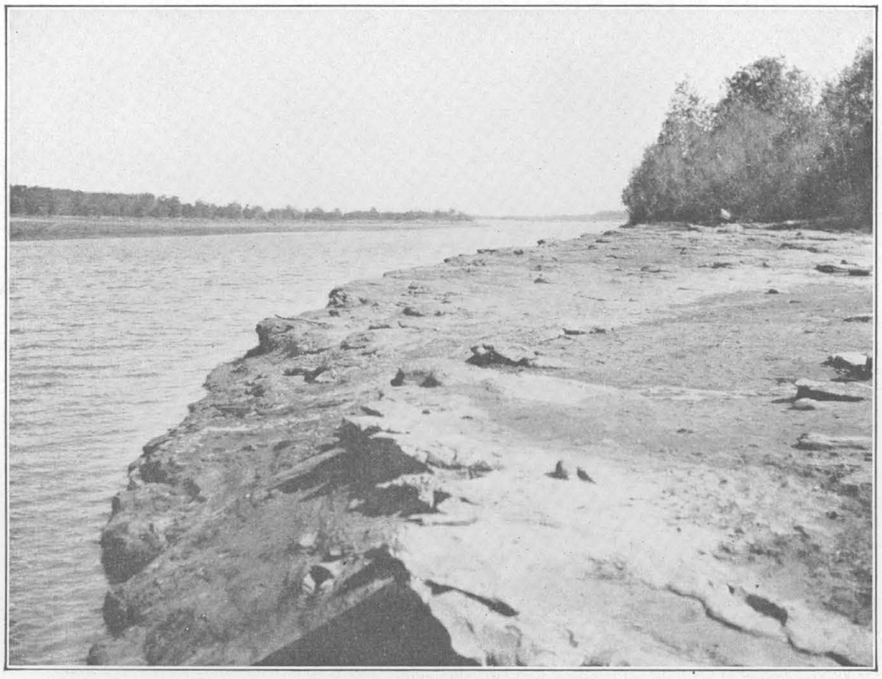
B, Phonolite sand from Owen place, between Center Point and Corinth, Howard County, Ark. The central grain is augite partly replaced by calcite. Replacement has left two residual areas of augite that extinguish simultaneously under crossed nicols and have saw-tooth secondary terminal faces on the lower border. The upper left grain is phonolite and the others quartz and orthoclase. Groundmass is calcite. Enlarged 100 diameters

C. Augite grains from Owen place partly repaced by calcite with the development of saw-tooth faces. Original outline of crystal fragment marked by zone of glauconite that appears black. Enlarged 100 diameters

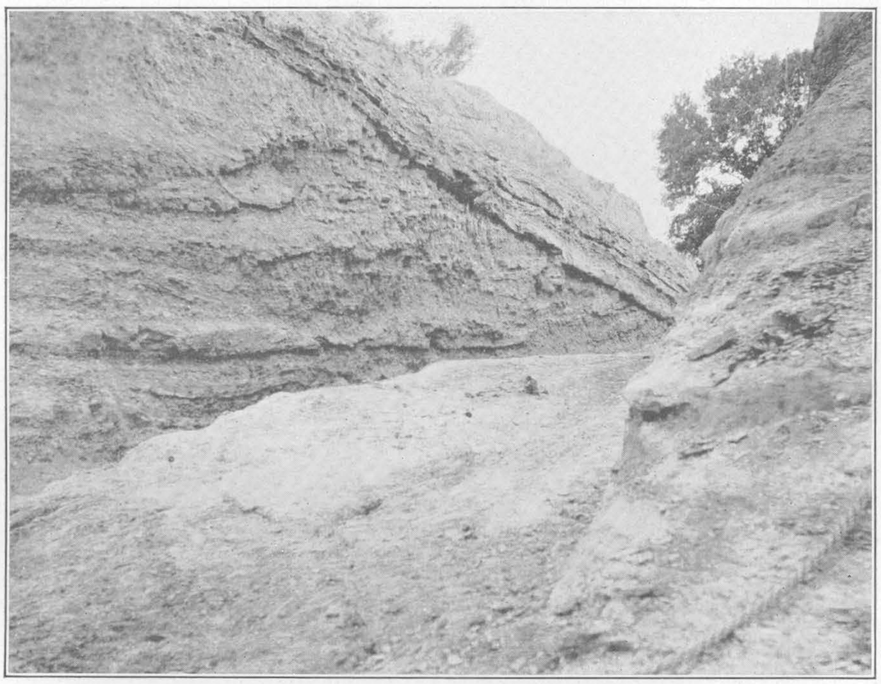


PHOTOMICROGRAPHS OF VOLCANIC ROCKS

A, Augite grains from phonolite tuff, Owen place, near Nashville, Ark. Secondary saw-tooth crystal faces have developed through corrosion and replacement by calcite. Enlarged 34 diameters
B, Etched augite grains from San Antonio Creek, Rio Arriba County, N. Mex. Enlarged 34 diameters
C, Etched augite grains from the Lebo shale member of the Fort Union formation, Montana. Enlarged 54 diameters
D, Augite grains partly replaced by glauconite and calcite, Prothro dome, Bienville Parish, La. Grains at left are phonolite. Groundmass is calcite. Enlarged 100 diameters

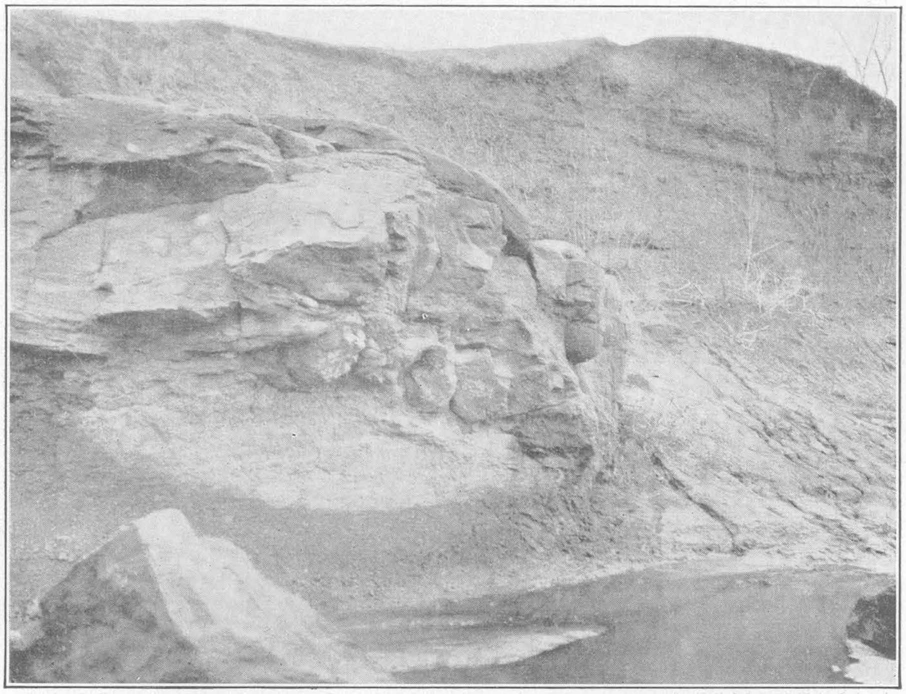


A. TUFFACEOUS SANDSTONE OF THE WOODBINE FORMATION AT SILVER CITY FERRY, RED RIVER, RED RIVER COUNTY, TEX.



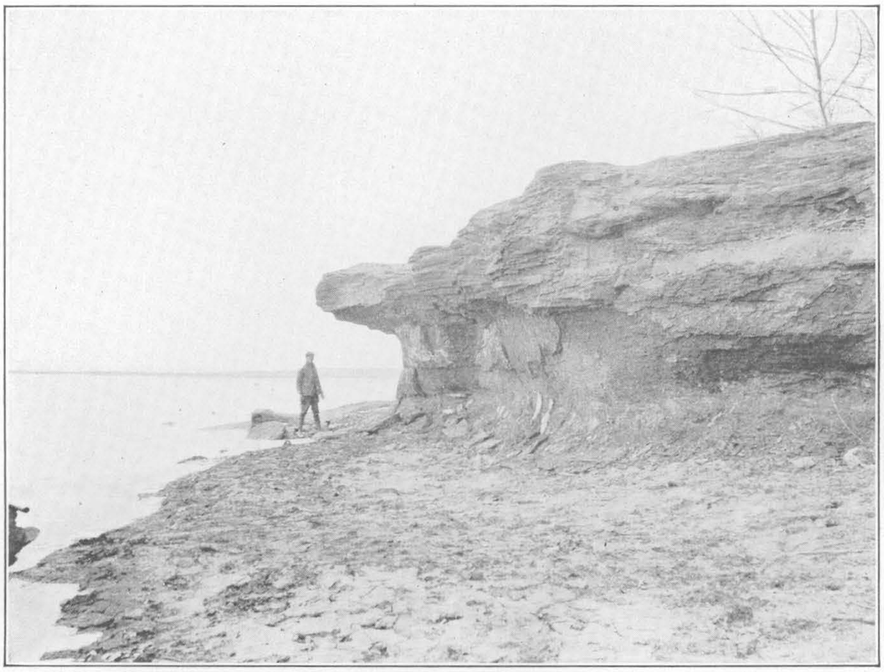
B. IRREGULARLY BEDDED SAND AND CLAY OF THE WOODBINE SAND IN ROAD CUT LEADING DOWN TO THE LOWER FERRY AT ARTHURS BLUFF, RED RIVER, LAMAR COUNTY, TEX.

Most of the fossil leaves from this locality described by E. W. Berry were obtained in the lower part of the section shown in the picture

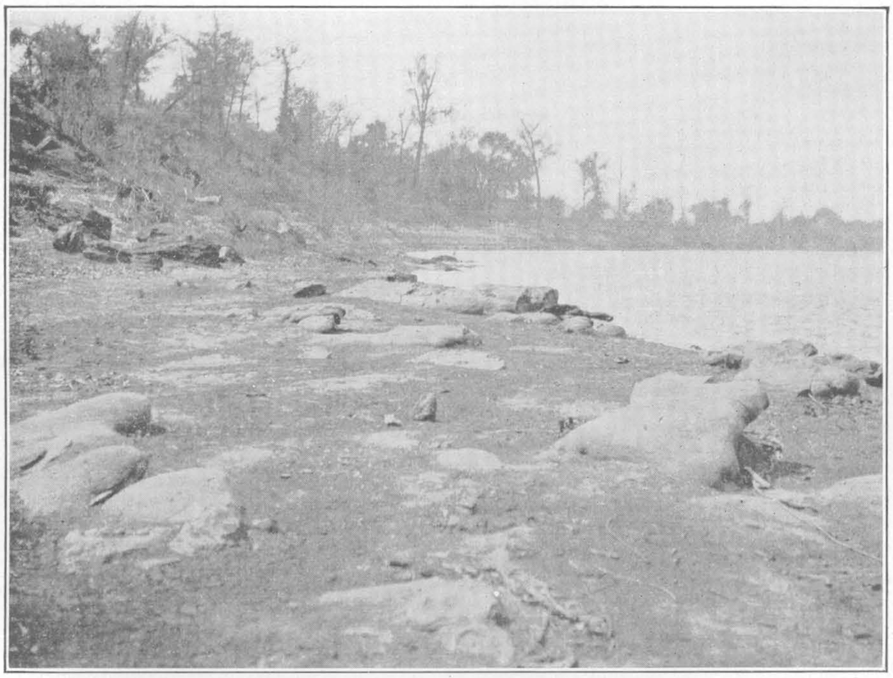


A. LENS OF TUFFACEOUS SAND IN LAMINATED SANDY CLAY OF THE WOODBINE FORMATION, ABOVE THE LOWER FERRY AT ARTHURS BLUFF, RED RIVER, LAMAR COUNTY, TEX.

B. TUFFACEOUS SANDSTONE OF THE WOODBINE FORMATION, BELOW THE LOWER FERRY AT ARTHURS BLUFF, RED RIVER, LAMAR COUNTY, TEX.



A. TUFFACEOUS SANDSTONE OF THE WOODBINE FORMATION AT HYATTS BLUFF, RED RIVER, FANNIN COUNTY, TEX.



B. TUFFACEOUS SAND OF THE WOODBINE FORMATION, PARTLY INDURATED TO CONCRETIONARY MASSES, NEAR THE UPPER END OF HYATTS BLUFF, RED RIVER, FANNIN COUNTY, TEX.

mineral that is normally derived from feldspathic material, and small proportions of augite, hornblende, zircon, and tourmaline that are characteristic of the volcanic rocks are present. It is therefore probable that the kaolin in these beds was derived from feldspathic volcanic material that had been reworked and deposited.

PERIDOTITE TUFF (?)

The lower beds of the Tokio formation on the Riley place and on the Twin Knobs, near Murfreesboro, Pike County, Ark., consist in large part of altered serpentine grains and peridotite fragments. Although the beds are water-laid, showing lamination and pronounced cross bedding, the igneous material may have been ejected into the air from the near-by vents and then fallen to or near its present position. There is, however, no evidence yet known that would preclude the derivation of the material from adjacent peridotite exposures by erosion.

Peridotite tuff (?) is present in small areas around the masses of peridotite, though it appears to be absent at two localities where exposures show the Tokio formation resting directly upon the peridotite.

CHEMICAL RELATIONS OF VOLCANIC ROCKS OF ARKANSAS

The following analyses show the chemical composition of the volcanic rocks and their relations to other igneous rocks of Arkansas:

Analyses of volcanic rocks of Arkansas and related intrusive rocks

	1	2	3	4	5	6
SiO_2	58.77	62.97	60.13	60.20	53.09	38.78
Al_2O_3	20.60	19.00	20.03	20.40	21.16	6.85
Fe_2O_3	1.40	} 1.13	{ 2.36	1.74	1.89	8.83
FeO	1.36		{ 1.33	1.88	2.04	1.99
MgO	.54	.26	.76	1.04	.32	26.34
CaO	.79	.54	.87	2.00	3.30	3.88
Na_2O	7.16	2.86	6.30	6.30	6.86	.78
K_2O	5.71	10.80	5.97	6.07	8.42	2.56
H_2O-	.89	.72	.16	.10	.24	1.95
H_2O+	2.19	1.26	1.41	.23	1.13	7.85
TiO_2	.37	.26	1.15	.14	.11	.89
P_2O_5	.03	.10	.06	.15	.15	
SO	.04				.08	
MnO	.24		Trace.	Trace.	.20	
BaO	Trace.					
SrO	.01					
CO_2	None.	None.	None.	None.	.82	.14
ZrO	.08		.05	Trace.	.04	
SO_3			.14	.13	None.	
BaO					.61	
Cl				.09	.02	
	100.18	99.90	100.72	100.47	100.48	100.84

1. Phonolite boulder, Mine Creek, Howard County, Ark. George Steiger, analyst.
2. Orthoclase trachyte, Coleman Creek, Howard County, Ark. George Steiger, analyst.
3. Foyaite, Braddock's quarry, Fourche Mountain, Little Rock, Ark. H. S. Washington, analyst. Washington, H. S., The foyaite-ijolite series of Magnet Cove [Ark.]: Jour. Geology, vol. 9, pp. 609, 611, 1901.
4. Pulaskite, Fourche Mountain, Little Rock, Ark. H. S. Washington, analyst. Idem.
5. Foyaite, Diamond Joe quarry, Magnet Cove, Ark. H. S. Washington, analyst. Idem.
6. Peridotite (probably hypabyssal) from Prairie Creek area, Ark. R. N. Brackett, analyst. Williams, J. F., Igneous rocks of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, p. 383, 1891.

Norms of volcanic rocks of Arkansas and related intrusive rocks

[The numbers correspond to those in the preceding table; analysis 6 represents an altered rock, and no norm has been calculated]

	1	2	3 [a]	4 [a]	5 [a]
Q		3.60			
Z	0.24				
C	1.10	1.80	1.53		
or	33.92	63.94	35.58	36.14	49.48
ab	44.44	24.10	49.26	42.44	8.12
an	3.89	1.95	4.45	9.17	2.22
ne	8.80		1.99	5.96	27.12
cc					1.80
Sal	92.49	95.39	92.81	93.71	88.74
di					5.45
wo					.81
hy		1.13			
ol	1.80		1.33	3.15	
mt	2.09		.93	2.55	2.78
hm			1.76		
il	.74	.46	2.13	.30	.15
ap		.34		.34	.34
Fem	4.65	1.93	6.15	6.34	9.53

[a] Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 271, 287, 305, 1917.

1. I.(4) 5.1''.'4.
2. I.5.1.2.
3. I.5.1''.3(4).
4. I''.5''.''2.3(4).
5. I(II).6''.1.3.

The analyses just given and the norms calculated from them show that two distinct types of rock have contributed material to the Arkansas tuffs. The most striking quality that these rocks have in common is the high percentage of the alkalies and the low percentage of iron and magnesia that go to produce ferromagnesian minerals. The phonolite boulder from Mine Creek, Howard County, Ark. (analysis 1), contains 92.49 per cent of salic minerals, of which 78.46 per cent consists of alkalic feldspars. It is low in femic minerals, low in anorthite, and very low in magnesium. It is therefore an alkalic phonolite rather rich in potassium, and, as would be expected in a rock of this type, the structure is trachytic. In normative composition it is very similar to the foyaite from Braddock's quarry, Fourche Mountain, Little Rock, Ark., and to the pulaskite from Fourche Mountain.

The rock from Coleman Creek, Howard County, Ark. (analysis 2), has a very unusual chemical composition. Only two rocks that fall in the groups I.5.1.1 and I.5.1.2 of the quantitative system are listed by Washington.[18] One of these is orthoclasite, an orthoclase-

[18] Washington, H. S., U. S. Geol. Survey Prof. Paper 99, p. 269, 1917.

rich dike rock from Alaska, and the other a pegmatite. The rock from Coleman Creek is closely related to the rock from Fourche Mountain (analysis 3) but is very much higher in potassium. With nearly 64 per cent of orthoclase, 88 per cent of alkalic feldspar, and only 1.93 per cent of femic minerals in the norm, it constitutes a new rock type for Arkansas and a type that has not heretofore been reported among volcanic rocks. It can be best described as an orthoclase trachyte.

The analysis of the massive hypabyssal peridotite is given to show the dissimilarity between the diamond-bearing rock of Pike County, Ark., and the volcanic tuffs of the same area.

AGE OF THE VOLCANIC ROCKS

The Woodbine and Tokio formations, both of which contain water-laid volcanic rocks, have yielded fossils from which the age of the formations may be determined. Fossil plants have been obtained from the Woodbine formation on Mine Creek 3 miles north of Nashville, Ark., and from the Tokio formation in the "Big" railroad cut, 2½ miles east of Tokio, Ark., and in the Adams kaolin pits, in sec. 24, T. 8 S., R. 25 W., 5 miles east-southeast of Murfreesboro, Ark. The plants at the Adams pits occur in a 5-foot bed of kaolin which is probably altered volcanic material; the plants on Mine Creek are in a lens of clay in a thick bed of tuff; and the plants at the railroad cut are in a dark gumbo clay that is overlain by sand and light-colored clay.

No fossil invertebrates have been found in the Woodbine formation in Arkansas, but the Tokio formation has yielded small collections from five or six localities, mostly of poorly preserved prints and molds.

The fossil plants from the Woodbine and Tokio formations in Arkansas have been studied by Berry.[19] Also a fossil flora composed of 43 species from the Woodbine sand at Arthurs Bluff, on Red River in Lamar County, Tex., has been studied by Berry.[20] The fossil plants there occur in coarse sandstone containing a considerable percentage of tuffaceous material and in more or less sandy cross-bedded clay interbedded with and overlying the sandstone. Berry says:

> I can therefore only state the well-known fact that the Woodbine and Bingen formations are at least partly contemporaneous. I am of the opinion, which is based on the range of the Woodbine plants in other formations, that Arthurs Bluff is approximately on the boundary between the lower and upper members of the Bingen as recognized by Miser in Arkansas in the specific area where he collected the plants.

Since the publication of Berry's papers on the fossil floras of the "Bingen formation" of Arkansas and the Woodbine sand at Arthurs Bluff in Texas much has been learned in regard to the age and stratigraphic relations of these and other formations of the Gulf series in Arkansas and northeastern Texas. Miser and Purdue[21] in 1919 divided the "Bingen sand" of Veatch, in Howard and Pike Counties, Ark., into the lower or main part of the formation and an upper "Tokio sand member." The distribution of the "Tokio sand member" as represented on the map accompanying the paper cited shows that it overlaps the main part of the "Bingen" and finally conceals the "Bingen" completely from west to east. The unconformity beneath the gravel bed at the base of the Tokio formation of the present report has since been traced by Dane southwestward as far as Little River, where it is concealed by the river alluvium. From northeast to southwest the Tokio, according to Dane,[22] becomes interstratified with beds of clay of increasing thickness, until in Sevier County the clay predominates over the sand.

The lower part of the "Bingen sand" of Veatch contains the thickest beds of volcanic tuff already mentioned, and thin beds of volcanic material are present in the overlying Tokio formation. The beds of volcanic tuff of the lower part of the "Bingen sand" have been traced westward from Arkansas through McCurtain, Choctaw, and Bryan Counties, Okla., and through the northern parts of Red River, Lamar, and Fannin Counties, Tex., where they form a continuous and characteristic deposit connecting directly with the upper part of the Woodbine sand. The tuffaceous beds are interbedded with the fossil plant bearing beds at Arthurs Bluff. In Lamar and Fannin Counties the volcanic tuffs have been definitely identified beneath the Eagle Ford clay, showing that the lower part of the "Bingen" is in reality the eastward extension of the upper part of the Woodbine sand.

The Tokio in Arkansas has been found by Dane to contain fossils at several stratigraphic positions, the lowest within 70 feet of the base, which according to Stephenson indicate with reasonable certainty that this division is younger than the Eagle Ford clay. Inasmuch as the lower part of the "Bingen"—that is, the Woodbine sand—passes beneath the Eagle Ford in Texas, and the upper part of the "Bingen"—that is, the Tokio formation—is younger than the Eagle Ford, it follows that the Eagle Ford is represented in Arkansas by the unconformity between the Woodbine and Tokio.

MANNER OF DEPOSITION OF VOLCANIC MATERIALS

The lithic tuffs of the Woodbine formation were water-laid, as is shown by the rounded pebbles of large and small sizes, the assortment of the larger pebbles into lenses at some places, the local occurrence of glauconite, and conspicuous cross-bedding, which

[19] Berry, E. W., Contributions to the Mesozoic flora of the Atlantic Coastal Plain, XII—Arkansas: Torrey Bot. Club Bull. 44, pp. 167-190, 1917.

[20] Berry, E. W., The flora of the Woodbine sand at Arthurs Bluff, Texas: U. S. Geol. Survey Prof. Paper 129, pp. 153-181, 1922.

[21] Miser, Hugh D., and Purdue, A. H., Gravel deposits of the Caddo Gap and De Queen quadrangles, Ark.: U. S. Geol. Survey Bull. 690, pp. 22-24, 1918.

[22] Dane, C. H., U. S. Geol. Survey press notice, Sept. 10, 1926.

is revealed in all exposures. Yet in spite of the water-laid character of these tuffs the orthoclase, augite, titanite, and spinels found in them, especially in the Nashville area, show very perfect crystal faces with little evidence of attrition.

The pumiceous orthoclase trachyte tuffs of the Woodbine formation display little or no evidence of bedding, but some of them contain leaf fragments suggesting that they, like the lithic tuffs, were deposited in water.

The tuffaceous sand of the Woodbine contains invertebrate fossils in some of the exposures in Oklahoma and Texas. The fossils together with the character of the sand indicate that the Woodbine was there deposited in marine and brackish waters.

The cross-bedding and assortment of the materials in peridotite tuff of the Tokio formation indicate that the tuff was water-laid. The kaolin beds that appear to be derived from material of volcanic origin in the Tokio formation were also water-laid, as is shown by the occurrence of horizontal laminae, an occasional grain of glauconite, and fossil plant leaves and stems lying parallel with the laminae.

VOLCANIC VENTS OF CRETACEOUS AGE IN ARKANSAS, OKLAHOMA, AND NORTHEASTERN TEXAS

The location of the vents that supplied the volcanic material in the Woodbine and Tokio formations may be inferred from the different kinds of volcanic material, from the thickness of the water-laid volcanic deposits, from their distribution, and from their change in character from place to place.

Of the known deposits of tuff in Texas, Oklahoma, and Arkansas, the thickest lie in Howard, Pike, and Sevier Counties, Ark. This fact, combined with the well known occurrence of volcanic activity at Murfreesboro, Pike County, suggests that the vent or vents through which the enormous quantity of tuff and ash in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas was ejected were situated in these three counties. The areas of Lower Cretaceous and older rocks in these and adjoining counties have been carefully studied by many geologists, but thus far no volcanic vents active in Cretaceous time except the peridotite vents near Murfreesboro have been discovered. If the Cretaceous vents supplying the other kinds of volcanic material were situated in the southern parts of the counties they are now concealed by beds of Upper Cretaceous and Quaternary age.

The volcanic center a few miles southeast of Murfreesboro, Ark., consisted of three or more volcanoes, here named the Murfreesboro volcanoes. (See fig. 18 and pl. 19.) The rocks that fill these old vents are exposed. Another vent that erupted volcanic material of a trachytic type was apparently a few miles northwest of Nashville, Ark., and a second was apparently half to three-quarters of a mile south of Lockesburg, Ark. These two vents are here named the Nashville and Lockesburg volcanoes. They supplied the tuffaceous material in the Woodbine formation. Neither of the vents is exposed. How many other centers, if any, there may have been in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas is not known. The exhaustive studies by different geologists of the syenites and related types of igneous rocks near central Arkansas have not suggested to them that the intrusion of these rocks was accompanied by volcanic explosions. The evidence for the assumption that volcanic vents were located near Lockesburg and Nashville is given in the several succeeding paragraphs.

The location of the three volcanoes mentioned above, as well as the location of distant volcanoes of Cretaceous age in these and adjacent States, is shown on Figure 18. The Monroe, Thrall, and Lytton Springs volcanoes were discovered by means of deep oil and gas wells.

The peridotite material at the base of the Tokio formation near Murfreesboro, Ark., is believed to be peridotite tuff. Its occurrence near the Murfreesboro volcanoes indicates that they were its source. The necks of these volcanoes are filled with three kinds of peridotite—porphyritic rock, breccia, and tuff. The breccia is diamond bearing and has yielded diamonds in small commercial quantities. The volcanic activity apparently took place in early Upper Cretaceous time, as is indicated by the upward extension of the necks through beds of the Trinity formation (Lower Cretaceous) and by the occurrence of deposits of water-laid peridotite material (peridotite tuff?) in the lower part of the Tokio formation (Upper Cretaceous).

The Murfreesboro volcanoes did not yield more than a small quantity of ejected material to the thick, widespread deposits of volcanic rocks in the Woodbine and Tokio formations, for no positive identification of peridotitic material has been made in the formations except at localities near Murfreesboro.

The volcanic rocks represented in the Woodbine and Tokio formations other than peridotitic material include two kinds whose sources will be considered separately. One kind is an orthoclase trachyte, characterized by pumice now largely altered to bentonite, and the other is characterized by beds of lithic phonolite pellets.

The fragments of orthoclase trachyte associated with the pumice tuffs are not rounded, and the crystal grains are all very sharply euhedral or angular where fractured. Some of the pumice beds contain no foreign detrital material of any kind, even where the beds above and below contain large proportions. Much of the pumice was composed of lenticular vesicles bordered by exceedingly thin walls that made it an unusually fragile material. There was no sorting or sizing of pumice, and sharply angular fragments are discernible in every thin section examined. The fragile nature of the pumice and its relations seem to preclude any extensive transportation. The purest pumice and trachyte tuffs are found on Coleman and Pleasant Valley Creeks (fig. 17), and the tuffs become less pure with distance from that locality. These circumstances seem to indicate rather clearly that the volcanic centers that supplied the pumice and trachyte tuffs were situated not more than a few miles from a point about 3 miles northwest of Nashville, Ark.

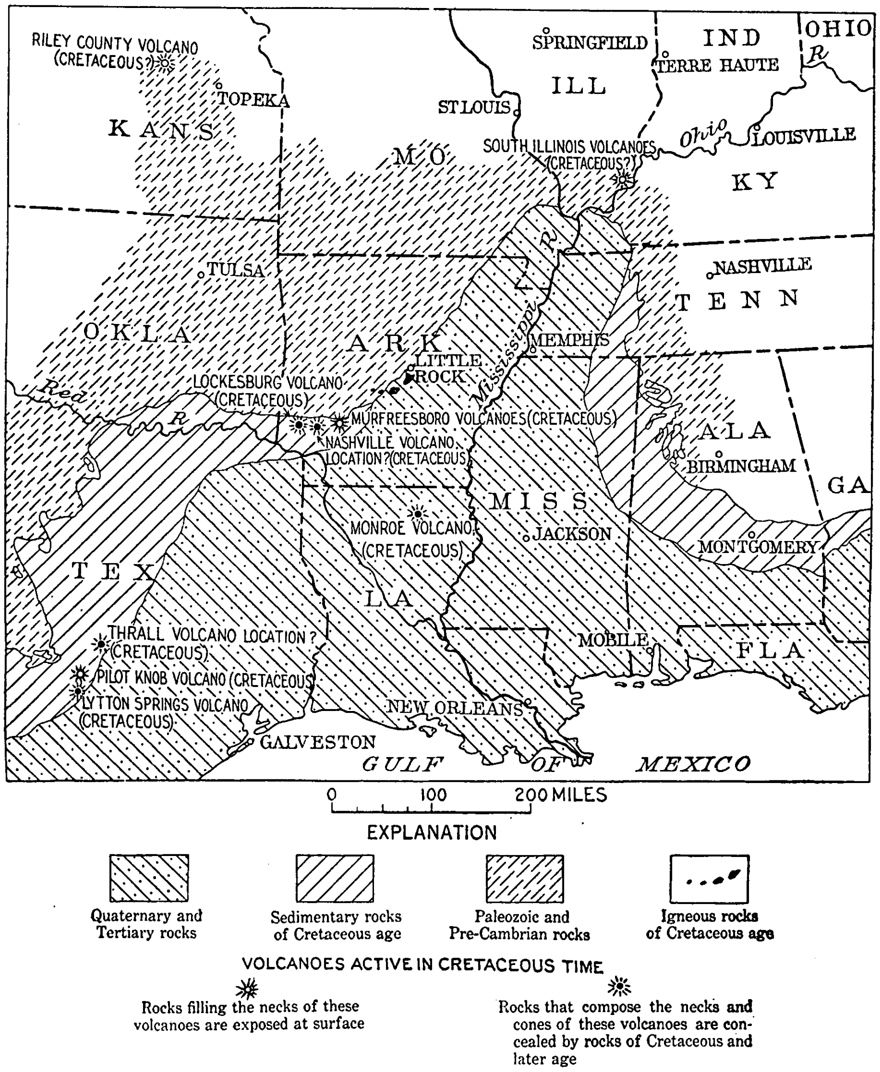


FIGURE 18.—Map of Arkansas and adjacent States showing the location of volcanoes that were active in Cretaceous time and the exposures of igneous rocks of Cretaceous age

The volcanic materials of the phonolite type are fresher and less mixed with foreign detrital débris in the area near Nashville, Ark., than in the Oklahoma and Texas areas. As the tuff beds are followed west into Oklahoma and southwest into Texas there appears to be an increase in the average proportion of quartz and other nonvolcanic detrital material. Phonolite is the characteristic volcanic rock material, but minor amounts of orthoclase and rock fragments of the trachyte type are present. The orthoclase crystals show crystal faces but are more rounded than in the Nashville area. Fresh augite is very rare but appears to have been abundant prior to replacement by calcite; magnetite, spinel, and other minerals that resist replacement are just as abundant as near Nashville. Pyrite and siderite have developed, augite has been replaced by calcite, and glauconite has formed films around and replaced mineral and rock grains.

These results make it seem possible that the easternmost parts of the tuffaceous beds of the phonolite type were nearest to the volcanic center that supplied the material. On the other hand, the cobbles of phonolite found on Mine Creek near Nashville, Ark. (fig. 17), were exceedingly well rounded and possibly somewhat weathered before they became incorporated in the tuffs and associated gravel beds. The small rock pellets that are characteristic material of the phonolite tuffs and sands are rounded and rather well sorted and more or less mixed with quartz and novaculite grains. This suggests that the phonolite material had been transported some distance, even in the Arkansas part of the region, though it could hardly have been carried by streams from the areas of igneous rocks near the center of Arkansas, the nearest of which is between 50 and 60 miles northeast of Murfreesboro. The evidence in favor of transportation is somewhat opposed by the euhedral shape and lack of rounding of the phenocrysts from the phonolite tuffs. On the whole, however, there seems to be no evidence that excludes considerable transportation of the phonolite volcanic material or that suggests a very exact location of the volcanic center or centers from which it came. Probably, however, the eastern tuff beds were nearer the source of supply than those in the Texas-Oklahoma region, where there is greater mixing with other materials and a greater rounding of mineral grains.

That a volcanic center was situated in the vicinity of Lockesburg, Sevier County, Ark., is suggested by natural phenomena there. Three-quarters of a mile south of Lockesburg broken and bent beds of the Trinity are revealed in a small exposure by the roadside.[23] No post-Cretaceous faulting and certainly no close Cretaceous folding has affected the Trinity at any other place in Arkansas, Oklahoma, or the adjacent part of Texas with which the writers are familar. The

[23] Dane, C. H., letter of Jan. 20, 1926.

steep dips and fractures in the Trinity are perhaps attributable to displacement in connection with volcanic activity. Weight is added to this suggestion by the occurrence of many large angular blocks of Paleozoic sandstone at the locality three-quarters of a mile south of Lockesburg. The blocks, measuring as much as 15 feet in length, 4 feet in width, and 3 feet in thickness, could not have been transported very far by streams that deposited the known gravel beds of Cretaceous age in Arkansas.[23] The nearest exposures of Paleozoic sandstone are in the Ouachita Mountains 10 miles north of Lockesburg. Moreover, the great abundance of the sandstone blocks at the Lockesburg locality indicates that they were probably not transported from the Ouachita Mountains. Their source was thus apparently near by. Possibly they came from a high ridge of Paleozoic sandstone that may have extended upward entirely through the Trinity, about 1,000 feet thick, or from blocks of sandstone brought upward by volcanic explosions. Ridges of so great height on the Cretaceous floor are not known in Arkansas, though ridges several hundred feet high are known near Spencerville, Choctaw County, Okla. At the volcanic neck near Murfreesboro, Ark., on which the Ozark, Mauney, and Arkansas diamond mines are located, there are masses of Paleozoic quartzite hundreds of feet in their longest dimension. These have all been lifted upward by the forces accompanying the volcanic activity, and it seems probable that the same explanation applies to the tilted Paleozoic blocks near Lockesburg.

WIDESPREAD VOLCANIC ACTIVITY DURING CRETACEOUS PERIOD [24]

Volcanic materials are widespread in the Woodbine formation, not only on the outcrop but in the deposits away from the outcrop, also in equivalent and overlying beds of Upper Cretaceous age. Furthermore, they are present not only in Arkansas and Oklahoma but also in Louisiana, Texas, and Alabama. The occurrences are briefly mentioned below.

Bentonite has been found in the "Bingen formation" (Woodbine and Tokio formations) in wells in Union County, Ark., as identified from samples sent to the Geological Survey by H. D. Easton.

Bentonite occurs in Louisiana in beds that appear to be the equivalent of the Arkadelphia clay or the Marlbrook marl (Upper Cretaceous), which are younger than the Woodbine and Tokio formations.[25]

Bentonite of exceptional purity which shows very perfect volcanic-ash structure occurs in the Eutaw formation, of Upper Cretaceous age, near Montgomery, Ala. Material from this deposit was collected by Doctor Carver, of the Tuskegee Institute, and submitted to Clarence S. Ross by Henry M. Payne for identification. The age of the bed is inferred by L. W. Stephenson [26] from the geographic location of the bentonite occurrence. Material from the same deposit has been submitted to the United States Geological Survey by E. M. Graves, of Montgomery.[26]

An unusually pure bentonite near Aberdeen, Monroe County, Miss., is reported by the State geologist [27] to be part of the Eutaw formation. The Eutaw formation is correlated by Berry [28] with the Tokio formation ("upper Bingen").

Volcanic ash is found in the Eagle Ford clay in wells in northeastern Texas.[29] This clay is regarded by Stephenson as occupying part of the hiatus represented by the unconformity between the Woodbine and Tokio formations.

Thin layers of bentonite reaching a maximum thickness of 1.5 feet, interbedded with shaly clay and platy limestone, have been observed by Stephenson and others in the lower part of the Eagle Ford clay in Texas as follows: In the vicinity of Austin, Travis County;[30] northeast of Georgetown, Williamson County; between Belton and Temple, Bell County; at several places along the strike of the formation in McLennan County;[31] near Grand Prairie, Dallas County;[32] and west of Pottsboro, Grayson County. These localities may prove to be parts of a continuous zone in the lower part of the Eagle Ford clay extending at least from Travis County to Grayson County.

Pilot Knob, 8 miles southeast of Austin, Tex., (fig. 18), marks the site of an ancient volcanic eruption, which probably took place late in Austin time and early in Taylor time.[33] Beds of tuff that are related to the central mass extend outward from it for 6 miles. The typical Austin chalk, according to Stephenson, is apparently represented by the Tokio formation. The lower part of the typical Taylor marl, also according to Stephenson,[34] is apparently equivalent to the Brownstown marl, which overlies the Tokio formation. If these correlations are correct,

[23] Dane, C. H., personal communication, Jan. 20, 1926.

[24] Since the present paper was written a comprehensive report, by J. T. Lonsdale, on the igneous rocks of the Balcones fault region of Texas, was issued Nov. 22, 1927, as Bulletin 2744, by the Bureau of Economic Geology of the University of Texas. Lonsdale describes not only the exposed igneous rocks but also those that have been found in wells. Brief references are made in the present paper to occurrences of of igneous rocks in Texas. The rocks of all the occurrences cited, as well as others, are described by Lonsdale. He describes their form, distribution, and petrographic character and also discusses the age and nature of the igneous activity.

[25] Bramlette, M. N., Bentonite in the Upper Cretaceous of Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 342–344, 1924.

[26] Stephenson, L. W., The Mesozoic rocks, in Geology of Alabama: Alabama Geol. Survey Special Rept. 14, p. 236, 1926.

[27] Lowe, E. N., personal communication.

[28] Berry, E. W., Contributions to the Mesozoic flora of the Atlantic Coastal Plain, XII-Arkansas; Torrey Bot. Club Bull., vol. 44, pp. 167–190, 1917.

[29] Waite, V. V., oral communication to H. D. Miser.

[30] Dr. J. A. Udden (oral communication) has recognized bentonitic clay in Eagle Ford shale, in exposures on a small southern tributary of Colorado River, just south of Austin, Tex.

[31] Adkins, W. S., Texas Univ. Bull. 2340, p. 107, 1923.

[32] Stanton, T. W., oral communication.

[33] Hill, R. T., and Kemp, J. F., Pilot Knob, a marine Cretaceous volcano: Am. Geologist, vol. 6, pp. 286–294, 1890. Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 120, 1924.

[34] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 154, 1919.

the eruption at Pilot Knob occurred during and soon after Tokio time. Intrusive igneous rocks are present farther southwest in Texas, particularly in Uvalde County. The volcanic activity in that county took place in Tertiary time.[35]

A buried sill of decomposed basalt, or possibly a bed of volcanic tuff, occurs in the Taylor marl near Thrall, Williamson County, Tex.[36] (See fig. 18.) As the lower part of the Taylor marl is equivalent to the Brownstown marl, the sill of basalt or bed of tuff may have been formed soon after Tokio time. Concerning the body of igneous rock Deussen [37] says:

> The body is evidently either a sill connected with some near-by volcanic neck or a tuff similar to those exposed near Austin, deposited by a submarine volcano that was active in this vicinity in early Taylor time. In any event the rock is closely related structurally and historically to the Pilot Knob disturbance near Austin.

At Lytton Springs, Caldwell County, Tex., a body of igneous rock [38] has been found in deep wells to project upward through the Austin chalk into the Taylor marl. The rock, which is now largely serpentine and chlorite, was originally volcanic ash, lava, and intrusive basalt and probably represents an old buried volcanic cone. The igneous rock here, like the serpentine rock at Thrall, yields oil in commercial quantities.

Beds of bentonite occur in the Navarro formation at a locality 3½ miles northwest of Macdona, Bexar County, Tex. The purer layers retain perfectly the characteristic structure of the glassy volcanic tuffs from which the bentonite was derived. Specimens collected by J. A. Udden and M. I. Goldman were examined. This deposit, previously referred to the Taylor marl, is believed by Stephenson to belong to the Navarro formation.

A succession of volcanic tuffs and flows underlies a part of the Monroe gas field of Louisiana. It is 1,100 to 1,200 feet thick and "seems to include the interval between the Nacatoch, Marlbrook, or Annona, and the Washita (of Comanche age)." [39] The differences in the thickness of the tuffs and flows and their distribution strongly suggest that they form a part of a volcanic cone which is buried in Cretaceous sediments. (See fig. 18). The inclosing sediments above and those below, being both of Cretaceous age, indicate that the volcano was active in Cretaceous time.

Volcanic tuff from the Prothro salt dome, in T. 14 N., R. 6 W., Bienville Parish, La., is identical in appearance and composition with some of the lithic tuffs in the Woodbine formation of Arkansas and Oklahoma; but, according to Stephenson, the fossils from the tuff at Prothro dome indicate that it is younger than the Eagle Ford clay and is probably of the age of the Tokio formation and the typical Austin chalk. The tuff, according to J. P. D. Hull,[40] who examined the locality in 1922, and also according to W. C. Spooner,[41] who has recently examined the locality, is exposed in almost vertical ledges 110 feet in total thickness. Mr. Spooner says he has found an outcrop of the same kind of rock in beds of the same age in the Rayburn salt dome, in T. 15 N., R. 5 W., Bienville Parish, La.

The tuffaceous sand of the Prothro dome contains phonolite with the same unusual and significant composition that characterizes the phonolite tuffs of Arkansas, and trachyte and pumice of the Arkansas type are present in minor quantities. Also the entire list of minerals associated with the tuffs is the same. The volcanic rocks in the two areas thus have the same lithologic character. Siderite has formed, calcite has replaced augite, and an unusual type of glauconite has been deposited in films around and has replaced augite crystals and phonolite grains in both areas.

Thus in the Prothro dome and in Arkansas, Oklahoma, and Texas the volcanic materials are the same (see table on p. 194), their relations are the same, and very peculiar and unusual secondary replacement processes affected the beds in both regions in the same way. The peculiar lithologic characters suggest in themselves that the beds in the Prothro dome represent the same formation that crops out in Arkansas, but the fossils discussed by Stephenson on page 200 seem to afford conclusive evidence that the Prothro dome and Woodbine beds are not of the same age.

The volcanic activity that produced the peridotite of Pike County and the nephelite syenites and associated types in other parts of Arkansas probably accompanied the down-warping of the Mississippi embayment in Upper Cretaceous time. The tuff and ash falls in the Woodbine and Tokio formations of southeastern Oklahoma and Arkansas probably took place at this time. As has been pointed out by Branner,[42] the igneous rocks of Arkansas occur near and parallel with the old Cretaceous-Tertiary shore line, which extended northeastward across the State. He believed that this shore line was affected by faulting or other weakness and that the igneous rocks of Arkansas had some possible connection with this line of disturbance. The similarity of the peridotite and lamprophyre dikes of western Kentucky and southern Illinois and the peridotite breccia of Riley County, Kans.[43] (fig. 18),

[35] Deussen, Alexander, op. cit., p. 121.

[36] Udden, J. A., Oil in an igneous rock: Econ. Geology, vol. 10, pp. 582–585, 1915.

[37] Deussen, Alexander, op. cit., p. 120.

[38] Bybee, H. P., and Short, R. T., The Lytton Springs oil field: Texas Univ. Bull. 2539, Oct. 15, 1925. Collingwood, D. M., and Rettger, R. E., The Lytton Springs oil field, Caldwell County, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 953–975, 1926.

[39] Bramlette, M. N., Volcanic rocks in the Cretaceous of Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 344–346, 1924. Spooner, W. C., and Bell, H. W., The Monroe gas field: Louisiana Dept. Conservation Bull. 12, pp. 5–6, figs. 1, 2, 1925. Easton, H. D., Oil and Gas Journal, Mar. 24 and Oct. 13, 1927.

[40] Letter dated Aug. 1, 1924. See also Hull, J. P. D., Prothro salt dome, Bienville Parish, La.: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 905–906, 1925.

[41] Letter dated Aug. 2, 1924; also Interior salt domes of Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 229–230, 248, 262–263, 1926.

[42] Branner, J. C., The former extension of the Appalachians across Mississippi, Louisiana, and Texas: Am. Jour. Sci., 4th ser., vol. 4, p. 365, 1897.

[43] Moore, R. C., and Haynes, W. P., An outcrop of basic igneous rock in Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 183–187, 1920.

suggests that the intrusion of the peridotite in those States occurred during Upper Cretaceous time. Although this is a mere suggestion, the writers know of no facts that would militate against this view. Plugs of volcanic breccia of acidic rocks occur in the same region as the dikes of southern Illinois (fig. 18) and "may represent an explosive phase of the region's igneous phenomena." [44]

VOLCANIC ACTIVITY IN GULF COASTAL PLAIN AND ADJOINING REGION IN PALEOZOIC AND TERTIARY TIME

Volcanic activity that affected the Gulf Coastal Plain and the adjoining country has taken place not only in the Upper Cretaceous epoch but at several other times. Bentonite occurs in the Ordovician rocks of Kentucky, Tennessee, and Alabama.[45] Bentonite and slightly metamorphosed tuff also occur in Ordovician rocks in Virginia [46] and Pennsylvania.[47] Volcanic ash is reported by C. W. Honess in the Missouri Mountain slate (Silurian), in McCurtain County, Okla.[48] Also volcanic ash and breccia are reported by Honess from two horizons in the Arkansas novaculite of Devonian age in McCurtain County, Okla.,[49] and he suggests that at least some of the Arkansas novaculite is silicified and devitrified volcanic ash. Volcanic tuff occurs in a bed 90 to 100 feet thick and in several thinner beds in the Stanley shale (Carboniferous) in Polk County, Ark., and McCurtain County, Okla.[50]

Beds of Tertiary bentonite of different ages are reported by Henry M. Payne [51] to occur at several localities in Mississippi and Alabama. The age of the beds is inferred by C. W. Cooke from the geographic location. The localities together with the age of the bentonite beds are as follows: In beds of probable Miocene age on the outskirts of Mobile, Ala.; in the Clayton formation, of Midway (Eocene) age, at Houlka, Chickasaw County, Miss.; in the Porters Creek clay, of Midway (Eocene) age, west of Woodland, Chickasaw County, Miss., and near Maben in Webster and Oktibbeha Counties, Miss.; and in the Clayton formation or the Porters Creek clay in western Union County, across Pontotoc County, and along the Gulf, Mobile & Northern Railroad in Tippah County, Miss.

An unusually pure bentonite occurring near Aberdeen, Monroe County, Miss., is reported by the State geologist [52] to be part of the Eutaw formation.

A bed of glassy volcanic ash probably of Jackson (late Eocene) age occurs in the northeast part of La Salle Parish, La.[53] The ash bed is 4 feet thick at the outcrop and is reported to be 35 feet thick in a drill hole near by. This material is nearly pure white and very fine grained and contains from 10 to 15 per cent of crystalline quartz, feldspar, etc.

Tuff of Oligocene or lower Miocene age is widely distributed in Live Oak and McMullen Counties, 65 to 90 miles south of San Antonio, Tex.[54]

Volcanic ash of several different ages in Arkansas and Louisiana is briefly described by Crider,[55] who says: "Volcanic ash has been discovered in a number of * * * localities in Louisiana and Arkansas ranging in age from Lower Cretaceous to the Jackson formation of the Eocene."

Volcanic ash is mentioned by Dumble [56] as occurring in Texas in the Fayette, Yegua, and Jackson formations (Eocene), in beds of upper Oligocene age, and in the Oakville sandstone (Miocene).

Volcanic ash from the Hayes district of Calcasieu Parish, La., has been described recently by Hanna,[57] though the age of the ash is not known to him. The core he examined came from a depth of 1,510 feet in the Duhig et al. No. 1 Levey well.

DISTRIBUTION OF THE TUFF TYPES

The general distribution of the tuff beds has been stated, but for the purpose of petrographic description it is convenient to take them up in five rather distinct groups of occurrences. One of these comprises the region north and northwest of Nashville, Ark., where the orthoclase trachyte pumice tuffs are the thickest and composed most largely of igneous material. Another is the area of Arkansas where the phonolite tuffs occur. Over part of the area the beds of the first group overlie those of the second, but from Blue Bayou west to the State line the pumice tuffs are not well developed so far as known. A third group of occurrences is in Oklahoma, and a fourth includes the

[44] Currier, L. W., Igneous rocks [of Hardin County, Ill.]: Illinois Geol. Survey Bull. 41, pp. 237–244, 1920.

[45] Nelson, W. A., Volcanic ash bed in the Ordovician of Tennessee, Kentucky, and Alabama: Geol. Soc. America Bull., vol. 33, pp. 605–615, 1922. Butts, Charles, The Paleozoic rocks, in Geology of Alabama: Alabama Geol. Survey Special Rept. 14, pp. 113–114, 131–133, 1926; U. S. Geol. Survey Geol. Atlas, Bessemer-Vandiver folio (No. 221), pp. 7, 16, pls. 10, 17, 1927.

[46] Taber, Stephen, Geology of the gold belt in the James River basin of Virginia: Virginia Geol. Survey Bull. 7, p. 43, 1913. Powell, S. L., letter dated March 24, 1925. Nelson, W. A., Volcanic ash deposit in the Ordovician of Virginia: Geol. Soc. America Bull., vol. 37, pp. 149–150, 1926. Giles, A. W., The origin and occurrence in Rockbridge County, Va., of so-called "bentonite": Jour. Geology, vol. 35, pp. 527–541, 1927. Ross, C. S., Paleozoic volcanic materials and criteria for their recognition: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 143–164, 1928.

[47] Bonine, C. A., Researches in sedimentation in 1925 and 1926, pp. 4–5, National Research Council, 1926. Stose, G. W., and Jonas, A. I., Ordovician shale and associated lava in southeastern Pennsylvania: Geol. Soc. America Bull., vol. 38, pp. 505–536, 1927.

[48] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 107–109, 1923.

[49] Idem, pp. 121–139.

[50] Miser, H. D., Mississippian tuff in the Ouachita Mountain region (abstract): Geol. Soc. America Bull., vol. 31, pp. 125–126, 1920. Honess, C. W., The Stanley shale of Oklahoma: Am. Jour. Sci., 5th ser., vol. 1, pp. 63–80, 1921; also op. cit.

[51] Personal communication.

[52] Lowe, E. N., personal communication.

[53] Personal communication from W. M. Weigel, mineral technologist of the Missouri Pacific Railroad.

[54] Bailey, T. L., Extensive volcanic activity in the middle Tertiary of the south Texas Coastal Plain: Science, new ser., vol. 59, pp. 299–300, 1924.

[55] Crider, A. F., Volcanic ash in northern Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 524–525, 1924.

[56] Dumble, E. T., A revision of the Texas Tertiary section with special reference to the oil-well geology of the coast region: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 424–444, 1924.

[57] Hanna, M. A., An interesting volcanic ash from Calcasieu Parish, La.: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 93–95, 1926.

tuff-bearing beds of Texas. The fifth comprises the occurrences in the Prothro dome and the Rayburn salt dome.

The minerals and their relative proportions differ greatly from place to place, and no single specimen is entirely characteristic of a locality, but tuffs from a locality in each of the above five groups were unusually fresh and have been studied in detail. The material was prepared for study by washing, and the heavy minerals were concentrated by heavy solutions. The results of this study are given in the table below. Where mineral or rock grains were present in essential amounts the approximate proportions were determined and are given in figures. If a mineral formed less than 1 per cent of the material, its presence but not its proportion was determined and is indicated by an ×. The purer specimens of all the tuffs were selected for study, and the figures given do not imply that all the specimens from a given locality had the high content of volcanic materials indicated.

Rocks and minerals of the tuffs

	Orthoclase trachyte tuffs	Phonolite tuffs			
	1	2	3	4	5
Phonolite	×	78	65	70	38
Trachyte	31	×	2	×	×
Pumice	45	------	×	×	×
Quartz	2	2	27	10	47
Novaculite	1	×	3	6	2
Orthoclase	20	×	1	11	9
Plagioclase	------	------	------	------	2
Augite	×	×	×	×	×
Hornblende	×	×	×	×	×
Biotite	×	×	×	×	×
Magnetite	×	×	×	×	×
Black spinel	×	×	×	×	×
Apatite	×	×	×	×	×
Zircon	×	×	×	×	×
Tourmaline	×	×	×	×	×
Staurolite	×	×	×	×	×
Garnet	------	------	×	------	×
Glauconite (marine)	------	×	------	------	×
Glauconite (replacement)	------	12	×	×	×
Pyrite	×	×	×	------	------
Siderite	×	×	×	×	×
Calcite	×	×	×	×	×
Phosphatic grains	------	×	×	×	×

1. From Blue Bayou, Ark., representing orthoclase trachyte tuffs.
2. From Owen Place, Ark., unusually pure phonolite tuff. (See fig. 17.)
3. From Garvin, Okla. (See pl. 20.)
4. From Arthur City, Tex. (See pl. 20.)
5. From the Prothro salt dome, La.

The last four columns of the table show a great variation in the proportions of volcanic and detrital sedimentary rock débris, but the igneous-rock minerals show practical identity, even though the localities from which they came were widely separated. The metamorphic-rock minerals and the minerals that developed subsequent to deposition are also identical. The orthoclase is all sanadine, the augite crystals all show the cockscomb habit, and the hornblende is similar in color and habit. Black spinel, which is a very unusual mineral in volcanic rocks, is present in every sample studied. The glauconite that formed films around rock and mineral grains was later than deposition in all the specimens.

THE TUFF BEDS OF ARKANSAS

MINE CREEK, HOWARD COUNTY, ARK.

The tuffs, tuffaceous sands, and associated gravel and boulder beds crop out for about 1 mile along Mine Creek, 3 miles north of Nashville, Ark. (See fig. 17.) The beds change greatly in character within short distances, and there is locally a very large admixture of nonvolcanic detrital rock. For this reason the tuff beds on Mine Creek are hard to describe systematically, but the chief types of material will be mentioned.

The tuff beds contain many beds and lenses of gravel and boulders, and the rock materials are predominantly quartz and novaculite, but locally there are many pebbles and cobbles of igneous rock of the same type that forms the small rounded rock pellets of the lithic phonolite tuffs. The most abundant igneous material on Mine Creek is composed of rounded grains of phonolite mixed with quartz and novaculite grains and with various proportions of pumice and trachyte fragments.

The bentonitic beds derived from glassy pumice usually contain large proportions of other rock materials, but one mass of unusual purity crops out at water level on the west side of the creek. It is cream-white and is composed of clay grains derived from pumice, a very little finely crystalline trachyte, and about 25 per cent euhedral orthoclase. The clay grains retain perfectly the fibrous pumice structure. The clay portion is of unusual purity and was separated and analyzed. (See p. 186.) At the base of the pumice mass is a layer of small phonolite pebbles that are almost completely kaolinized.

At nearly the same horizon are beds of deep-red sandy clay that are composed of orthoclase, pumice fragments altered to clay, and altered trachyte fragments. The red layer is in sharp bedded contact above and below with beds of normal color, and it is evident that oxidation occurred during or before deposition and is not the result of recent weathering.

Pebbles of red clay were noted by C. H. Dane [58] in the tuff three-quarters of a mile south of Lockesburg. They were apparently derived from a bed of red clay older than the tuff, and they were oxidized before they were deposited in their present position, which is about 20 feet above the base of the Woodbine.

[58] Oral communication.

COLEMAN CREEK, HOWARD COUNTY, ARK.

The tuff layer crops out for about three-quarters of a mile along the banks and in the bed of Coleman Creek, locally called Temperanceville Creek, about 3 miles northwest of Nashville. (See fig. 17.) The total thickness of the exposed beds is about 12 to 15 feet, and two small prospect pits have penetrated the tuffs some feet below water level. The beds are all claylike, for they are all derived from pumice tuff, and they contain accessory grains and fragments of lithic trachyte. Phonolite tuff beds are not exposed on Coleman Creek. The pumice contains abundant orthoclase, but other phenocrysts make less than 2 per cent of the rock.

The minerals identified after concentration by heavy solutions are biotite, titanite, magnetite, and black spinel. Augite is present but it was possibly derived from phonolite fragments and not from the pumice tuffs. A little tourmaline and garnet are occasionally seen among the heavy minerals.

The predominant material is the gray bentonitic clay derived from angular altered grains of glassy pumice. These beds contain many calcite concretions that form masses with a maximum diameter of several feet that are especially abundant in the creek bed. It was one of these masses of calcite-cemented tuff from Coleman Creek, submitted to the Geological Survey by Mr. J. N. Garner, that led to the recognition of volcanic material in the region.

The rock fragments in the pumice tuffs are angular or subrounded, not well rounded like the phonolite rock fragments. The trachyte fragments have resisted weathering better than the phonolite and are fresh for the most part, and these heavy minerals are identical with those found in the pumice tuffs. The analysis of the orthoclase trachyte given on page 186 was made on fresh grains that were picked by hand from the tuffs on Coleman Creek. These ranged from 1 to 10 millimeters in diameter and were nearly white. They were composed of euhedral orthoclase in a very fine grained aphanitic groundmass of alkalic feldspar without characteristic crystal form. The rock was almost without dark minerals, but an occasional grain of biotite, titanite, magnetite, or black spinel could be observed.

PLEASANT VALLEY CREEK, HOWARD COUNTY, ARK.

Pleasant Valley Creek drains eastward into Mine Creek, and along its bed the tuffs are well exposed. (See fig. 17.) Here there is a smaller admixture of nonvolcanic rock débris than on Mine Creek, and claylike material, derived from glassy volcanic tuffs, and angular lithic fragments are the most conspicuous materials of the beds. Small fragments of trachyte are especially abundant in the creek bed but do not differ from those on Coleman Creek.

BLUE BAYOU, HOWARD COUNTY, ARK.

Some of the most extensive exposures of volcanic tuff in the entire region are found on Blue Bayou, extending from a point a short distance west of Forgy almost to Center Point. The best of these are near Blue Bayou Church, where about 40 feet of the tuff is exposed. (See fig. 17.)

All types of volcanic débris are represented, but the gray and blue-gray claylike material is probably the predominant component. With this are mixed trachyte pumice fragments and angular orthoclase trachyte fragments, rounded rock pellets of the phonolite tuff, and various proportions of nonvolcanic rock material. The beds are lens-shaped and show very marked cross-bedding, and the size and character of the material at a particular horizon change laterally within a few rods.

The most abundant form of tuff at Blue Bayou Church is a loosely coherent material of light bluish-gray color. It is made up of claylike pellets that have been derived from glassy pumice fragments, trachyte grains, igneous-rock phenocrysts, and a small amount of quartz and other detrital material derived from sedimentary rocks. The grains range in diameter from about 1 millimeter to 15 millimeters.

The minerals are largely orthoclase, but biotite, titanite, and black spinel form less than 2 per cent of the rock. The orthoclase is very perfectly euhedral for the most part, but a few crystals are etched, and many are fractured so that only one end of the crystal is complete. Biotite is the most abundant dark mineral and occurs in flakes with euhedral outline. The black spinel has euhedral form and very brilliant crystal faces. Pale-brown shotlike pellets of siderite with radial structure and a little pyrite are secondary minerals that developed subsequent to the deposition of the ash.

Another specimen from Blue Bayou Bluff represents material that is composed of lithic and vitric tuffs in about equal parts. It is light bluish gray and is composed of fragments that reach a maximum length of about 5 millimeters. These are angular fragments of finely crystalline trachyte, flattened fragments of pumice, and mineral grains that represent igneous-rock phenocrysts.

A microscopic study of thin sections shows that the pumice has been altered to a bentonitic clay mineral, many grains of which have a lens shape, which is due to flattening by compression and loss of the original pumiceous porosity. The microscope shows that many of these clay grains are made up of a micaceous mineral with high birefringence. Each pumice fragment appears to be a single distorted individual crystal of clay material. It is evident that during alteration the porous individual grains became flattened and accommodated themselves to the contour of the contiguous grains and thus assumed a distorted shape.

Of the mineral grains that represent phenocrysts from the igneous rock, orthoclase is the only one that is abundant. Rare dark minerals are augite, biotite, titanite, green and brown hornblende, apatite, magnetite, black spinel, and pink garnet. The rock differs from the phonolitic tuff on the Owen place, described below, in having abundant biotite but little augite.

OWEN PLACE, HOWARD COUNTY, ARK.

The basal part of the tuff beds, where the phonolite tuffs are exposed in unusual perfection, crops out along the northern border of the tuff area at many points between Center Point and Corinth, Howard County, Ark. One of the best sections is found on the Owen place, about 3 miles west of Corinth, in the valley of a small northward-flowing stream. (See fig. 17.)

Boulders, some of which reach a maximum diameter of several feet, are scattered over the surface and locally they are very abundant. These are indurated masses of pumiceous tuff that were originally cemented with calcium carbonate. The carbonate has since been partly or wholly leached away in the boulders that have long been lying on the surface, but others that have not been subjected to prolonged weathering still contain much calcium carbonate.

The delicate structure of very porous, almost feather-like pumice fragments is to be seen in many of the boulders where the pumice has been exposed by the leaching away of the inclosing calcium carbonate. In other boulders the pumice glass itself has been partly or wholly replaced by calcium carbonate, and in these the pumice structure has been completely preserved and is recognizable under the microscope even where the rock is all calcium carbonate. (See pl. 22, *B*.)

The calcium carbonate boulders occur embedded in the bentonitic clay beds derived from tuffs, and as the structure is the same in both types of material, it seems evident that both are derived from the same glassy pumice beds. The local cementation of the glassy pumice into the boulderlike masses must have taken place before the tuffs were altered, for the delicate tuff structure and the thin-walled vesicular cavities are perfectly preserved. The greater part of these beds remained uncemented, and underwent the normal devitrification process by which glassy volcanic tuff was altered to a bentonitic clay mineral.

Outcrops of clay beds derived from pumice tuff are not numerous in the area, but these beds do not form good outcrops, and it is probable that deposits of pumice tuff are more numerous and thicker than the exposures would indicate.

The phonolite tuffs on the Owen place, 3 miles west of Corinth, are among the best examples of this type of material in the entire region. Large masses have been completely indurated by the infiltration of calcium and iron carbonates. The color of phonolite tuff is gray-green or dark olive-green. The material is rather well sorted, as only a small portion of the grains range between 0.2 and 0.4 millimeter in diameter and most of them are between 0.5 and 1 millimeter. All the grains are surrounded by a film of gray-green glauconitic material about 0.01 millimeter in thickness, and the igneous rock and minerals have been partly replaced by it. Well-rounded fragments of phonolite rock form one-third to two-thirds of the pellet-like grains that make up the rock and are the most abundant single material present. The fine-grained groundmass feldspar of the phonolite appears to be fresh, although there has probably been some kaolinization, and the associated ferromagnesian minerals are fresh. All rock grains retain the texture of a trachytic phonolite, and some are so fresh that nephelite can be recognized. Novaculite grains are present but are not abundant, quartz in well-rounded grains is the next most abundant material present, and red grains of iron oxide form several per cent of the rock.

Volcanic-rock minerals that represent phenocrysts make up about 5 per cent of the grains. These in the order of their abundance are orthoclase, pale-green augite, dark-green hornblende, titanite, magnetite, black spinel, biotite, red-brown basaltic hornblende, apatite, and zircon. Most of these crystals are perfectly euhedral. A few show a very little rounding, but the greater part have sharp, brilliant crystal faces. This is especially true of spinel, magnetite, hornblende, titanite, and orthoclase. The pale-green augite has the cockscomb-like multiple terminations shown in Plate 24, *A*.

Carbonate completely fills the spaces between the grains in the indurated boulderlike masses. The presence of these nodular masses and the manner in which some of the mineral grains have been replaced indicate that the calcium carbonate was brought in by solution. This inference is confirmed by the presence of the glauconitic films around the grains that must have been formed in place and prior to the deposition of the calcium carbonate.

THE TUFFACEOUS SANDS IN TEXAS

The tuffaceous sands of the Woodbine formation in northeastern Texas occur mainly in a well-defined zone 200 or 250 feet below the top of the formation as it is defined in Red River and Lamar Counties. The sands of this zone have been examined at seven localities, six of which are alined in a nearly direct east-west line in the northern part of Red River and Lamar Counties and the seventh is in the northwestern part of Fannin County. (See pl. 20.) A small percentage of volcanic material has been found also in sands of questionable Eagle Ford or basal Austin age near Woodland, in Red River County, and near Medill, in Lamar County, but these sands can hardly be called tuffaceous, and their small content of volcanic material may have here been derived by reworking from older tuffaceous beds. The rocks at this locality, though they resemble the Woodbine formation contain the species *Ostrea sannionis* White, which by comparison with the occurrence of the type of this species in the Western Interior, suggests either the Benton or the lower Niobrara and therefore either the Eagle Ford or the lower Austin age of the beds. As high as 20 per cent of volcanic material was found in a greenish-gray sandstone lying only 10 feet below the top of the Woodbine formation and having an exposed thickness of 3 or 4 feet, in a low bluff on Red River, 1½ miles north of the Ragtown settlement in the northwestern part of Lamar County.

The mineral composition of material from the locality is as follows:

Composition of sandstone containing volcanic material 1½ miles north of Ragtown, Tex.

	Per cent
Quartz	80
Orthoclase	6. 5
Phonolite	12
Magnetite	1
Titanite, biotite, zircon, tourmaline, staurolite, and black spinel	Less than 1

The tuffaceous sands of Texas are similar to the phonolite tuffs from the Owen place and Blue Bayou in Arkansas. (See fig. 17.) Most of them contain a larger proportion of detrital quartz and a little novaculite, but a few specimens are predominantly volcanic material. The igneous material at Arthur City is largely in the form of rounded fragments of fine-grained phonolite, but a few grains of the trachyte are present, and a very few grains of altered glassy pumice are to be found. The mineral grains observed are orthoclase, a very little sodic plagioclase, biotite, augite, hornblende, titanite, magnetite, black spinel, and apatite. Magnetite, spinel, and titanite appear to be nearly as abundant as in the Arkansas localities, but hornblende and augite are extremely rare in most of the Texas deposits. A study of thin sections indicates that augite was originally abundant but has been almost completely replaced by calcium carbonate. The orthoclase, titanite, biotite, spinel, and magnetite show subhedral to euhedral forms but are less commonly euhedral than in Arkansas. A few grains of brown tourmaline are present in all the samples. Orthoclase biotite, titanite, and black spinel are minerals that are more abundant in the pumice and trachytic tuffs than in the phonolite tuffs in the Arkansas areas, and this seems to indicate that trachyte and phonolite have both contributed material to the Texas beds, although few trachyte grains and less glass are now recognizable in them. It seems probable that the greater distance of the Texas beds from the volcanic source has resulted in the destruction of the more delicate structures during transportation, and that in this way the pumice has largely disappeared, but at the same time the orthoclase and other minerals that represent the phenocrysts from the same source have escaped destruction.

SILVER CITY FERRY, RED RIVER COUNTY

Silver City Ferry, on Red River, is in Red River County, Tex., about 17.5 miles almost due north of Clarksville, the county seat. The bluff below the ferry reveals about 15 feet of tuffaceous sandstone of the Woodbine sand, overlain by about 10 feet of river alluvium consisting of loam, clay, and sand, with a band of gravel along the base. (See pl. 25, *A*.)

The tuffaceous sandstone is a coarse green pebbly cross-bedded sand, irregularly cemented with calcite, which gives to the rock a silvery sheen. Thin veins of calcite also cut the sandstone in places. The sandstone dips perceptibly downstream and is underlain between the main exposure and the ferry by 10 feet of dark clay containing some vegetable particles and near the top a few poorly preserved leaves. Near the middle of the clay is a band of soft cross-bedded sandstone containing a few poorly preserved pelecypod casts and molds and some nodules of marcasite.

About 100 yards above the ferry and apparently at a lower stratigraphic level than the dark clay the bluff exposes 6 or 8 feet of greenish-gray clay with partly indurated sandy lenses near the base, and below this clay is 4 or 5 feet of mottled purplish sandy clay exposed just above water level.

All the materials exposed in the vicinity of the ferry, except the overlying river alluvium, belong to the Woodbine sand.

The specimens collected at Silver City Ferry are a dark gray-green calcite-cemented tuffaceous sand, in which volcanic-rock materials are more abundant than detrital grains. The following rock materials and minerals have been identified: Phonolite, quartz, novaculite, orthoclase, hornblende, magnetite, black spinel, titanite, zircon, apatite, garnet, and tourmaline.

EAST OF KANAWHA, RED RIVER COUNTY

Five or six feet of tuffaceous sand of the Woodbine formation is exposed in a ravine 2 miles east of Kanawha, about 0.2 mile southeast of the intersection of the Manchester-Klomatia and Kanawha-Scrap roads. (See pl. 20.) The locality, which is about 20 miles northwest of Clarksville, is especially interesting on account of the occurrence of many individuals of *Ostrea soleniscus* Meek, a characteristic Woodbine species, in the tuffaceous sand.

The sand is irregularly bedded and consists of quartz, fragments of volcanic rock and minerals, glauconite, and novaculite, named in the approximate order of their abundance. Some clay is interbedded with the sand. The sand is irregularly indurated to nodular masses. The oysters occur in great numbers, mainly in the lower 3 feet of the section, where in places the shells are attached to one another in clusters. The shells are not well preserved and are difficult to collect in good condition. This locality was reported to Stephenson by W. B. Sprague, a geologist of the Gulf Production Co., who visited it in 1924.

The calcite-cemented tuffaceous sands examined from the Kanawha locality contained not more than 25 per cent of volcanic materials among the mineral grains. The specimens are characterized by numerous fossil fragments, by a large proportion of cementing calcite between the mineral grains, and by abundant glauconite. Augite was originally present but has been completely altered to a calcite-glauconite aggregate. The following table gives the approximate mineral composition:

Minerals and rock grains of tuffaceous sand east of Kanawha

Quartz	47
Novaculite	5
Glauconite	25
Orthoclase	8
Phonolite grains	15

Minerals present in small quantities are biotite, hornblende, magnetite, black spinel, titanite, garnet, apatite, phosphatic grains, siderite, and pumice.

PINE BLUFF FERRY, RED RIVER COUNTY

The tuffaceous sand of the Woodbine is well exposed at Pine Bluff Ferry, Red River County, about 23 miles northwest of Clarksville, Tex. (See pl. 20.) The river touches the edge of a high terrace plain at this locality, revealing the following section:

Section at Pine Bluff Ferry, on Red River, Red River County, Tex.

	Feet
Pleistocene terrace deposit: Alluvial loam, sand, and gravel	15
Upper Cretaceous (Woodbine sand):	
Massive sticky clay, poorly exposed	15
Coarse water-laid tuffaceous sand with only a small percentage of quartz and novaculite; the sand is partly indurated, exhibiting many oval to irregular concretionary masses	25
Stratified tuffaceous sand with subordinate layers of quartz sand and some thin interbedded clay layers; contains some comminuted plant fragments	33
Concealed by flood water; reported	6
	94

The specimens collected at Pine Bluff are a dark gray-green calcite-cemented tuffaceous sand, in which volcanic materials are unusually abundant and fresh. The rocks and minerals present are listed below:

Mineral and rock grains of tuffaceous sand at Pine Bluff Ferry, Tex.

Phonolite	70
Orthoclase	10
Quartz	5
Novaculite	3
Augite	4

Small quantities of hornblende, magnetite, black spinel, titanite, garnet, apatite, and zircon are present.

GOLDEN BLUFF, RED RIVER, LAMAR COUNTY

Golden Bluff on Red River, 3 miles east of Arthur City, Lamar County, Tex. (see pl. 20), exhibits another section in the edge of a high Pleistocene terrace, the lower 35 feet of which is composed of tuffaceous sand.

Section at Golden Bluff on Red River, Lamar County, Tex.

	Feet
Pleistocene terrace deposit: Alluvial sand, poorly exposed	35
Upper Cretaceous (Woodbine sand):	
Gray, more or less sandy, crumbly clay, with comminuted plant fragments	25
Soft to hard, fine-grained, finely glauconitic sandstone, with fossils abundant in places	0. 5–1
Interbedded sandy shaly clay and impure fine sand, weathering somewhat mealy; a few imperfect fossil leaves noted	30
Coarse, irregularly bedded mealy tuffaceous sand, indurated in part to irregular, more or less nodular masses. The sand is mainly quartz but contains a considerable percentage of volcanic material, a few pebbles, and a few fragments of fossil wood. Only 15 feet is exposed at the lower end of the bluff, but the sand rises upstream, reaching an exposed thickness at the upper end of the bluff of	35
	126

The molluscan species found in the glauconitic sandstone are for the most part poorly preserved and with one questionable exception have been only generically identified. The bivalves include *Nucula*, *Ostrea soleniscus* Meek?, *Exogyra*, *Pecten*, *Plicatula*, *Pholadomya*, *Isocardia*?, *Aphrodina*, and *Cyprimeria;* the univalves are represented by *Gyrodes*?, *Apporhais* and several unidentified forms; and there are two chambered shells belonging to the ammonite genera *Metoicoceras*, and *Metengonoceras*. Although in the light of present knowledge of the ranges of these fossils none of them afford conclusive evidence of the age of the containing bed, comparison with other collections suggests that the bed belongs to the upper part of the Woodbine formation.

The tuffaceous sands at Golden Bluff are predominantly quartz but contain about 25 per cent of volcanic materials. Phonolite rock fragments form about 20 per cent, and small amounts of orthoclase, plagioclase, biotite, chlorite, apatite, and calcite-glauconite areas that represent altered augite are present.

ARTHURS BLUFF, LAMAR COUNTY

Arthurs Bluff, on the south bank of Red River just north of Arthur City, Lamar County, Tex., is one of the most accessible localities for studying volcanic material in the Woodbine sand, being reached both by rail and by highway. (See pls. 20, 25, *B*, and 26.) The bluff serves as the south abutment of the Frisco Lines railroad bridge across Red River and as the south abutment of the bridge on the highway between Paris, Tex., and Hugo, Okla.

Exposures of cross-bedded tuffaceous sand occur below the highway bridge and at and below the lower ferry and extend up the face of the bluff to a level about 10 feet above the river. (See pl. 25, *B*.) The sand is interbedded with and overlain by dark laminated more or less sandy clay, which rises at least 20 feet above the river and which contains many well-preserved fossil plants. A collection of plants, obtained chiefly in clay above the main band of tuffaceous sandstone at this locality, was described by Berry,[59] but fossil leaves were noted in the tuffaceous beds also. The sand is in large measure cemented by calcium carbonate, and the parts so cemented crop out as ledges and as nodular and irregular masses a foot or more in diameter. The sand is coarse to fine grained and is olive-green when fresh but changes to yellowish green on weathering. Thin layers of clay ironstone (iron carbonate) are common in the sand, but at the lower ferry there is a lens of this carbonate ranging in thickness from a feather edge to 15 inches. Just below the highway bridge a projecting ledge of tuffaceous sandstone, in places 5 feet thick, contains pebbles of novaculite and other rocks and in its lower part laminated masses of clay ironstone as much as 3 feet in diameter that have been tilted into all positions from horizontal to vertical. The sandstone of the projecting ledge is thus a conglomerate.

At the upper ferry, above the railroad bridge, a section is exposed which consists chiefly of irregularly bedded dark-gray to greenish-gray sandy shaly clay of the Woodbine formation rising 20 to 25 feet above the river. At the upper end of the bluff several lenses of tuffaceous sand were noted in the clay. Leaf impressions occur in the clay in places.

The Woodbine at Arthurs Bluff is overlain by 2 to 15 feet of Pleistocene alluvial terrace deposits.

The volcanic tuffs are very well represented at the Arthur City Ferry, and their unusual purity at some horizons and the perfect preservation of materials make this the best locality in Texas for their study. The color ranges from yellowish green to dark gray-green where perfectly fresh. The color is due to glauconitic films around the individual mineral and rock grains. Secondary calcite has cemented the grains into rounded concretions, and commonly the concretions, several inches in diameter in large areas, have uniform orientation and give an ophitic appearance to the rock. The rock and mineral grains average about 0.5 millimeter in diameter.

A representative specimen of the rock is made up of mineral and rock grains in the following proportions, and these are inclosed in calcite:

[59] Berry, E. W., The flora of the Woodbine sand at Arthurs Bluff, Tex.: U. S. Geol. Survey Prof. Paper 129, pp. 153-181, 1922.

Mineral and rock grains of tuff beds at Arthur City Ferry

Quartz	10
Novaculite	6
Phonolite	70
Orthoclase	11

With these are minor quantities of trachytic rock grains, pumice, augite, hornblende, biotite, magnetite, black spinel, apatite, zircon, tourmaline, staurolite, siderite, and phosphatic grains.

In all the specimens phonolite is the dominant igneous rock material, but trachytic volcanic rock fragments, orthoclase, and small quantities of dark minerals are always present. The phonolite grains have been largely altered to a green "chloritic" material that chemical tests seem to indicate are glauconite.

GARRETS BLUFF, RED RIVER, LAMAR COUNTY

The next locality west of Arthurs Bluff at which the main bed of tuffaceous sand of the Woodbine has been examined is at Garrets Bluff on Red River, about 18 miles northwest of Paris, Lamar County, Tex. (See pl. 20.) The section is in the edge of a Pleistocene terrace that lies about 25 feet above low-water level, and the upper 15 feet of the section is composed of river alluvium.

The tuffaceous sand is exposed beneath the alluvium for about 100 yards along the face of the upstream end of the bluff. The sand is coarse, greenish, and cross-bedded and is made up of quartz sand and volcanic materials in differing proportions in different parts of the bluff. One sample was obtained that was composed largely of volcanic materials. The sand is unevenly indurated, in places exhibiting round concretionary masses. One relatively small lens of hard, dense shattered iron carbonate was observed. A few pieces of silicified wood were noted in the sand. The tuffaceous sand dips perceptibly upstream and is underlain first by several feet of dark laminated clay and below this by massive purplish-mottled clay, which chiefly makes up the bluff below the alluvial covering for the remainder of the distance downstream to the lower end of the bluff which has an estimated length of about half a mile. The section is very similar in its lithologic characters and in the succession of beds exposed to the bluff at Silver City Ferry, in Red River County. The tuffaceous sand at Garrets Bluff has a characteristic mineral and rock composition similar to that at Arthur City Ferry.

HYATTS BLUFF, FANNIN COUNTY

Hyatts Bluff, on the south bank of Red River, 7 miles northwest of Ravenna, Fannin County, Tex., reveals the westernmost observed exposure of tuffaceous sand in the Woodbine formation. (See pls. 20 and 27.)

The exposure, about half a mile long and 25 feet high, is in a steep slope and cliff that rise from the water's edge. The upper half of the exposure shows dark laminated clay interbedded with thin layers of greenish tuffaceous sand. Both the clay and the sand contain many nodules and lenses of dark-gray clay ironstone (iron carbonate), some of them 2 inches thick, and in one layer of clay marine invertebrate fossils were found. The lower half of the exposure consists of greenish fine to coarse-grained cross-bedded sandstone in which there are a few invertebrate fossils and some clay ironstone both as pebbles and nodules. Some of the sandstone on weathering takes the form of spherical masses, the largest a few feet in diameter. The rocks in the exposure at this locality were described by Stephenson [60] in 1918, but the tuffaceous character of some of the beds was not then recognized.

The tuffaceous sands from Hyatts Bluff are predominantly volcanic material, but with this is an unusually large proportion of siderite in rounded grains with a radial habit. There are many rock grains made up of quartz and feldspar in a greenish clay matrix, and these evidently represent fragments of an older sedimentary rock that have been transported to their present location without disintegration. The presence of volcanic material in the grains indicates that redeposition has taken place since the first volcanic activity. The phonolite fragments are unusually well preserved, but associated with these are trachyte and pumice fragments. Therefore both phonolite and trachyte have contributed material to form the beds at Hyatts Bluff.

PHONOLITE TUFFS OF LOUISIANA

Volcanic tuffs of the phonolite type crop out on the Prothro salt dome, in T. 14 N., R. 6 W., Bienville Parish, La.,[61] where they form beds 75 feet thick that stand almost vertical. Volcanic material of the same kind has been found in the Rayburn salt dome, in T. 15 N., R. 5 W., Bienville Parish. It has also been found at a depth of 2,945 feet in sec. 28, T. 14 N., R. 6 W., Bienville Parish, about 3 miles south of the Prothro salt dome, and at a depth of 2,456 feet in a well in sec. 16, T. 22 N., R. 3 W., Claibourne Parish. Specimens from the Prothro dome were collected by Spooner, and the minerals and lithology were studied by Ross and the fossils by Stephenson. The fossils indicate, according to Stephenson, that this rock is younger than the Eagle Ford clay and is probably of the age of the typical Austin chalk and of the Tokio formation.

The tuffaceous sand that crops out in the Prothro dome, although younger than the phonolitic tuff beds in Arkansas, Oklahoma, and Texas, differs from them in no essential characteristic. The approximate proportions of its rock and mineral components are listed on page 194. Small, well-round edgranules of phonolite low in dark minerals are, next to quartz, the most abundant material in the rock. Orthoclase is present in considerable proportions, and augite, plagioclase, hornblende, titanite, biotite, magnetite, black spinel, apatite, and zircon are igneous-rock minerals that occur in small proportions. Minerals that have developed since deposition are glauconite, siderite, calcite, and pyrite. Metamorphic-rock minerals are garnet, tourmaline, and staurolite. The beds are completely cemented with calcite like some of those in the Texas areas. Two types of glauconite are present; one, consisting of small rounded blue-green granules composed of overlapping crystal plates, is the normal glauconite that is believed to form on the sea bottom during sedimentation, and the other is the yellow-green material that formed after sedimentation ceased and replaced mineral grains and rock fragments. The beds at the Prothro dome differ slightly from the tuffs of Arkansas in containing marine fossils, a larger proportion of the marine type of glauconite, and a little plagioclase. Volcanic material of the same type occurs in the Rayburn salt dome, about 5 miles northeast of the Prothro dome.[62]

RILEY PLACE AND TWIN KNOBS, PIKE COUNTY, ARK.

The best exposures of the peridotite tuff (?) are on the Riley place, in the W.½ SW.¼ sec. 22, T. 8 S., R. 25 W., half a mile northeast of the Ozark diamond mine near Murfreesboro, Pike County, Ark. (See pl. 20.) The material, which was studied by Miser in 1912, was revealed at the time of examination in a well, a pit, and two trenches. Marion Riley, who dug the well, says it was originally 41½ feet deep and that the tuff (?) extends to the bottom and the well did not go through it. The well at the time of examination was only 18 feet deep. The pit south of the Riley house is 12 feet deep. The bed here consists of a greenish-yellow coarse-grained earth and shows lamination and cross-bedding. It consists principally of well-rounded grains of quartz sand intimately mixed with possibly an equal or larger quantity of altered serpentine grains and a little mica in small flakes. Some quartz pebbles and fragments of gray sandstone, semivitrified clay, black shale, and weathered peridotite are also present. A horizontal layer of clay and several lenses of clay lying along bedding planes were observed. Some diamond prospectors have thought that the tuff (?) bed is weathered peridotite and that it forms a part of an eastward extension of the peridotite body that is exposed half a mile to the southwest, near the mouth of Prairie Creek. The mineral com-

[60] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, pp. 145-146, pl. 25 *A*, 1918.

[61] Spooner, W. C., Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 245-256, 1926.

[62] Spooner, W. C., op. cit., pp. 260-265.

position of the bed and the arrangement of its material, however, show without doubt that the bed was water-laid. The bed apparently lies at the base of the Tokio formation (Upper Cretaceous) in this locality.

Another exposure of the peridotite tuff (?) was observed in 1912 by Miser in two small pits on the north side of Twin Knobs, near the center of sec. 22, T. 8 S., R. 25 W., a mile east-northeast of the Ozark diamond mine. The following section was measured on the north slope from the base to the top of the north knob.

Section of Tokio formation at Twin Knobs

	Feet
Gravel on top of hill and on slope; in places there are exposures of clay	60
Gravel	20
Clay; the earth shown in the two pits is near the middle of this bed; altered serpentine grains and mica are present in the material	40
Gravel (base of Tokio formation)	10±
Clay (Trinity formation)	10±

DIAMONDS IN VOLCANIC DEPOSITS OF WOODBINE AND TOKIO FORMATIONS

Diamonds have been prospected for in the peridotite tuff of the Tokio formation on the Riley place, half a mile northeast of the Ozark diamond mine, near Murfreesboro, Ark. Search has also been made for them in volcanic tuff in the Woodbine formation on and near Mine Creek, from 3 to 4 miles north of Nashville, Ark. (See fig. 17.) No diamonds have thus far been reported from the Riley place, but the discovery of five small stones has been reported from the Will Sanger place, 4 miles north of Nashville, and three small stones have been reported from the George Power place, 3 miles north of Nashville. (See fig. 17.)

Some stones may occur in the peridotite tuff (?) on the Riley place and at other localities of such tuff, but it does not seem likely that the diamond content would equal that of the diamond-bearing peridotite at the mines near Murfreesboro, Ark. This conclusion apparently follows from the fact that much sand and sedimentary clay are component parts of the tuff.

The discovery of additional stones may be reported from the volcanic tuff of the Woodbine near Nashville, but the fact that only a very small quantity of peridotite fragments—if any actually are present—occurs in the tuff leads to the conclusion that not more than a few stones will ever be found in the tuff.

The peridotite tuff (?) on the Riley place, contains pebbles of peridotite and grains of altered serpentine that were washed from an exposure of peridotite or were ejected as fragmental material from volcanic vents. This material apparently lies at the base of the Tokio formation in this locality. To determine whether or not the material contains diamonds the Ozark Mines Corporation washed 1,000 loads (16 cubic feet each) of it. No diamonds were found.

The prospecting for diamonds on Mine Creek 4 miles north of Nashville has been done at times by various persons. The work, which has been done on land belonging to Will Sanger, consisted of digging volcanic tuff from the bed and bank of the creek and sinking a pit 20 feet deep on the west side of the creek. During the work a small sluice trough was used to separate grains of transparent feldspar from the claylike material inclosing the feldspar grains. The strata exposed in the bed and banks of the creek at this locality consist of greenish volcanic tuff containing lenses of gravel, the pebbles of which include both igneous and sedimentary rocks. The tuff is a part of the main tuff bed in the upper part of the Woodbine formation. Some persons have thought that a part of the material in the tuff at this locality was derived from peridotite and that consequently the tuff might be diamond-bearing. That a very little of it was so derived is likely, but the microscopic study of the tuff by Ross failed to disclose any fragments of peridotite. Prospecting that was done here in 1920 by Captain Dixon is reported by him to have led to the discovery of five small diamonds, which have been presented to the American Museum of Natural History.

Three small diamonds shown to Ross and Miser in 1923 are said by George Power to have been found in that year on his place in sec. 11, T. 9 S., R. 27 W., about 3 miles north of Nashville. (See fig. 17.) Mr. Power says that two of the stones, one a light-yellow stone weighing about a third of a carat and the other a white stone weighing about one-fifth of a carat, were found on the pile of material obtained from digging his well in 1919. The well passed through 14 feet of gravel and then penetrated 36 feet of greenish and gray material without passing through it. This material, although much weathered from four years' exposure on the surface, is apparently volcanic tuff. It was in this apparent volcanic tuff that Mr. Power says he found the two diamonds. A third stone, white with a flattened rice-like shape, was, according to Mr. Power, found by him 100 yards southeast of his house and thus some distance away from the material removed from the well.

DEPOSITS OF KAOLIN (ALTERED VOLCANIC MATERIAL)

Beds of kaolin occur in the Tokio formation in the hilly, wooded region between Murfreesboro and Delight, Ark. (See pl. 20.) The kaolin, as explained on pages 186 and 187, is probably altered and reworked feldspathic material derived from volcanic ash. It occurs as horizontal layers near the tops of hills at several localities. The greatest thickness observed by the writers is 5 feet, but the greatest reported thickness is 9 feet. The deposits have been prospected, and the kaolin is reported to be a satisfactory fuller's earth for refining edible oils and petroleum.

One of the best-known occurrences is at the Adams kaolin pits, on land of the Ozan Lumber Co., in the NE. ¼ SE. ¼ sec. 24, T. 8 S., R. 24 W., 5 miles east-southeast of Murfreesboro. Here a 5-foot bed has been opened by three or four cuts on the hill slopes. The kaolin is underlain by a bed of sand fully 32 feet thick and is overlain directly by sand and this sand in turn by gravel. The sand and gravel overburden on one hill is 13 feet thick and on a near-by hill, southwest and west of the first pit, 20 to 25 feet thick. The bed lies horizontal. Apparently not enough prospecting has been done to determine the extent or continuity in thickness of the bed, though the thickness in the two cuts examined by the writers is 5 feet.

The kaolin at the Adams pits is chalky white to creamy, but the lowest layer, a foot thick, has a lavender color. The kaolin is very fine grained, breaks with a conchoidal fracture, and readily absorbs water, sticking tightly to a person's tongue, but it does not become plastic even with fine grinding. It shows laminations along which it splits with some difficulty, and it contains a few fossil leaves, a collection of which was obtained from the two principal openings. The collection has been studied by E. W. Berry and found by him to represent an Upper Cretaceous flora.

A second locality, which is about 1,000 feet east-northeast of the Adams pits, is in the SE. ¼ NE. ¼ sec. 24, T. 8 S., R. 25 W., on land of the Grayson-McLeod Lumber Co. The locality has been prospected by several pits, but the results are not known except that a 5-foot bed of kaolin similar to that at the Adams pits was found.

The kaolin on the land of the Ozan Lumber Co. and the Grayson-McLeod Lumber Co. has been tested by commercial firms to determine its value both as a china clay and as a fuller's earth. Test pieces of china made from the clay are said to have been of excellent quality except that the color of the fired china was cream to yellow. Tests are said to show that the kaolin as fuller's earth has proved satisfactory in the refining of both edible oils and petroleum. That the kaolin has the properties of fuller's earth was verified in the chemical laboratory of the United States Geological Survey by testing a sample collected by Miser from the Adams pits.

Thinner deposits of kaolin were examined by the Arkansas Geological Survey some 35 years ago. One of these, containing 2 feet of kaolin the upper foot of which is pink and the lower foot white, occurs in the NW. ¼ SW. ¼ sec. 19, T. 8 S., R. 24 W.[63] Analyses are given below.

Analyses of kaolins from Vaughn Creek, Pike County, Ark.

[Dr. T. C. Van Nuys, analyst]

	Upper bed	Lower bed
Silica (SiO_2)	48. 87	47. 39
Alumina (Al_2O_3)	36. 51	34. 67
Ferric oxide (Fe_2O_3)	. 98	2. 31
Lime (CaO)	. 19	. 32
Magnesia (MgO)	. 25	Trace.
Potash (K_2O)	--------	. 20
Soda (Na_2O)	--------	. 39
Water	13. 29	13. 89
	100. 11	97. 17
Water at 110° to 115° C	--------	1. 00

Other reported deposits in the same vicinity as the three localities described above are briefly described by Branner. Some of the thicknesses reported to members of the Arkansas Geological Survey were as great as 9 feet.

A 5-foot bed of kaolin like that at the Adams pits was reported by C. W. Adams to lie in a small hill in the SW. ¼ SE. ¼ sec. 24, T. 8 S., R. 25 W. The overburden of sand and gravel is said by Mr. Adams to be 15 to 20 feet thick.

A bed of kaolin 23 inches thick was observed by Miser in 1909 in a cut and pit in the NE. ¼ sec. 29, T. 8 S., R. 24 W. It is pearly white, is free from sand, and does not appear to be plastic. It is closely laminated, and thin films are stained red and yellow along the laminae.

Two pits revealing hard nonplastic kaolin were examined by Miser in 1909 in the southeastern part of sec. 9, T. 8 S., R. 24 W. One of the pits showed 24 inches and the other 28 inches of white kaolin stained with iron oxide along many joints and laminae. The kaolin is underlain by sand and is overlain by sand and gravel that probably attain a thickness of 15 to 20 feet on the top of the hill.

[63] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, pp. 148-153, 1908.

ALGAE REEFS AND OOLITES OF THE GREEN RIVER FORMATION

By W. H. Bradley

INTRODUCTION

Reefs or beds and isolated nodules of fresh-water algal limestone are abundant in several parts of the Green River formation of Wyoming, Colorado, and Utah. Locally they constitute more than 8 per cent of the basal member of the formation and occur in single reefs or groups of reefs as much as 5.5 meters (18 feet) thick. (See pl. 29, *A*.) Oolitic limestone and algal pebble beds are also plentiful but thinner.

These algae reefs and oolitic beds are interesting not only because they make up an appreciable part of the formation but also because they indicate that the parts of the lakes in which they and the associated beds were formed were shallow and clear except in times of storm, that the lakes had sheltered bays in which an emergent vegetation flourished, and that the streams feeding the lakes brought in a copious supply of dissolved calcium salts.

It is also worthy of passing note that the algae reefs of the Green River formation, although formed in inland lakes during the middle part of the Eocene epoch, are remarkably similar to those found in the Miocene lake beds of the Rhine Valley in Germany. The same species of alga has been the chief agent in forming the reefs in each of these two widely separated localities, and, so far as the writer is aware, deposits with a comparable internal structure are elsewhere unknown.

STRATIGRAPHY AND ECOLOGY

The algae reefs of the Green River formation are most plentiful in shore phases of the formation, as between White and Yampa Rivers in Moffat and Rio Blanco Counties, Colo., and in the northeastward extension of the Bridger Basin in Sweetwater County, Wyo. In both these areas the formation consists of silty shale, sandstone, ostracode and oolitic limestone, and shell marl. Oil shale is practically absent, and beds of shale containing even a small quantity of organic matter are not abundant. In these areas bedlike algae reefs are irregularly distributed through the entire thickness of the formation, but elsewhere in the Green River formation algae reefs are confined almost wholly to the basal member, whose lithology is similar to that of the shore phases. The left-hand column of the section shown in Plate 28 illustrates the kinds of rocks with which algae reefs are habitually associated. This lithology, moreover, is fairly typical of the basal member of the Green River formation in Wyoming as well as in Colorado and Utah, although the proportions of the different kinds of rock vary considerably from place to place.

So far as the writer has observed algae reefs are nowhere closely associated with beds of even moderately rich oil shale but only with sandy and limy shale beds whose oil yields range from a trace to about 5 gallons a ton. This is not surprising, however, because the conditions on the lake bottom where beds of richer oil shale formed were utterly different from those where algae reefs formed. The formation of rich oil shale requires stagnation of water and active putrefaction of vast quantities of organic matter, the products of which would quickly precipitate the lime in solution and also foul the bottom so that it would be unfavorable for most benthonic plants except saprophytes. These conditions are clearly inimical to the formation of algae reefs and explain their absence from the oil-shale zones and also from much of the remainder of the Green River formation, which consists predominantly of shale that may be conveniently termed low-grade oil shale, defined as somewhat limy shale that is finely laminated and that contains enough organic matter to yield on distillation less than 15 gallons of oil to the short ton. In most places beds of richer oil shale are interbedded at rather wide intervals with the low-grade oil shale. The middle and right-hand columns of Plate 28 show the typical lithology of the Green River formation above the basal member.

Locally, as in the vicinity of Parachute Creek, Colo., that part of the section between the basal member and the lowest oil-shale zone consists of hard limy or silty shale and contains a few thin algae reefs. In a few places that part of the formation above the uppermost oil-shale zone also contains thin algae reefs, as in the vicinity of Indian Canyon and near the Duchesne-Uinta county line in Utah. (See pl. 31.)

Each of the two great Eocene lakes, one in Wyoming and the other in Colorado and Utah, in which the basal member of the Green River formation accumulated may be pictured as a very broad sheet of water flooding a large, nearly level fluviatile plain, the top of the Wasatch formation. This plain was built up of clay, silt, and sand brought down by streams from the surrounding mountains, and as the alluvial material is predominantly clay the basinward slopes must have been very gentle.

The beds of clay and stream-channel sandstone of the Wasatch formation in the greater part of each basin are comparable to the youngest flood-plain deposits in Sacramento Valley, Calif., between Butte City and Montezuma Hills, which, according to Bryan [1] consist chiefly of blue clay and silt with deposits of coarser sand and gravel that were laid down in more or less braided stream channels. The gradient of Sacramento River through this area is a little less than 19 centimeters to the kilometer (1 foot to the mile). If this gradient is assumed for the basin floors over which the earliest Green River lakes spread and if it is also assumed that the water was not more than 3 or 4 meters (10 or 15 feet) deep near the shores where the algae reefs formed, then the deepest parts of the lakes near the centers of the basins may have been as much as 15 or 18 meters (50 or 60 feet) deep. But other things being equal, lacustrine sedimentation must soon have lessened this relief on the lake floor so that while the greater part of the basal member was being formed the lake bottoms were nearly level. On the other hand, the earliest lakes may have started as small ponds and backwaters along the stream courses in the alluvial plain and expanded very gradually, filling their basins and leveling up the plain as they grew, until finally they spread over the entire plain from mountain flank to mountain flank.

In these two great shallow lakes algae flourished and built bedlike reefs that expanded broadly over the smooth lake floors. Fish, mollusks, crustaceans, and aquatic insect larvae were also plentiful in the lakes, and turtles (*Baptemys* sp. and *Echmetemys* sp.), crocodiles, birds, and small camels, as well as myriads of winged insects, frequented the lake shores. Along some shores there were marginal swamps which persisted for a considerable time and whose former positions are revealed now by thin coal beds.

But these lakes, despite their enormous area and slight depth, must have been fairly stable water bodies, for some of the thicker algae reefs required, according to the writer's estimate, at least 355 years to form. During that time only slight changes in water level, rate and manner of circulation, and rate of sedimentation could have occurred. Such changes would register in the growth layers of the reef. A considerably longer period of static equilibrium is indicated by the composite reef near the divide between Douglas and Salt Creeks, Colo., which is 5.5 meters (18 feet) thick.

The periodic stability indicated by the algae reefs suggests that the lakes had outlets during at least part of the time, for lakes in inclosed basins are extremely sensitive to climatic changes, and their levels fluctuate perceptibly even "when ordinary weather observations, taken at a limited number of localities in their neighborhood, fail to indicate analogous changes in atmospheric conditions." [2] It is possible that between such periods of stability in the early stages of the Green River lakes they did not overflow. The prevalence of sun-cracked bedding planes and mud curls in some parts of the basal member supports this hypothesis. Yet complete desiccation was probably not frequent, if indeed such an extreme condition was even approached. In the basal member no salt crystallized out in the bottom mud. These lakes, however, may have been comparable in relative permanence, depth, and content of dissolved salts to Goose Lake, Oreg. Goose Lake lies in a region whose average annual rainfall is about 51 centimeters (20 inches). It contains about 1,000 parts per million of dissolved salts, rarely overflows, and although very shallow has never been known to dry up.[3]

It is plain that in later stages of the Green River lakes they had no outlets, for they became progressively more saline until finally large quantities of glauberite crystallized out in the bottom mud. During the saline stages many of the principal oil-shale beds formed. The deposits of these later stages are clearly different from those of the basal member and reflect marked changes in the aspect and constitution of the lakes as they grew older.

FIELD WORK AND ACKNOWLEDGMENTS

This paper describes a collection of algae reefs and oolites made during the field seasons of 1923, 1924, and 1925. During 1923 the writer was assisted by C. H. Dane, of the United States Geological Survey; in 1924 by C. E. Erdmann, also of the Geological Survey; and in 1925 by R. D. Ohrenschall. These men the writer wishes to thank for their cooperation in the field and their interest in the problems that have since arisen.

In the autumn of 1925 the writer visited Canandaigua Lake, N. Y., to collect recent algal pebbles, and in July, 1926, he visited Green Lake, N. Y., to examine and collect specimens of the algae reefs now forming there.

MODERN ALGAE REEFS IN GREEN LAKE, N. Y.

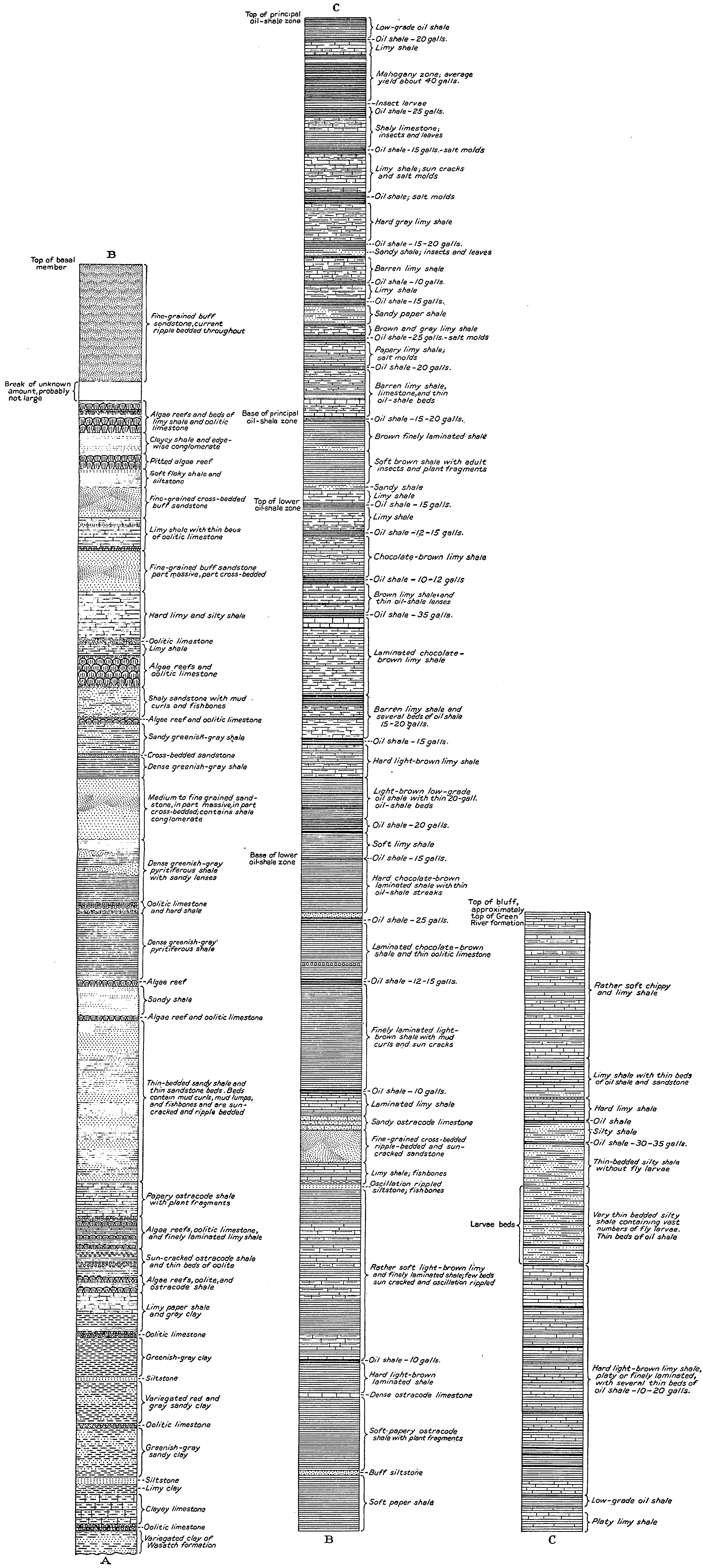
STRUCTURE

An examination of the structure of algae reefs now forming in Green Lake, N. Y., assists greatly to in-

[1] Bryan, Kirk, Geology and ground-water resources of Sacramento Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 495, pp. 7, 10, 39–43, 1923.

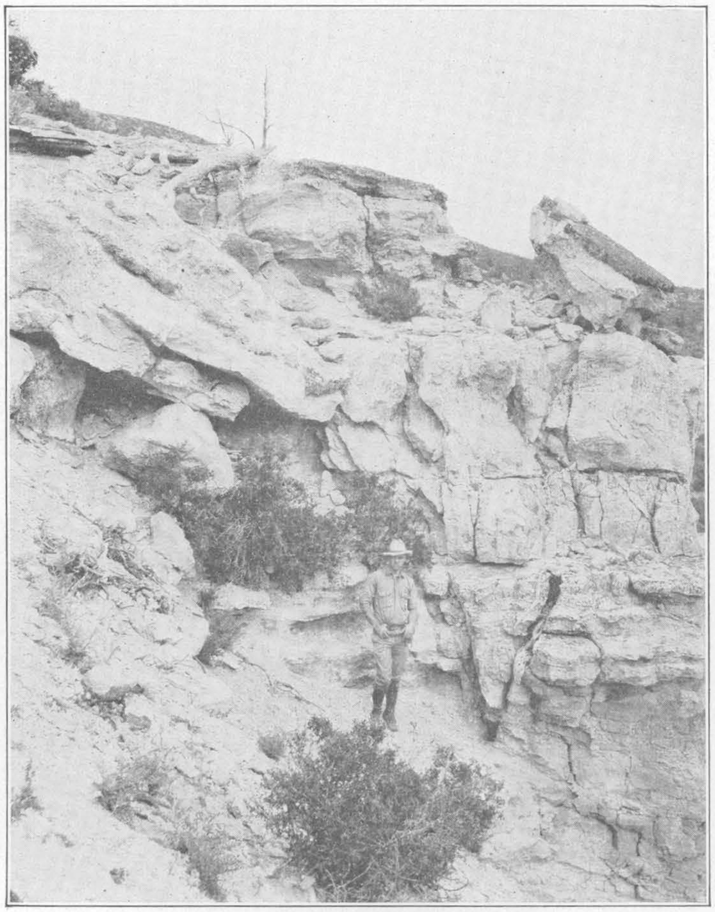
[2] Russell, I. C., Lakes of North America, p. 71, 1895.

[3] Waring, G. A., Geology and water resources of a portion of south-central Oregon: U. S. Geol. Survey Water-Supply Paper 220, pp. 12, 38, 1908.



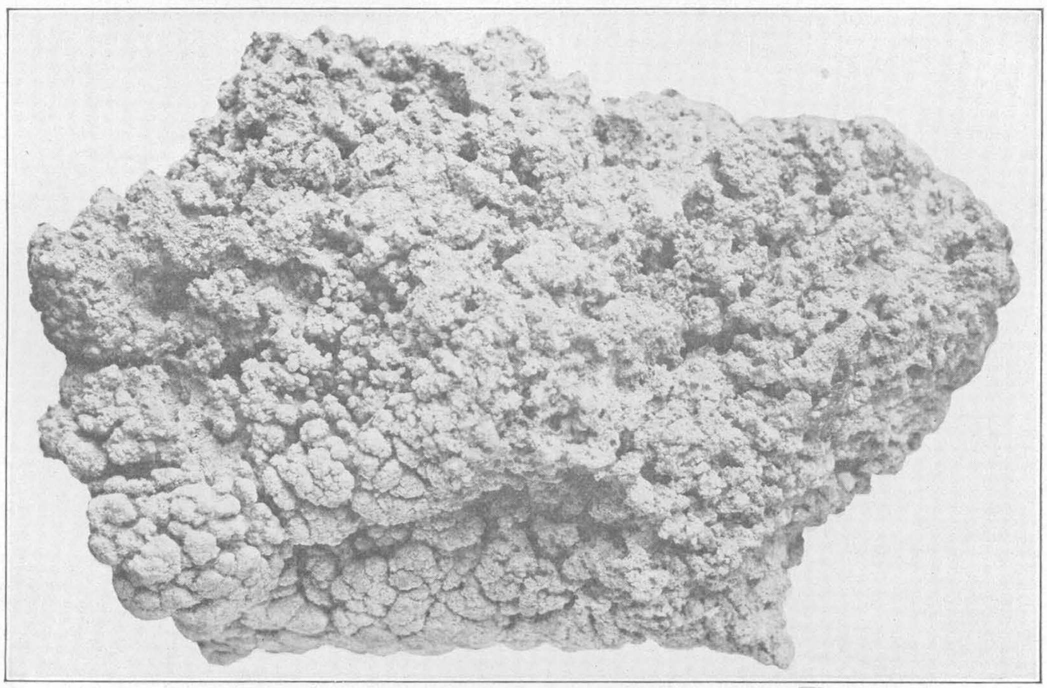
COMPOSITE SECTION OF THE GREEN RIVER FORMATION SHOWING THE DISTRIBUTION OF THE ALGAE REEFS AND THE CONTRAST IN LITHOLOGY BETWEEN THE BASAL MEMBER AND THE REST OF THE FORMATION

The basal member, up to the break near its top, was measured along the Fruita-Rangely road on the divide between Douglas and East Salt Creeks, Colo. The remainder of the section was measured near the head of Cathedral Creek, approximately in sec. 6, T. 3 S., R. 99 W., Colo. The yields of the oil-shale beds are estimated. Scale, 1 inch = 50 feet



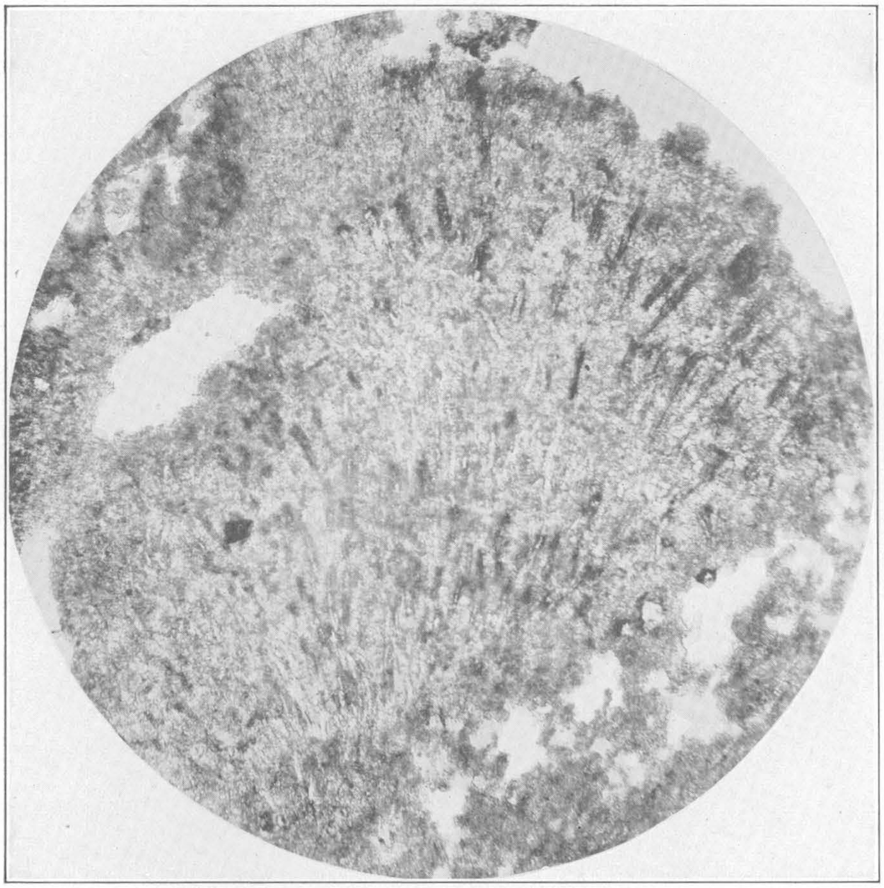
A. GROUP OF SUPERIMPOSED ALGAE REEFS IN THE UPPER PART OF THE BASAL MEMBER OF THE GREEN RIVER FORMATION NEAR THE DIVIDE BETWEEN WEST DOUGLAS AND EAST SALT CREEKS, COLO.

The man's feet are at the base of the lowest reef, which truncates the shaly sandstone beds below; his shoulders are level with a thin reef that has unusual pencillated structure. The thin dark-colored bed at the top of the unit consists of algal pebbles some of which are shown in Plate 46, *B*. The group is about 5.5 meters (18 feet) thick



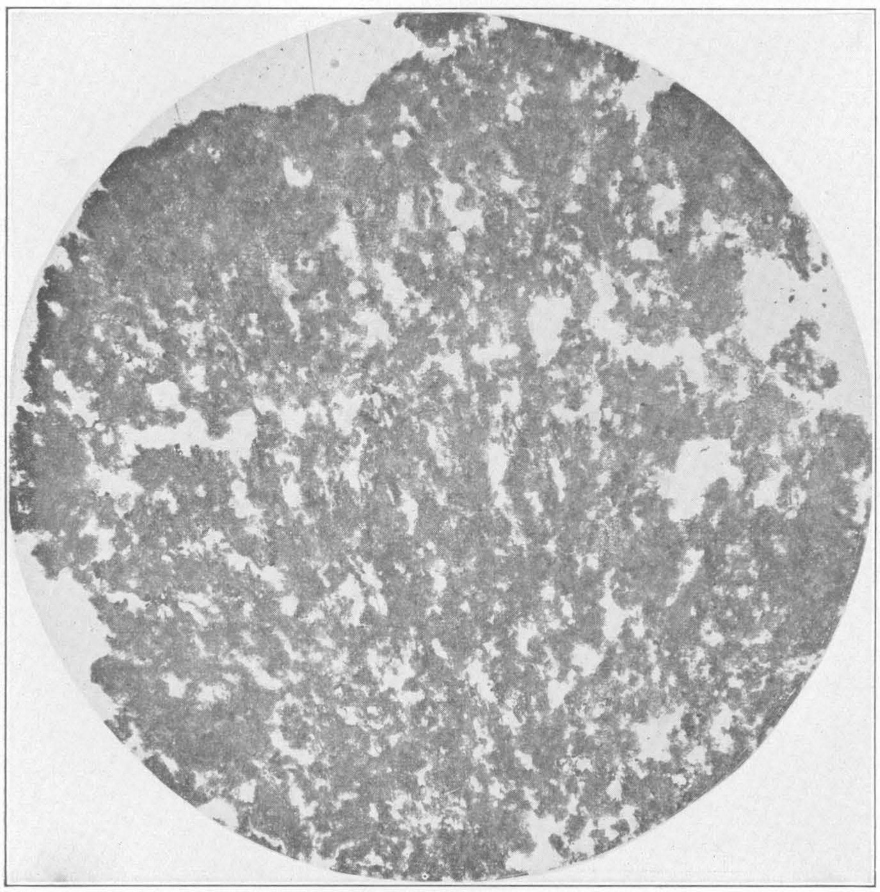
B. RECENT ALGAL DEPOSIT FROM GREEN LAKE, N. Y.

The upper rough part is grayish green, owing to the dense felt of algae, whose tips were only thinly incrusted with lime. The lower, smoother part, which was buried in a soft limy mud, is yellowish gray, dense, and without living algae. Natural size



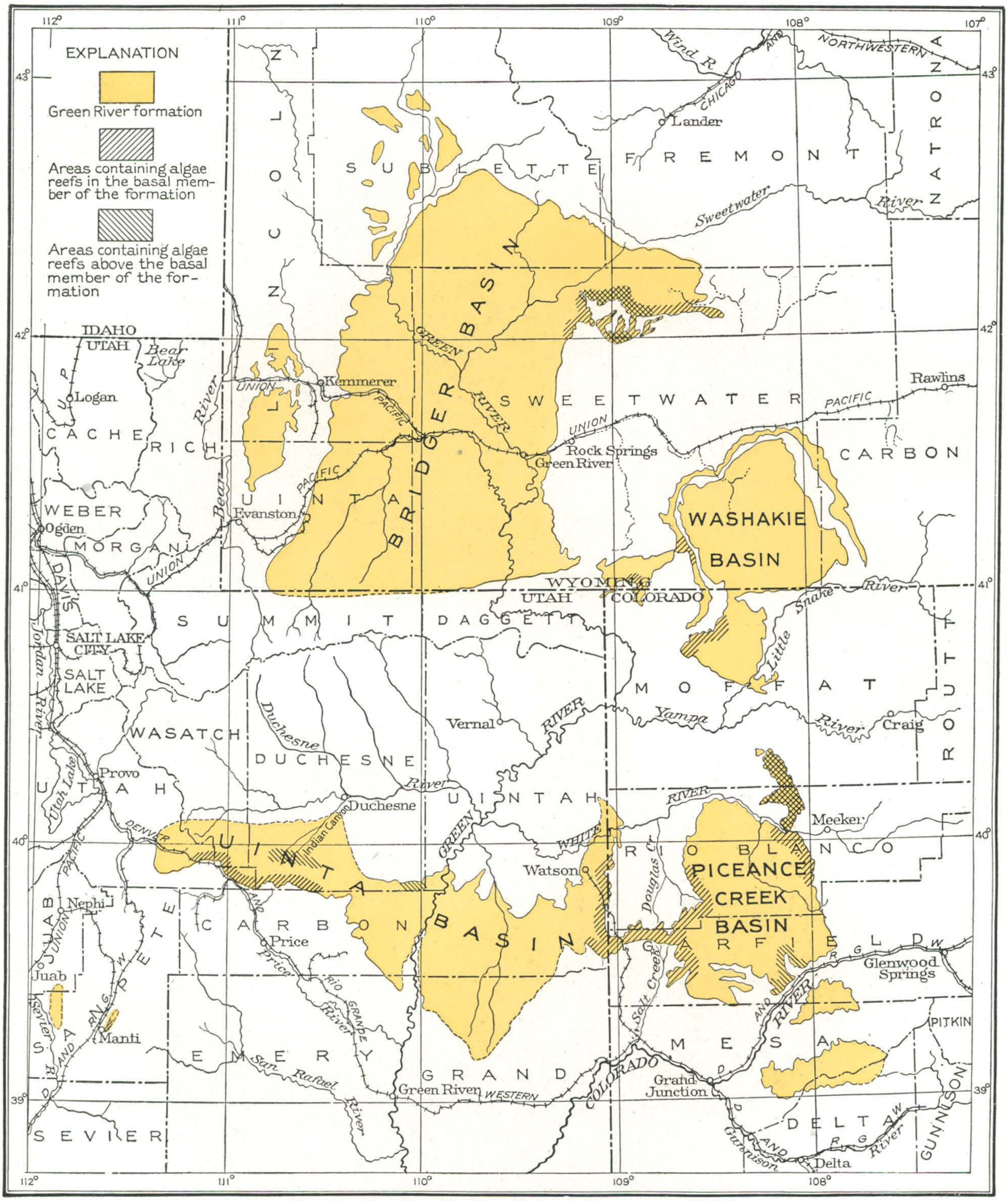
A. THIN SECTION OF A RECENT ALGAE REEF FROM GREEN LAKE, N. Y.

Showing the tubular molds of the thalli of a filamentous alga, *Microcoleus paludosa* (Kützing) Gommont, in a matrix of microcrystalline calcite. The darkest molds contain bakelite with which the specimen was impregnated for sectioning. Enlarged 75 diameters



B. THIN SECTION OF A RECENT ALGAE REEF FROM GREEN LAKE, N. Y.

Showing the typical spongy structure of the microcrystalline calcite produced by a felt of fresh-water algae. This also shows a portion of the recrystallized and more dense surface layer in the upper left quadrant. Enlarged 30 diameters



GEOLOGIC MAP SHOWING THE DISTRIBUTION OF THE ALGAE REEFS IN THE GREEN RIVER FORMATION

Geology compiled from published reports of Winchester, Schultz, Veatch, Sears, Ball, and Bradley and unpublished field data of E. E. Smith and E. G. Woodruff terpret the spongy structure of many fossil reefs. In Green Lake algae form not only fringing reefs but also thick incrustations on the trunks and branches of trees that have fallen into the water. All these deposits are exceedingly porous or spongy and consist of more or less closely intergrown arborescent masses that are richly nodose. They resemble arborescent native copper but are more profusely branched. (See pl. 29, *B*.) An outer layer ranging in thickness from about 0.25 to 3.0 centimeters is soft and crumbly, but below that the deposit is as hard as ordinary porous limestone.

Apparently the form of the limy deposit is determined by the growth habit of the algae, for if the calcium carbonate in the softer outer layer is dissolved in dilute acetic acid there remains a very dense felt of algae which retains the original dimensions and intricate form. Close to the surface the calcium carbonate, in the form of minute granules 3 to 6 microns in diameter, partly fills the interstices between the algae filaments and unicells and thus makes a very imperfect cast of the interstices or, stated differently, a mold of the plants. But because the algae are so densely entangled the resulting molds are those of groups or small felts of the plants rather than of individual plants. Only rarely in such complex assemblages of algae are the individual filaments or unicells so widely separated that recognizable molds of them are formed. (See pl. 30, *A*.)

A little below the surface of these deposits the calcium carbonate is somewhat coarser grained. The crystal growth thus indicated diminishes a little the spaces originally occupied by algae and also distorts whatever molds of individual plants may have formed. This diminution of pore space, however, is slight, and the resulting deposit after the algae have decayed and completely disappeared is exceedingly porous and exhibits the typical spongy structure. Some of it shows clearly the dominant radial lineaments of the algae. (See pl. 30, *B*.) Although this spongy deposit shows neither cell structure nor any molds of algae, it is highly distinctive and owing to its unusual external form is not readily confused with limestone of any other kind.

The spongy structure of these recent algae reefs is practically identical with that found in many of the fossil reefs from the Green River formation. (See pl. 34, *A*.) However, few fossil deposits are so porous, because some or even all the interstices have subsequently been filled with calcite or silica. These secondary fillings are, nevertheless, clearly distinguishable from the original deposit.

Those parts of the algal deposits in Green Lake, N. Y., which have been buried in a finely granular gray or white limy silt have been somewhat modified. The intricately arborescent and finely nodose or granular protuberances have become smoother, more rounded, and more compact. (See pl. 29, *B*.) Thin sections of these parts show that the interstices have been filled with calcite, so that an outer layer 0.1 to about 1 centimeter thick is dense and somewhat banded concentrically. Along these bands many of the calcite crystals are radially elongated. The change is apparently inorganic and confined to those parts that are buried. Perhaps ammonia from the decomposing algae hastened the precipitation and recrystallization of these buried parts.

ORGANISMS

The dense felt of algae obtained by dissolving out the calcium carbonate from the material collected in Green Lake, N. Y., consists of an assemblage of blue-green algae together with a few green algae. The most abundant forms are *Microcoleus paludosa* (Kützing) Gommont, *Palmella miniata* Leiblein, *Chroococcus helveticus* Nägeli, and *Lyngbya subtilis* W. West; and of these *Microcoleus*, by reason of its greater bulk, predominates, yet the minute cells and colonies of *Palmella* are vastly more numerous. *Palmella* cells are probably the unidentified "rounded or oval, very small cells" that C. A. Davis referred to in his notes on the lime deposits of Green and Round Lakes, N. Y., published in Walcott's description of some pre-Cambrian algal deposits.[4] *Lyngbya* and *Palmella* are most plentiful close to the surface of the algal felt, where they are associated with the algae listed below in the order of their estimated abundance:

- Hapalosiphon aureus West and West, locally plentiful.
- Gloeocapsa sp.
- Radiofilum sp.
- Rivularia sp.
- Dicothrix orsiniana (Kützing) Bornet and Flahault.

Diatoms belonging to several genera are scattered through the mass of other algae.

The calcium carbonate precipitated by these algae was tested to see whether it was aragonite or calcite. The two most generally used chemical tests with cobalt nitrate and ferrous sulphate were applied but gave inconclusive results. Pieces tested in cobalt nitrate became pinkish lavender, whereas crystals of aragonite used as a check turned lavender but with a perceptibly bluer tone. Calcite crystals also immersed for a check remained colorless. In ferrous sulphate pieces of the material caused a yellow precipitate, which, however, had at first a dull greenish cast. Johnston, Merwin, and Williamson[5] have pointed out the uncertainty of these tests, especially if the material is finely divided or in the form of aggregated fine particles.

C. S. Ross, of the Geological Survey, kindly examined some of the material for the writer and found

[4] Walcott, C. D., Pre-Cambrian Algonkian algal flora: Smithsonian Misc. Coll., vol. 64, p. 88, 1914.

[5] Johnston, John, Merwin, H. E., and Williamson, E. D., The several forms of calcium carbonate: Am. Jour. Sci., 4th ser., vol. 41, pp. 476–478, 1916.

that all the crystals large enough to be determined optically were uniaxial and therefore calcite.

There remains the possibility that some of the finer grains are or were originally aragonite. That they are now aragonite appears unlikely, for Johnston, Merwin, and Williamson[6] have demonstrated that in aqueous solutions aragonite is unstable in the presence of finely divided calcite. These grains are very small, 3 to 6 microns in diameter, and are interlocked with the minute calcite grains. Moreover, these deposits formed under water, where they remained for a considerable time. It also seems improbable that these finest grains were originally aragonite, for the small calcite crystals with which they are associated in the surface layer of the deposit are not idiomorphic, as they probably would be if recrystallized from aragonite. Moreover, older parts of the deposit obviously furnished calcite nuclei, a fact which in itself makes the original deposition of aragonite very improbable, as pointed out by Johnston, Merwin, and Williamson.[7]

Hassack[8] and Chambers[9] have demonstrated that the function of algae in the precipation of calcium carbonate is merely to remove by their photosynthesis the carbon dioxide from the system. Under the conditions which occur in Green Lake, N. Y., calcite is the stable product. Perhaps in a lake that contained considerable sulphate in solution aragonite containing some calcium sulphate in solid solution would be the stable form.[10]

GENERAL FORM OF THE FOSSIL ALGAE REEFS

The algae reefs of the Green River formation have the form of irregular lenses or beds rather than of ridges or mounds, and they differ considerably in thickness from place to place. Little is known about their extent and proportions, partly because the exposures are inadequate but chiefly because the urgency of other field work has always left insufficient time to map them. Plate 31 shows their distribution in a general way. The shaded portions represent areas in which the writer has observed reefs together with a narrow border zone that represents their probable minimum extent beneath cover and along the strike of the beds from the observed outcrops. Their actual extent is almost certainly considerably greater than that shown. Those portions of the outcrops along White River from the vicinity of Meeker to Douglas Creek, Colo., along the east side of the Bridger Basin in Wyoming from the Union Pacific Railroad north to the area indicated on the map by shading, from White River to Green River in Utah, and between Little Snake and Yampa Rivers, together with several localities in the adjoining country to the northwest, have been examined and found barren of algae reefs. The remainder of the unshaded portions represent either unexamined outcrops or areas where the formation, though near the surface, is not exposed.

The shape and size of modern algal deposits appears to be governed largely by the lake-shore profile. The modern algal tufas of Pyramid Lake, Nev., like most of the Pleistocene tufas of the ancient Lake Lahontan, are true fringing reefs, because the shore profiles are steep and the maximum depth at which they could form is not far from shore. Similarly in Green Lake, N. Y., the shore of which has an exceedingly steep profile, the algal reefs are narrow and fringing. In lakes with more gently sloping shores, such as Ore Lake, Mich.,[11] the algal deposits are more bedlike but thickest near shore and progressively thinner outward where the water deepens. Baumann[12] shows that the beds of algal pebbles now forming in Unter See, Germany, below the outlet of the Lake of Constance are rather thin but extend over very large areas in the shallow bays (1 to 4 meters deep), which are free from strong currents. Some of those deposits are nearly equidimensional, but more of them are two to three times longer than broad.

Apparently, therefore, algal deposits must of necessity be bedlike in shallow lakes which are free from strong currents and whose bottoms have a gentle slope and but slight relief. Over such bottoms they may expand freely, their size and shape being limited only by a decrease in the lime supply or changes in environment that would be unfavorable to the propagation of the algae—for example, a considerable increase in either the turbidity or the depth of the water or long-continued stagnation and fouling of the water.

The few reefs of the Green River formation that have been traced in the field serve to illustrate their probable variety of form. Some of these, 2 meters (6 feet) or more thick, cover only a small area and end abruptly; others cover many square miles and apparently thin progressively toward the borders. Most of the reefs are of this bedlike type. On a few there are portions that rise above the general level of the reef as much as 1.3 meters (4 feet). This relief evidently existed until reef building ceased, because the bedding of the overlying shale conforms to the marked irregularities of the reef surface and laps up tangentially against the steepest sides of these high parts.

The under surfaces of reefs conform to the substrata, which, unless they are algal, are practically flat. An exception to this rule, however, is found in a

[6] Idem, p. 501.

[7] Idem, p. 483.

[8] Hassack, Carl, Über das Verhältnis von Pflanzen zu Bicarbonaten ünd uber Kalkincrustation: Untersuchungen aus dem Bot. Inst. zu Tübingen, vol. 2, pp. 467–473, 1888.

[9] Chambers, C. O., The relation of algae to dissolved oxygen and carbon dioxide with special reference to carbonates: Missouri Bot. Garden Ann. Rept., vol. 23, pp. 188–204, 1912.

[10] Johnston, John, Merwin, H. E., and Williamson, E. D., op. cit., p. 482.

[11] Pollock, J. B., Michigan Acad. Sci. Twentieth Ann. Rept., p. 249, 1918.

[12] Baumann, Eugen, Die Vegetation des Untersees (Bodensee): Archiv Hydrobiologie u. Planktonkunde, Suppl. Bd. 1, pp. 26–31, pl. 11, 1911.

reef in Sweetwater County, Wyo., which apparently filled a rather broad and shallow depression in the lake bottom. Its upper surface is essentially level.

Small isolated algal heads or groups of them are scattered in the beds below many reefs. These are precursors of the major reefs, are not connected with them, and are not to be confused with rootlike processes that extend downward from reefs into the underlying rocks, such as those in the Buntsandstein described by Kalkowsky.[13]

Each reef consists of an aggregate of more or less dome-shaped or puffball-shaped masses of algal limestone. These will be referred to as heads. They may be entirely separate one from another, or they may be merely botryoidal convexities or arches in a continuous layer. (See pls. 40, *A*; 44, *A*; 45, *A*.) Moreover, each head may be simple and consist of superimposed smooth, concentric, or slightly eccentric layers, or it may be compound and consist of few to many smaller heads which in nearly all reefs are fused together. (See pl. 44, *B*.) Such small heads, particularly if formed by a single species of alga, may represent the growth of individual colonies. But if the deposit was formed by a complex assemblage of algae then they represent merely areas of more rapid growth, and generally, though not invariably, these are somewhat arborescent, are less uniform in size, and have a less regular distribution in the larger head. (See pl. 43, *A*.)

ORGANISMS AND STRUCTURE

UNICELLULAR ALGAE

Many algae reefs of the Green River formation are built up of successive crescentic groups of small, closely packed spherical or ellipsoidal shells of calcite separated by thinner layers of microcrystalline calcite. These delicate shells range in diameter from 103 to 122 microns and consist of a mosaic of comparatively large platelike crystals of clear calcite. In the silicified reefs they are filled with small anhedral grains of secondary quartz, but in the unsilicified reefs they are empty. Where they are closely appressed many are caved in on one side, greatly distorted, or completely crushed.

Each delicate limy shell is the mold of a unicellular alga formed by the precipitation of $CaCO_3$ on the surface of the living plant through its photosynthesis, a process by which the plant abstracts CO_2 from the water and its dissolved bicarbonates and thus, by diminishing the concentration of the carbonate ion in the system, reduces the solubility of the normal carbonate to the point of precipitation.

These algae are almost identical with *Chlorellopsis coloniata* Reis. Except for a slight difference in the size of the cells the original description of the genotype will serve for the algae of the Green River formation.

[13] Kalkowsky, Ernst, Oolith und Stromatolith in norddeutschen Buntsandstein: Deutsche geol. Gesell. Zeitschr., vol. 60, p. 112, 1908.

Genus CHLORELLOPSIS Reis

Chlorellopsis coloniata Reis

Plate 32, *A* and *B*

Chlorellopsis coloniata Reis, Kalkalgen and Seesinterkalk aus dem rheinpfalzischen Tertiar: Geognostische Jahresh., vol. 36, pp. 107–109, pl. 3, figs. 1, 2, pl. 4, figs. 3–6. Miocene lake beds of the Rhine graben, Germany, 1923.

A free translation of Reis's description is as follows:

Body perfectly spherical, consisting of a shell of very fine interlocking grains of calcite, which is preserved only if filled with precipitated microcrystalline calcium carbonate that enters it through an accidental rupture in the cell wall (or a break formed by swarm spore liberation?). Otherwise the spherical cavity is later filled with coarser-grained clear calcite similar to the rock matrix. In all occurrences the spheres have approximately the same diameter: the few odd-sized ones range in diameter from 110 to 140 microns. * * * The spheres occur mostly in colonies, more rarely in a series or row, commonly without definite arrangement in little low heaps, often, however, also in structures with steep and even overhanging sides; they might therefore have been held together in a jelly. They are found, nevertheless, in niches, little pits, and depressions in various kinds of limy growths * * * but never in the detrital grains around them; they often also occur in protected places, as the insides of snail shells. They are always separated from the substratum and from each other, but the spacing is not regular.

The spheres occur not only in groups by themselves that are separated by thin limy layers by also sporadically associated with all the other kinds of algae in the Miocene Tertiary marls of the Rhine lake basin, although more rarely in beds containing solely marine animal remains or in the fine-grained limestones intercalated with them.

Living spherical algae of comparable size are *Halosphaera* (marine), *Eremosphaera* (100 to 145 microns), *Chlorella*, which lives in marine lower organisms and of whose species *Chlorella infusionum* is of the same size as our fossil. The marine *Palmophyllum* should be related to *Chlorella*. It forms a rounded and lobate thallus of unicells held together in a jelly which is attached to calcareous algae, etc.

The spherical shells in the reefs of the Green River formation range in diameter from 103 to 122 microns and so are only slightly smaller than these and surely not so different as to determine another species. Their mode of preservation is slightly different, and they have not yet been found in snail shells, but the identity of the Green River alga with *Chlorellopsis coloniata* Reis seems beyond question.

It was perhaps somewhat misleading to compare *Chlorellopsis coloniata* with the living *Chlorella infusionum*, because of the confusion that exists in the nomenclature of the living algae. Beyerinck,[14] who without apparent reason proposed *Chlorella* to supersede *Zoochlorella* Brandt, described *Chlorella infusionum* as free living, never in families, with small cells (1 to 4 microns) which are often flattened and rarely short cylinders. Furthermore, Beyerinck [15] regarded this alga as identical with *Chlorococcum infusionum*

[14] Beyerinck, M. W., Culturversuche mit Zoochlorellen, Lichenengonidien und anderen neideren Algen: Bot. Zeitung, vol. 48, p. 726, 1890.

[15] Idem, p. 758.

(Schrank) Mengehini as described by Rabenhorst,[16] in spite of the fact that his and Rabenhorst's descriptions are utterly different. However, *Chlorococcum infusionum* (Schrank) Mengehini as described by Rabenhorst [17] agrees rather closely with the fossil alga, and hence it seems to the writer unfortunate that the fossil should have been likened to *Chlorella infusionum* Beyerinck rather than to *Chlorococcum infusionum* (Schrank) Mengehini. Consequently the name *Chlorellopsis* Reis is also unfortunate, for, although it does not necessarily imply consanguinity with the living plant, it nevertheless links the fossil to some extent with a doubtful genus which the species *coloniata* resembles considerably less than it does *Chlorococcum*.

For comparison a translation of Rabenhorst's description of *Chlorococcum infusionum* [18] is given below.

Aquatic, green, mucous; cells perfectly globular, size exceedingly variable; integument hyaline, distinct, thick, concentrically laminated; cytoplasm suffused with chlorophyll, homogeneous, and dark olive color, forming a great number of gonidia.

Diameter of cells, all the way up to [usque] 0.0045 inch (114.3 microns).

Habit, everywhere in stagnant water, either affixed to submerged bodies or free floating.

Collins [19] says of the habit of this alga that its cells are loosely united into light-green gelatinous masses that are attached to submerged objects but are easily scattered.

Although there is a strong resemblance in form and habit between the fossil algae and *Chlorococcum infusionum* (Schrank) Mengehini, their mode of reproduction and color are unknown, and therefore their systematic position must remain uncertain.

FILAMENTOUS ALGAE

Indisputable calcite molds of filamentous algae have not been found in the reefs of the Green River formation, although in a small partly silicified area of an algae reef from the "Manti beds," probably a part of the Green River formation, there is a network of slender branching white lines, which are circular in cross section and whose algal origin can be demonstrated. They are embedded in a translucent matrix and can be seen to best advantage in a polished specimen. (See pl. 33, *C*.) A thin section of this area showed that the white lines consist of an interlocking aggregate of irregular microscopic granules of chalcedonic quartz and that the matrix is microcrystalline or almost cryptocrystalline calcite.

Although these fossils show cellular structure in places and very probably represent more than one genus, they can not be positively identified and are therefore provisionally referred to the indefinite form genus *Confervites* Brongniart.

Genus CONFERVITES Brongniart

Confervites mantiensis Bradley, n. sp.

Plate 33, *A*

Filaments consisting of a single series of cells, straight or slightly curved, tips rounded or bluntly tapered, 90 to 138 microns in diameter and 0.5 to 1.25 millimeters long. Most are simple, but some are sparsely branched at rather wide angles, resembling many Confervae.

Several of these quartz filaments contain centrally placed, short chains of excellently preserved cells of an alga resembling *Nostoc*. These cells range from 39.4 to 67 microns in diameter and 27.5 to 50 microns in length and apparently represent more than one species. None of them are branched, and only one contains a cell that seems clearly to be a heterocyst. The uniform zone of silica between the chains of cells and the microcrystalline calcite apparently represents a gelatinous sheath around which the calcite was precipitated. Presumably the silica replaced the organic structure subsequent to the formation of the calcite mold and apprently so late that only fragments of the plants remained. (See pl. 33, *A*.) There are also fragments of filaments which have short cylindrical cells and suggest some of the Oscillatoriaceae.

Associated with *Confervites mantiensis* are many very well preserved though small coprolites. (See p. 33, *B*.) They are cylindrical, have irregularly or squarely truncated or rounded ends, are of various lengths, and range in diameter from 38 to 77 microns but are mostly about 60 microns. Some are compact and dense, but many of them consist of a close mesh of ragged, irregular or dendroid opaque particles resembling organic tissue that has been very strongly macerated. A few consist of more or less loosely aggregated black subangular to spherical particles about 1.5 to 2 microns in diameter.

SPONGY STRUCTURE

Several algae reefs of the Green River formation contain zones of radially arranged thin bifurcating lines of clear calcite, more coarsely grained than the matrix, which may be casts of filamentous algae. (See pl. 34, *B*.) However, most of the reefs or parts of them, which show these zones in places, consist of spongy or porous masses of microcrystalline calcite which, aside from forming crescentic or mammillate layers, show no systematic structure. (See pl. 34, *A*.) Deposits of this kind seem to be exactly comparable to that formed within the dense felt of algae in the reefs now growing in Green Lake, N. Y., and in other recent fresh-water algae reefs as described by Clarke,[20]

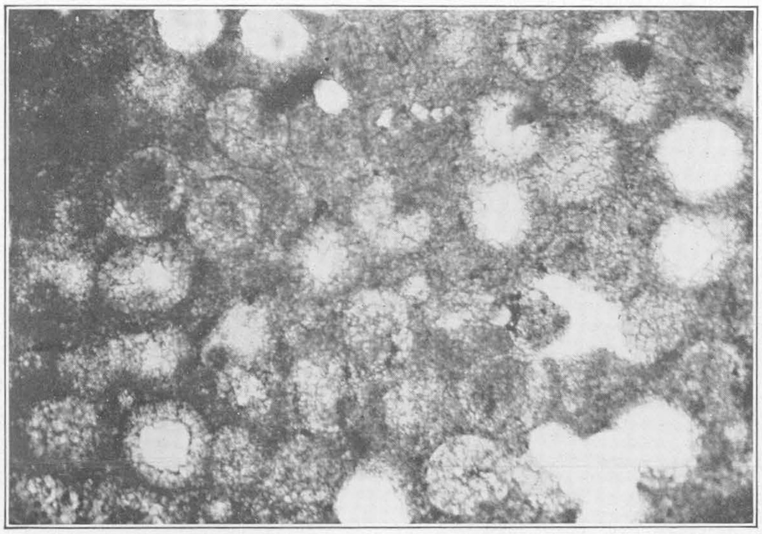
[16] Rabenhorst, Ludvico, Florae Europae algarum aqae dulcis et submarinae, vol. 3, p. 57, Leipzig, 1868.

[17] Idem, p. 57.

[18] Idem, p. 57.

[19] Collins, F. S., The green algae of North America: Tufts College Studies, vol. 2, No. 3, p. 144, 1909.

[20] Clarke, J. M., The water biscuit of Squaw Island, Canandaigua Lake, N. Y.: New York State Mus. Bull. 39, pp. 195–198, 1900.

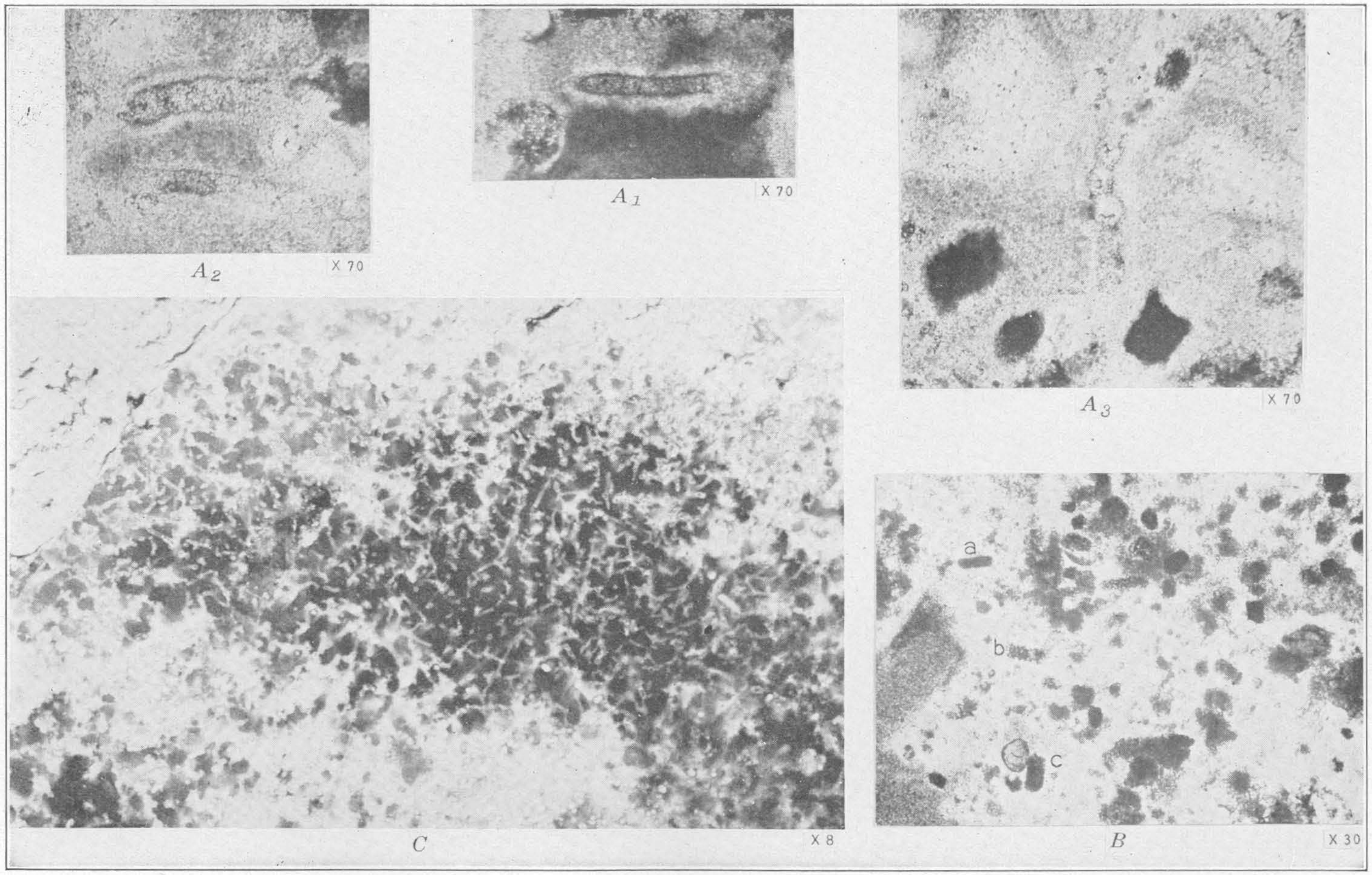


A. PHOTOMICROGRAPH OF A THIN SECTION SHOWING IN DETAIL THE INDIVIDUAL CELLS OF CHLORELLOPSIS COLONIATA REIS

The walls of each hollow sphere consist of a mosaic of moderately coarse grained calcite crystals. The dark matrix is microcrystalline calcite. Enlarged 100 diameters

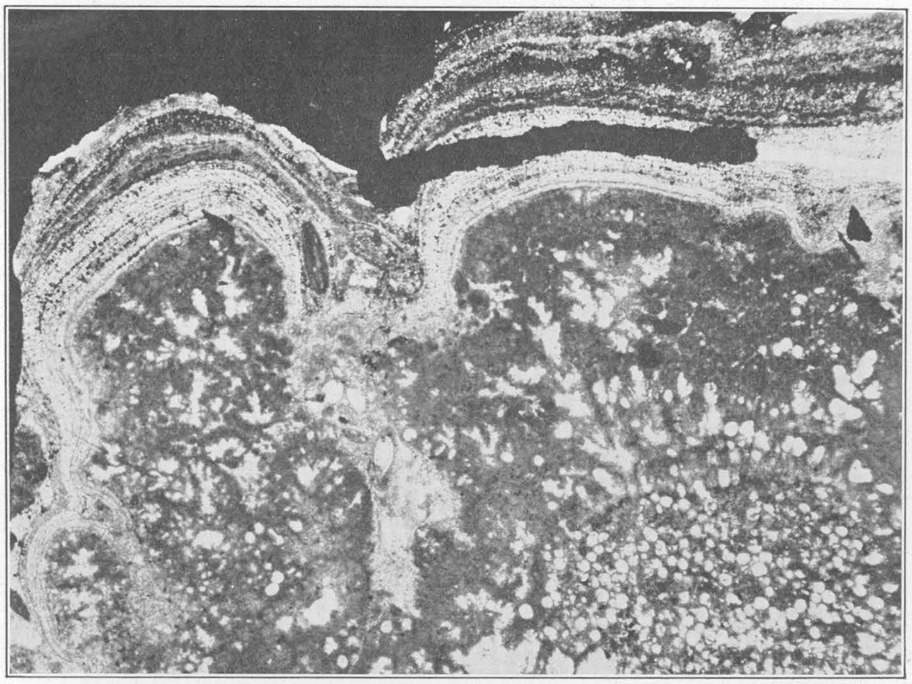
B. PHOTOMICROGRAPH OF TYPICAL LOBATE COLONY OF CHLORELLOPSIS COLONIATA REIS

Showing the vague layering of the unicells. Enlarged 10 diameters



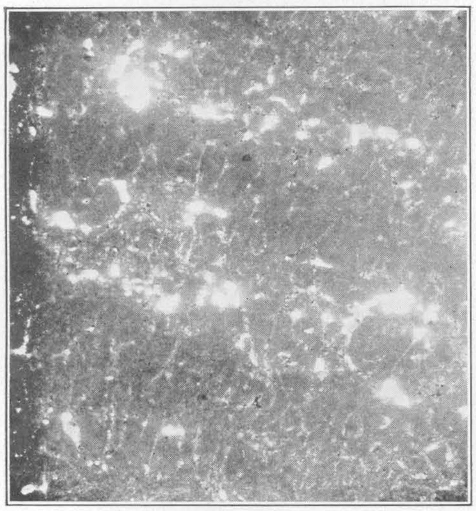
CONFERVITES MANTIENSIS AND ASSOCIATED COPROLITES

A. Photomicrographs of cellular parts of *Confervites mantiensis* Bradley, n. sp.: 1, Tip of a filament with quadrate cells and a bluntly tapered apical cell, resembling some species of *Lyngbya;* 2, tip of a filament with large spherical cells and a wide sheath; 3, filament with intercalary heterocyst resembling *Nostoc*. *B*. Photomicrograph of small coprolites (a, b, c) in a partly silicified groundmass of microcrystalline calcite, associated with filamentous algae in an algae reef from the "Manti beds." *C*. Polished specimen showing sparse colony of *Confervites mantiensis* in a partly silicified area of an algae reef from the "Manti beds." The white areas are calcite; the darker ones chalcedonic silica



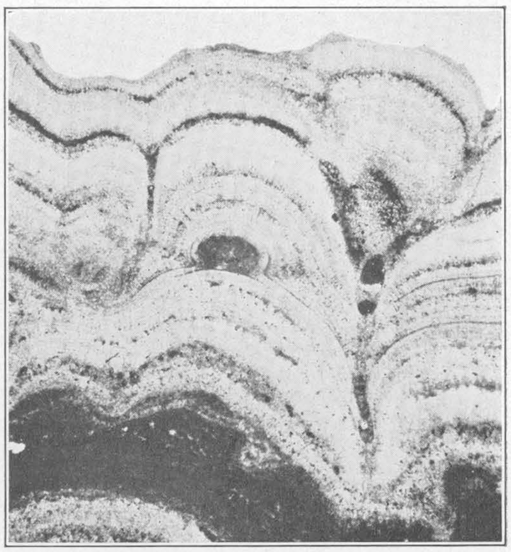
A. PHOTOMICROGRAPH SHOWING THE ASSOCIATION OF THE THREE PRINCIPAL TYPES OF STRUCTURE FOUND IN THE ALGAE REEFS OF THE GREEN RIVER FORMATION

Small area of the reef shown in Plates 43, *A*, and 45, *A*. In the lower right-hand quarter is a colony of the large spherical cells of *Chlorellopsis coloniata* Reis, above that is a thick zone of typical spongy deposit, and at the top and also down the left side is an inorganic incrustation. Enlarged 10 diameters



B. PHOTOMICROGRAPH OF PART OF AN ALGAE REEF

Showing thin radial lines of medium-grained calcite, which may be casts of filamentous algae. The matrix is a spongy algal deposit of microcrystalline calcite. Enlarged 21 diameters. Compare with Plate 30, *B*

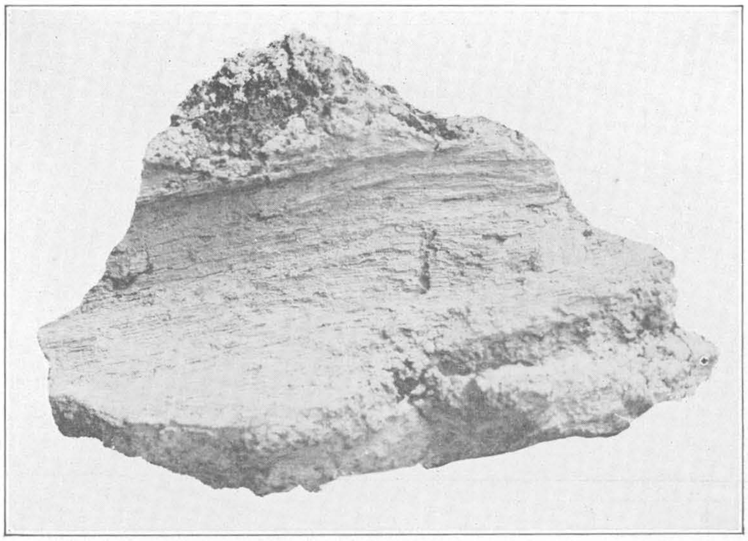


C. PHOTOMICROGRAPH OF TYPICAL PHYSICO-CHEMICAL INCRUSTATION OF CALCITE

Showing the radial fibrous structure interrupted by thin concentric zones of limonite granules. The irregular black layer at the base and the small rounded cushion-shaped area near the center are spongy algal deposits, which appear almost opaque because they consist of calcite that is almost cryptocrystalline. Enlarged 10 diameters

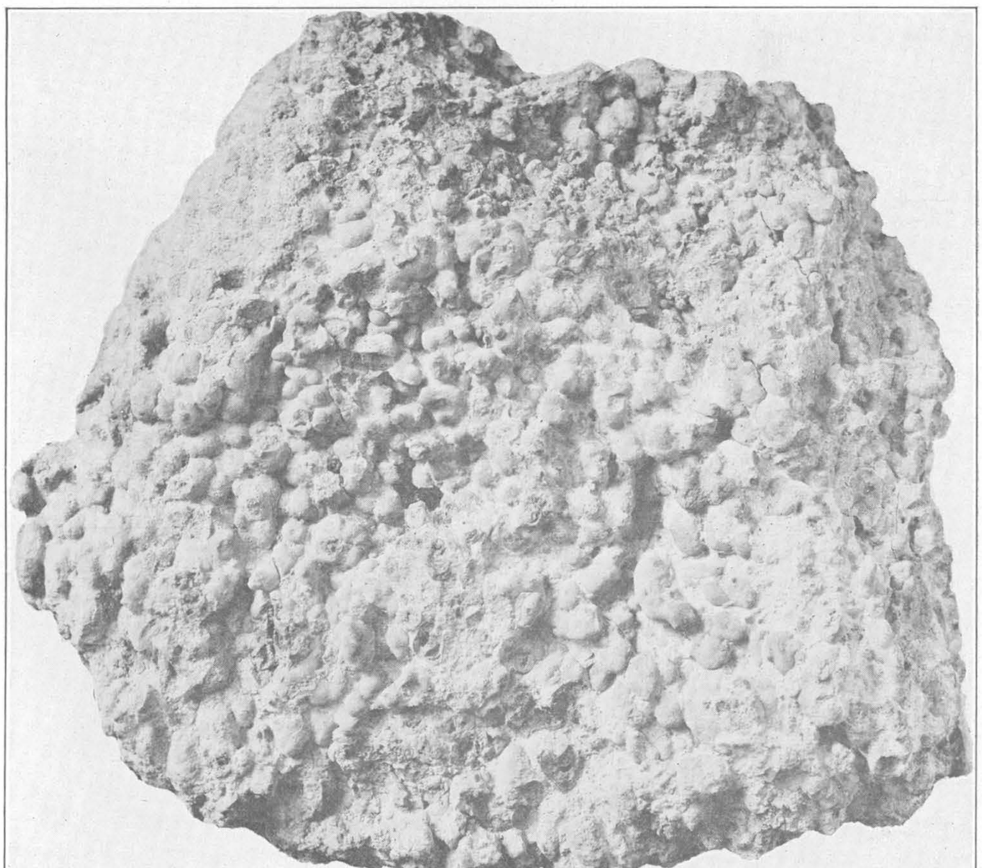
POLISHED VERTICAL SECTION OF A CHLORELLOPSIS REEF

Showing the irregular and vaguely radial arrangement of the lobate algal colonies; also a part of the oolitic sandstone upon which it rested. The lightest-gray areas are fine-grained sandstone, the black grains are oolite grains, and the medium-toned gray areas are fragments of silty limestone, alga reefs, and mud lumps. Natural size



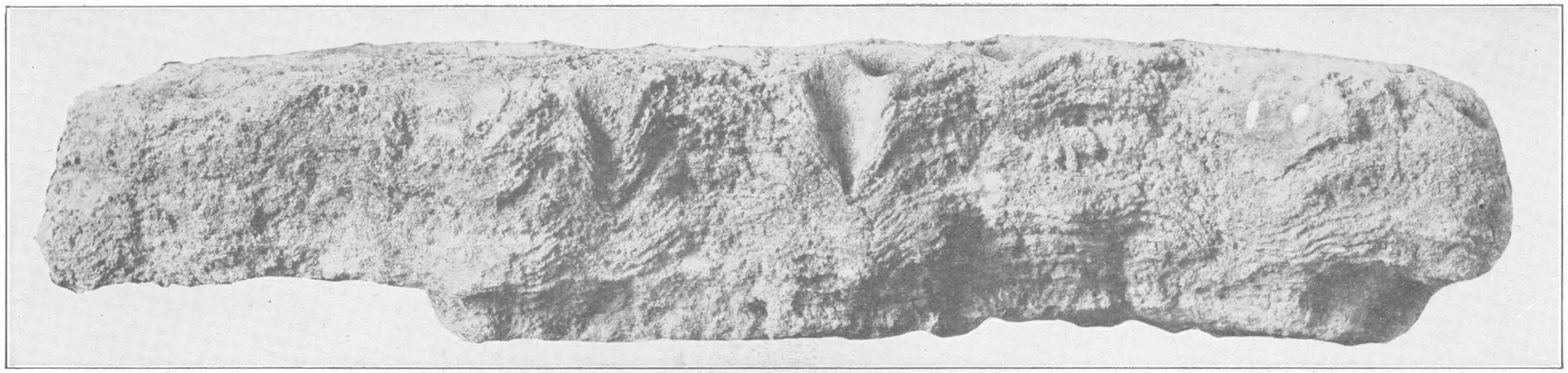
A. DEPOSIT FORMED AROUND WOOD BY CHLORELLOPSIS COLONIATA REIS

Natural size



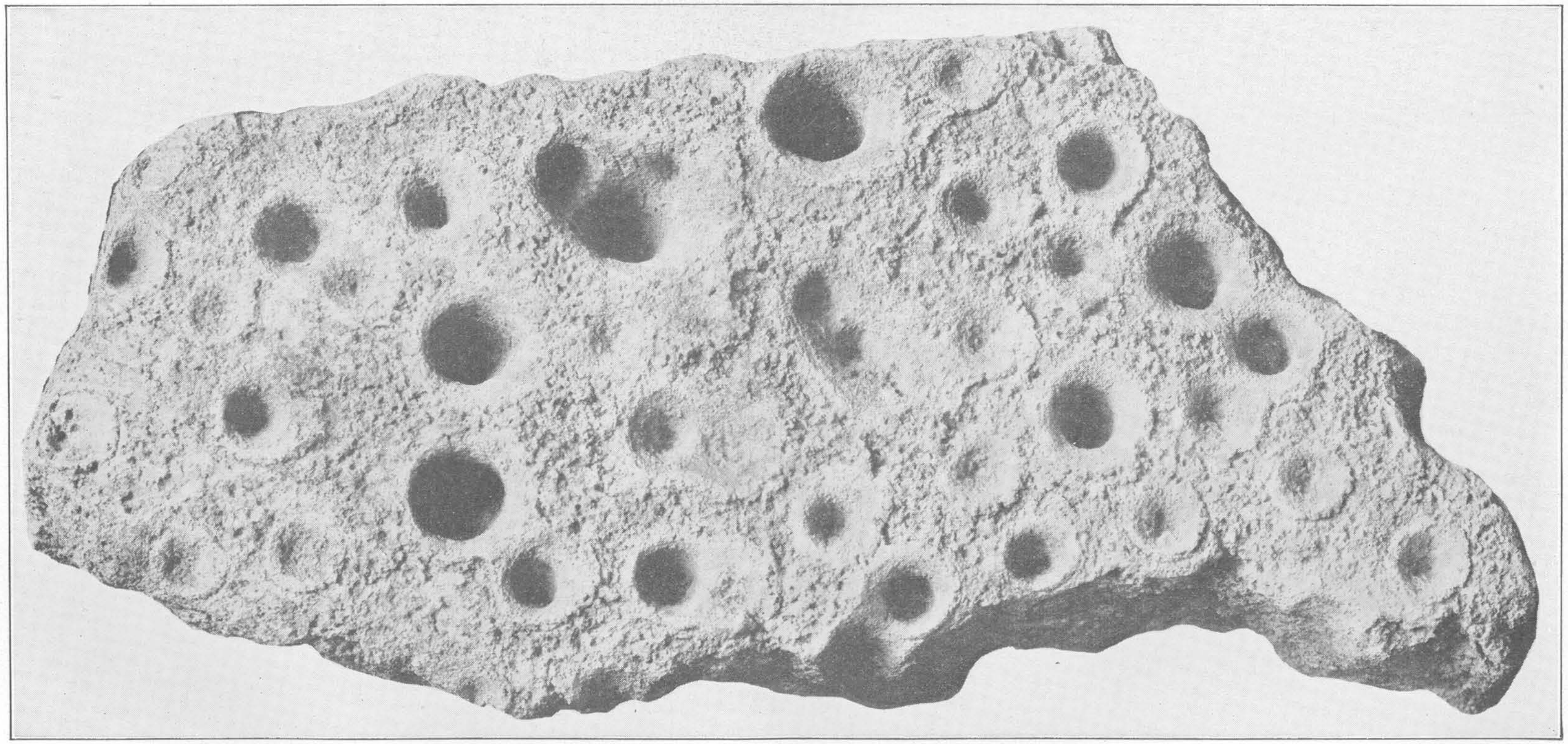
B. TUBERCULATE OR PAPILLATE EXTERIOR OF THE TYPE CHLORELLOPSIS COLONIATA REEF

Each tubercle represents a single colony of algae. From the base of the Laney shale member of the Green River formation, NE. ¼ sec. 27, T. 25 N., R. 103 W., Sweetwater County, Wyo.



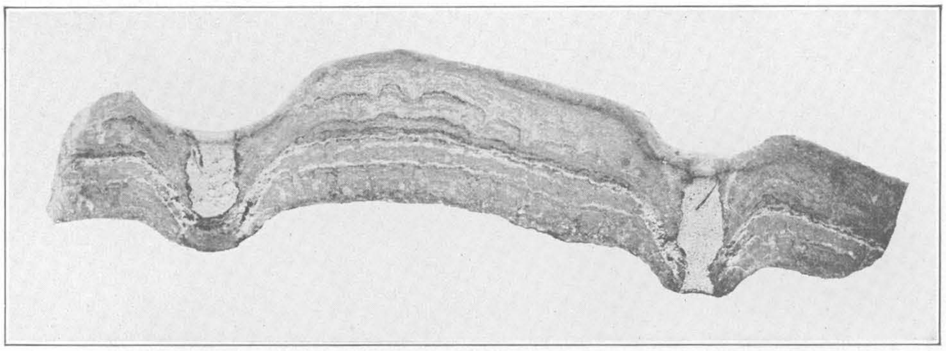
A. TRANSVERSE SECTION OF CHLORELLOPSIS REEF

Showing the conoidal pits in section and the thinning of the algal layers toward the pits. Natural size



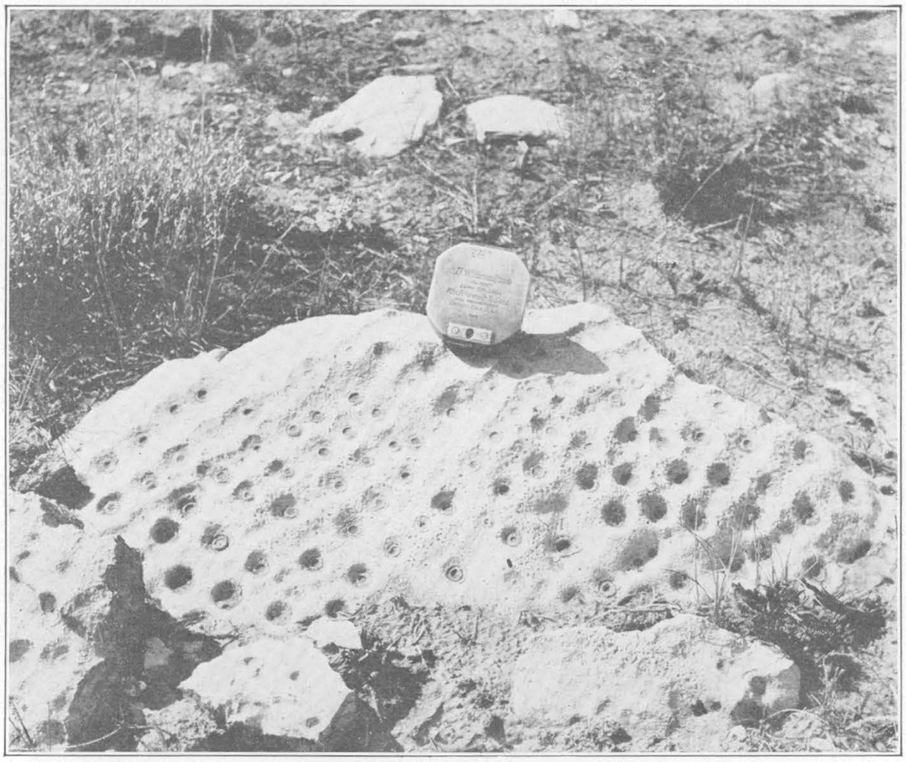
B. UPPER SURFACE OF CHLORELLOPSIS REEF

With conoidal pits showing their relative size and distribution and the difference in texture between the interior of the pits and the general surface of the reef. Natural size



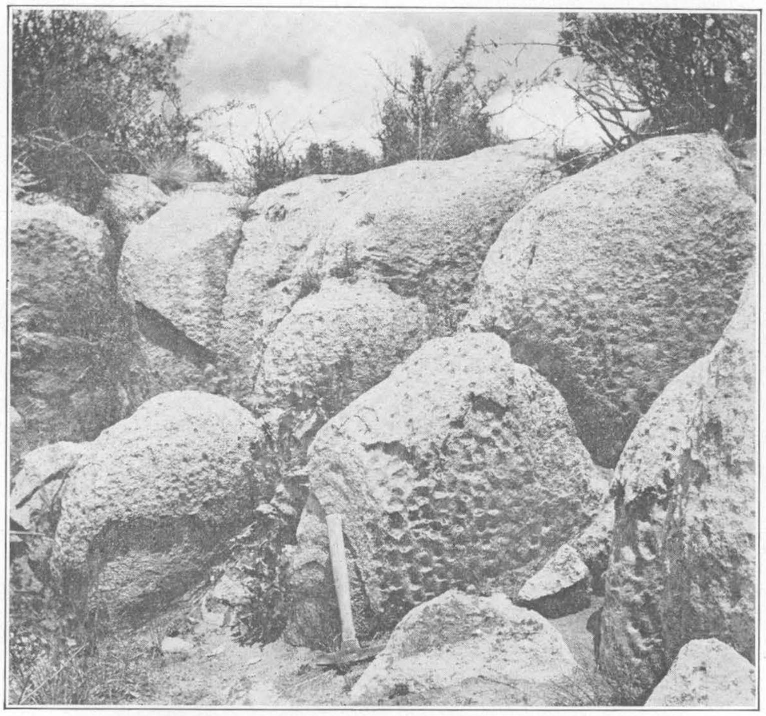
A. TRANSVERSE SECTION OF THE PITTED CHLORELLOPSIS REEF SHOWN IN *B*

Showing the cores of sand-filled ringed pits and the conoidal excrescences at their lower ends. This also shows the marked thickening of the algal layers between pit cores. Natural size



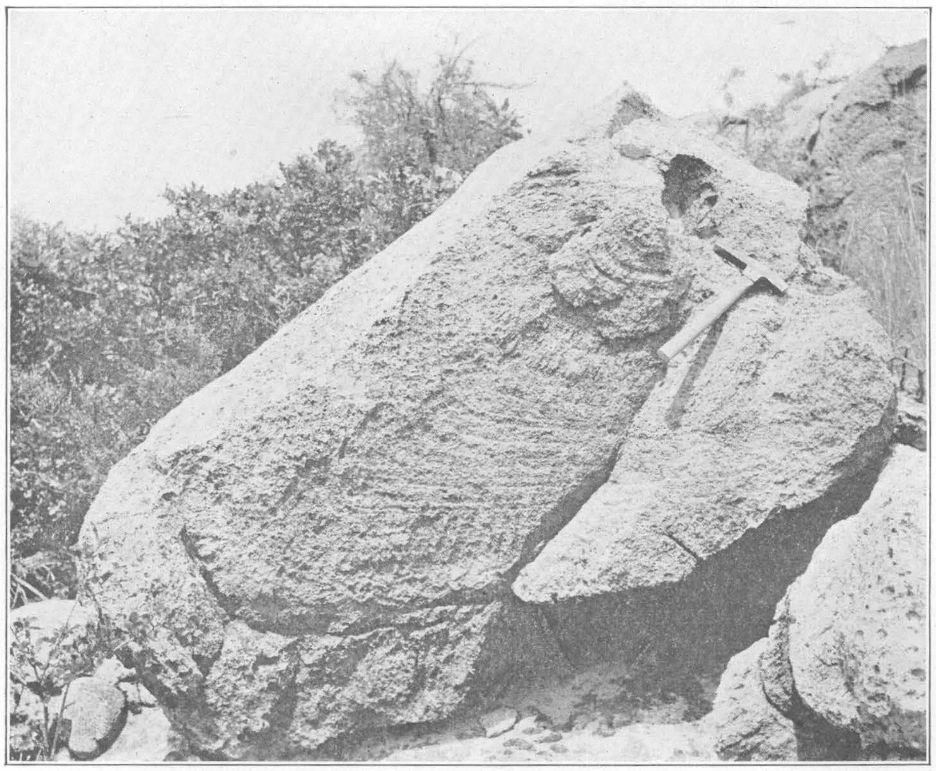
B. CUP-SHAPED, RINGED PITS IN THE UPPER SURFACE OF A CHLORELLOPSIS REEF

Showing their general uniformity of size and arrangement. At the left they are arranged in fairly definite rows. The vermiculate surface between the pits shows best in a small area a little to the right of the center



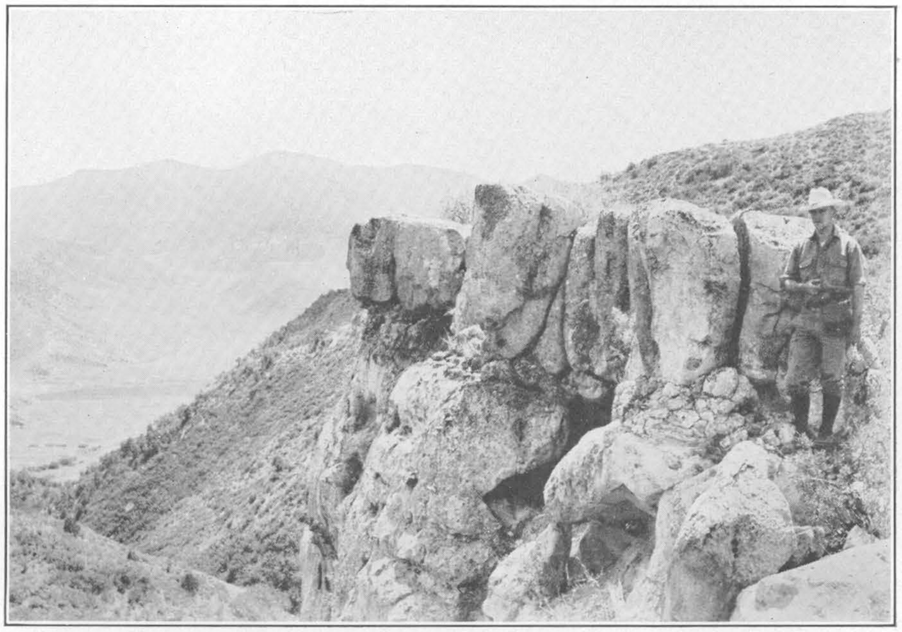
A. HEMISPHERICAL HEADS OF PITTED ALGAE REEF

Showing that the pit tubes are very nearly vertical, even where they emerge from the side of a head. The pits in the very steep sides of the head near the hammer make concave niches with nearly horizontal bottoms. The upper surface of the reef at this place is weathered nearly smooth



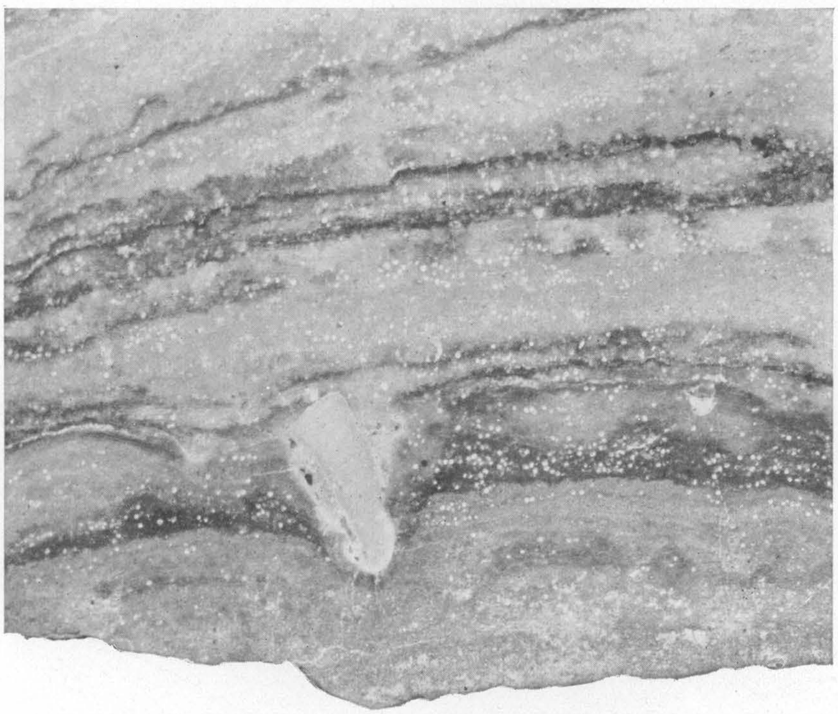
B. OVERTURNED AND BROKEN HEAD OF THE PITTED REEF SHOWN IN *A*

This shows, near the hammer head, a hole that contained the nucleus. It also shows the eccentric growth layers, which may be annual, and near the top of the head (the lower edge of the photograph near the center) several open pit tubes. These are indistinct, partly because they are weathered and partly also because they were somewhat overgrown with algal deposits as the reef formed



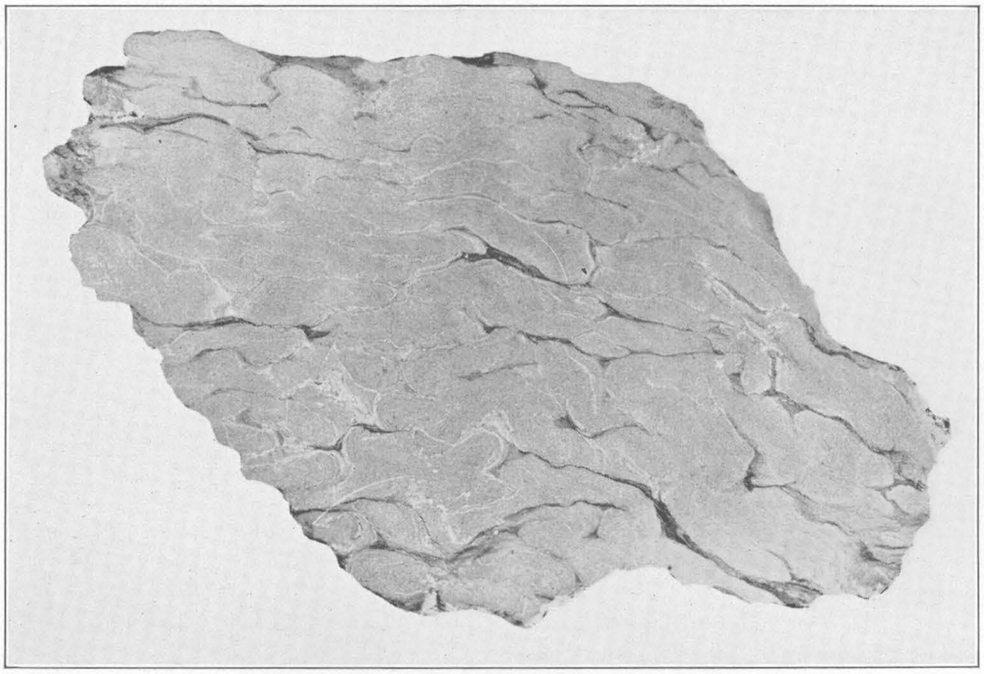
A. LARGE PITTED REEF CONSISTING OF SEPARATE, CLOSELY SPACED, TURBINATE HEADS WHICH REST UPON A BED OF SMALLER ALGAL NODULES

The nodule bed rests upon medium-grained massive sandstone that is locally cross-bedded. The second and third heads to the left of the man show fluting. The minimum time required for the formation of this reef is estimated at 355 years



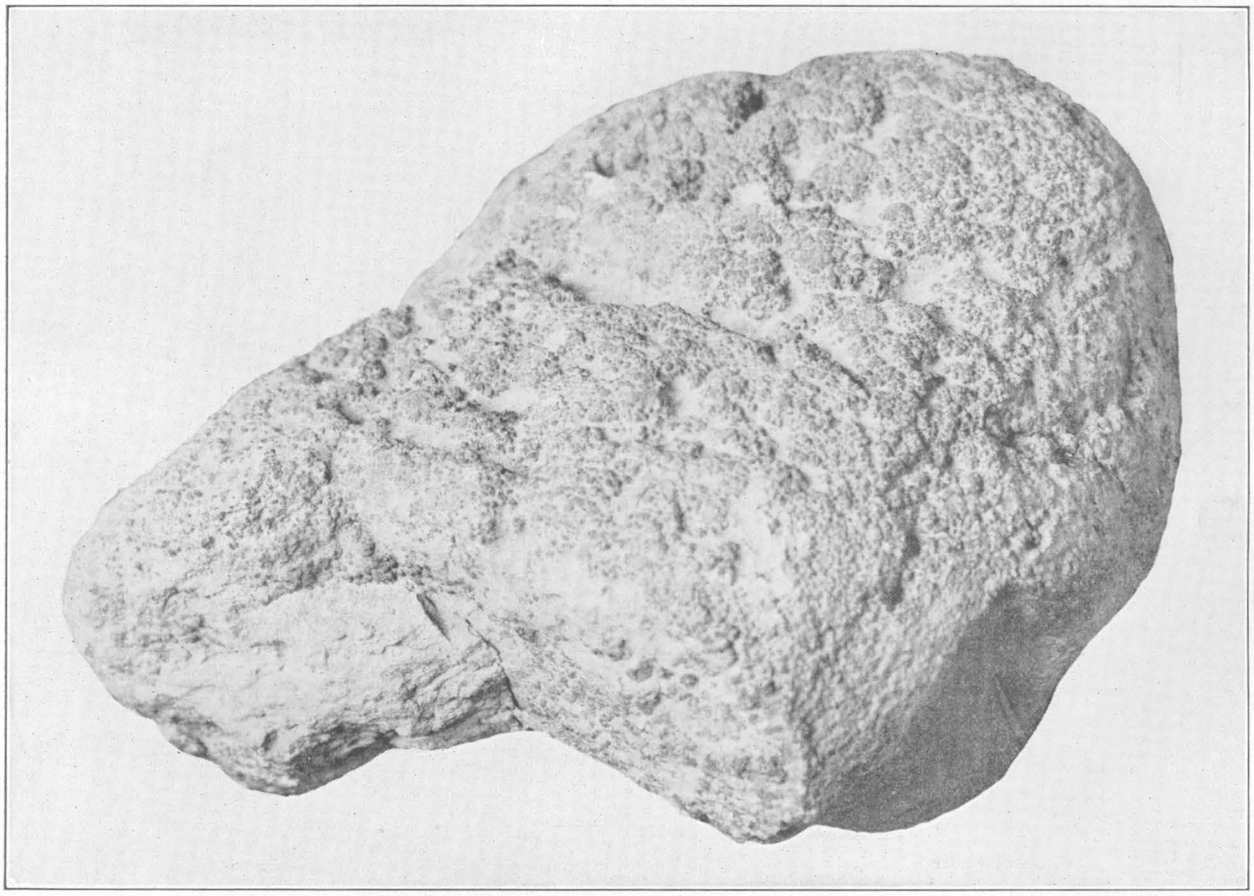
B. POLISHED VERTICAL SECTION OF A CHLORELLOPSIS REEF

Showing a large flat algal colony in part broken and in part deeply indented by a fragment of limestone that fell on it while the deposit was forming. Enlarged 5 diameters



A. POLISHED VERTICAL SECTION OF A REEF FORMED OF RECUMBENT DISCOID COLONIES OF CHLORELLOPSIS COLONIATA REIS

The colonies near the center and upper parts of the specimen show faintly the concentric growth layers, which are convex outward along the radii of the colonies. Natural size



B. ISOLATED ALGAL HEAD WITH DIGITATE SPONGY STRUCTURE

Resembles in form and sculpturing the marine *Lithothamnion*. Natural size. See also Plate 42, *A* and *B*

Roddy,[21] Jones,[22] and others. Jones[23] also illustrates clearly a deposit of this type now being formed in Salton Sea.

Although algae were apparently the active agents that localized the precipitation of the calcium carbonate and gave the deposit its characteristic botryoidal form and eccentrically layered structure, the resulting reefs are not strictly comparable to those built up predominantly of casts or molds of algae such as *Chlorellopsis coloniata* Reis or various marine Corallinaceae. They are really only pseudomorphs of the original botryoidal algal colonies and not fossil algae like the others, which retain not only the outward form of the colony but also the form and some of the structural details of the individual plants.

PHYSICO-CHEMICAL INCRUSTATIONS

A few reefs of the Green River formation contain layers whose origin is more obscure. These layers consist wholly of tiers of radially arranged acicular crystals of calcite separated by thin layers of granular calcite and limonite grains and show neither organic structure nor the characteristic spongy structure just described. (See pl. 34, *C*.) Moreover, these layers appear to line cavities in the reefs and in a few places fill shallow cracks. They resemble layers of algal deposit in thinning and in places wedging out on the steep or overhanging sides of dome-shaped protuberances, but unlike the algal deposits many continue as thin incrustations into the bottoms of pocket-like depressions or infolds and up the sides of the adjoining excrescences. Furthermore, they differ from layers that are patently algal in tending toward a simpler surface form where many are superimposed. They fill the invaginations between algal colonies and bridge gaps between them, and above such bridges each succeeding layer becomes more uniform in thickness and so smooths out the surface contour. (See pl. 45, *A*.) Where these layers are of essentially uniform thickness the junction between arcuate sections of them is virtually a straight line. This feature resembles agate structure much more closely than algal structure. (See pl. 34, *C*.)

In describing similar finely banded agate-like deposits which coated gastropod shells Bucher[24] pointed out that the insides of the shells were also incrusted and that as the interior of the shell was dark the deposit could hardly have resulted from the photosynthesis of algae.

The radially fibrous layers in the reefs of the Green River formation may perhaps be recrystallized deposits localized by algae like *Schizothrix rupicola* Tilden or *Chantransia pygmaea* (Kützing) Sirodot, which according to Tilden[25] grow in weak light and deposit calcium carbonate. It is also possible that these layers of radial acicular crystals were formed by repeated exposure to the air, as at the lake shore, where they would be alternately moistened with lime-bearing water and dried. There is, however, no evidence to substantiate this supposition. It seems much more probable that they were formed without the assistance of plants and represent physicochemical deposits formed rapidly upon the algal layers as substrata.

Bucher[26] has produced thin layers of this kind experimentally and in further support of the hypothesis of their inorganic origin points out[27] that they are connected by all stages of transition with oolites for which he has adduced convincing arguments of an inorganic origin.

REEFS BUILT CHIEFLY OF CHLORELLOPSIS

The molds of the simple alga *Chlorellopsis coloniata* make up the greater part of many algae reefs of the Green River formation. These reefs have a variety of forms and internal structure. The specimens described below have been chosen as representative of the distinctive varieties.

TYPE CHLORELLOPSIS REEFS

The typical *Chlorellopsis* deposits (pls. 35; 36, *B*) form reefs of huge puffball-shaped heads 0.7 to 1.7 meters (2½ to 5½ feet) high and 0.6 to 0.7 meter (2 or 3 feet) in diameter. They also occur as isolated ellipsoidal heads 0.3 to 0.9 meter (1 to 3 feet) in maximum dimension and as thin layers of small extent whose lower surface is flat but whose upper surface is vigorously nodose.

Some of these reefs are inclosed in beds of very fine grained oolite mixed with fine sand, some in fine-grained current ripple bedded sandstone; others rest on limy shale that contains scattered oolite grains and are overlain by hard greenish-gray pyritiferous shale that shows only obscure bedding. White silty limestone contains nodular masses of the type deposit in parts of the formation in Wyoming. The surfaces of the reefs differ somewhat, but most are irregularly vermiculate or verruculose, with protuberances 2 to 4 millimeters high. A few have markedly tuberculate surfaces. (See pl. 36, *B*.)

Vertical sections of these reefs show that they consist of an aggregate of closely spaced or intergrown, very irregular, elongate simple or branched lobes that are crudely elliptical in cross section. These range in diameter from 2 to 7 millimeters near the base and taper slightly to a rounded tip. Some are expanded laterally

[21] Roddy, H. J., Concretions in streams: Am. Philos. Soc. Proc., vol. 54, pp. 246–258, 1915.

[22] Jones, J. C., Quaternary climate; Geologic history of Lake Lahontan: Carnegie Inst. Washington Pub. 352, pp. 6–14, 1925.

[23] Idem, pl. 1, fig. 10.

[24] Bucher, W. H., Über einige Fossilien und über Stromatolithbildung im Tertiär der bayerishchen Rheinpfalz: Geognostische Jahresh., vol. 26, p. 79, 1918.

[25] Tilden, J. E., Some new species of Minnesota algae which live upon calcareous or siliceous matrix: Bot. Gazette, vol. 23, pp. 102–103, 1897.

[26] Bucher, W. H., On oolites and spherulites: Jour. Geology, vol. 26, p. 608, 1918.

[27] Idem, pp. 593–604.

into leaf-like forms about 5 millimeters thick and as much as 20 millimeters across. The lobes have a crudely radial arrangement but no definite base or substratum and are not arranged in definite layers. The largest are about 3.5 centimeters long. A few branch dichotomously at an acute angle, but most of them bear short thick protuberances directed at a rather wide angle away from one side. (See pl. 35.)

Microcrystalline quartz and chalcedony have filled the spaces between the lobes of some reefs; fine limy oolite grains, fine sand, or silty limestone fill them in others.

Thin sections show that these lobate bodies consist of many successive limpet-shaped colonies of *Chlorellopsis coloniata*, some of which are very highly arched and decidedly asymmetric. (See pl. 32, *B*.) Their growth was evidently periodic. Each colony represents a brief period of growth and is separated from the next succeeding colony by a thin even layer of microcrystalline calcite, which was probably deposited without the agency of plants in an interval of lessened or no algal growth.

The groups of algal colonies or lobes taper upward slightly, pinch and swell, or retain about the same size but do not swell out into bulbous or saclike masses with overhanging sides, as if they had had plenty of space to expand. This restricted habit is due partly to their close spacing, and yet in parts of the deposit where they are much more widely spaced they retain the same habit. Apparently there was also another factor that prevented lateral expansion of the colonies. If the limy mud or fine oolite and sand grains accumulated nearly as rapidly as the algae grew, then in order to maintain themselves they would probably have built chiefly upward—expanding if possible, contracting if necessary. Such a mode of growth would account for their irregular tuberoid form. Moreover, the groups of algal colonies are not definitely arranged as if there had been a substratum upon which all the colonies were established at once and flourished unhindered. Instead their bases are at various heights above the base of the reef, indicating that they are not all colonies of the same age and that the substratum upon which the successive new colonies started was continually being raised.

The fine-grained and sandy oolite beds in which some of these reefs occur indicate shallow water activated by moderate currents or waves, for the oolite grains, which average about 0.5 millimeter in diameter, have been transported; they are gently cross-bedded and are mixed with fine clean sand that contains fishbone fragments. Locally there are also small groups of oolite grains in their original matrix, indicating that the jelly-like ooze in which they were formed had at least partly solidified before the grains were disturbed and transported. The grains within these small pieces of dense calcite do not touch one another but appear to have been suspended. Coarse angular mud flakes and considerable limonite in the oolite beds suggest also that the water was very shallow. At other places, however, quieter water is indicated, as the reefs rest upon limy shale with oolite grains and are covered by shale.

One zone of ellipsoidal heads and nodules of this type was found approximately at the top of the basal unit of the Green River formation at the southwest corner of sec. 30, T. 1 N., R. 95 W., Rio Blanco County, Colo. A reef of great puffball-shaped heads occurs also in the upper part of the basal unit about 101 meters (330 feet) above the base of the formation along the road from Fruita to Rangely near the divide between Douglas and East Salt Creeks, Colo. A layer of discrete ellipsoidal heads from 4 to about 25 centimeters in diameter, of a very porous algal deposit of this kind, occurs between a large pitted algal reef and a thick, massive medium-grained sandstone bed in the NW. ¼ SE. ¼ sec. 26, T. 4 N., R. 96 W., Moffat County, Colo. (See pl. 13, *A*.) In Sweetwater County, Wyo., in the NE. ¼ SW. ¼ sec. 14, T. 25 N., R. 103 W., there is a reef of this type at the base of the Morrow Creek member of the Green River formation. Subangular fragments of a silicified reef were found in a remnant of coarse bench gravel at the top of the Tipton tongue of the formation at the north quarter corner of sec. 1, T. 24 N., R. 100 W., Sweetwater County, Wyo. The horizon which these pieces represent is unknown.

MODIFICATIONS OF THE TYPE

An unusual algal deposit whose internal structure is closely similar to the type just described was also found in Sweetwater County, Wyo. It formed dense incrustations around logs and branches, and some of the incrustations were as much as 60 centimeters (2 feet) in outside diameter, 20 to 25 centimeters (8 to 10 inches) in inside diameter, and 1.8 to 2.4 meters (6 to 8 feet) long. The outer surface of the deposit is minutely nodose or papillose. The surface next the wood bears a very sharp impression of the woody fibers and in places has retained the cellular structure. (See pl. 36, *A*.) Apparently the bark had fallen away and the wood had started to decay, as is shown by the crudely rectangular depressions which the limy deposit filled. Thin sections of the deposit show that it consists of lobate colonial groups of *Chlorellopsis coloniata* that are of the same form as those of the type deposit but have a definite radial arrangement. Microcrystalline calcite that contains scattered angular grains of fresh plagioclase feldspar fills the interstices between the lobes and also obscures the verruculae which the tips of lobes would otherwise make. The papillose surface is due simply to differential weathering and is not structural, as in the reefs described on page 209. These algal deposits which incrusted logs were associated with an irregular reef that has a similar internal structure. They were found in the Tipton tongue of the Green River formation in the SE. ¼ sec. 23, T. 25 N., R. 103 W., Sweetwater County, Wyo.

Another algae reef closely related to the type *Chlorellopsis* reefs described on pages 209–210 occurs 286 meters (940 feet) above the base of the Green River formation in the NE. ¼ SE. ¼ sec. 30, T. 4 N., R. 96 W., Moffat County, Colo. It forms hemispherical heads 1 to 1.3 meters (3 to 4 feet) in diameter which are made up of concentric "shells" 4 to 6 centimeters thick. The reef rests upon a thick unit of fine-grained buff to gray soft sandstone which is current ripple bedded throughout and is overlain by fine-grained but somewhat shaly sandstone. The upper surface is vermiculate or verruculose. The under side has a very spongy aspect and consists of closely spaced or intergrown subcircular tubercles whose tips are either concave or contain conoidal depressions that apparently conform to the nodose surface of the underlying "shell." A polished cross section shows that the reef consists of tiers of radially arranged irregular clavate to bulbous groups of *Chlorellopsis coloniata* colonies, some of which are bifid. Most of the spaces between colonial groups or lobes are filled with medium-grained sand mixed with ostracode valves, but some are empty, and some contain dense buff calcite, probably of inorganic origin, which is similar to the thin layers that separate the tiers of algal colonies.

PITTED CHLORELLOPSIS REEFS

Algae reefs with large, distinct pits (pls. 37, *A* and *B;* 38, *A* and *B;* 39, *A* and *B;* 40, *A*) are apparently peculiar to the Green River formation of Colorado. They were not found in that formation in Utah nor in Wyoming, and as yet the writer has found no mention in the literature of any comparable algal deposit.

Walcott's pre-Cambrian genera *Greysonia* and *Copperia* [28] contain large tubes filled with extraneous material, but in them the part regarded as algal is small—so small, indeed, that the deposits are utterly different from those of the Green River formation. These Eocene deposits form reefs of considerable extent which are 0.3 to 1.8 meters (1 to 6 feet) thick and consist of closely appressed hemispherical or turbinate heads. They are interbedded with algal deposits of other kinds or occur between thick beds of clean light-gray medium-grained cross-bedded sandstone.

Circular pits of two distinct kinds cover the upper surfaces and in part also the sides of the heads. Those of one kind are shallow, cup-shaped, and fairly uniform in size and contain a more or less prominent raised concentric ring or collar in the bottom. In a few there are two such concentric rings. (See pl. 38, *B.*) Within the ring is another pit, circular or obovate in section, which is the end of a sand-filled tube that extends down into the reef. In some parts of the reef the pits are about equally spaced and without definite arrangement, but in other parts they have a distinct linear arrangement in the rounded bottoms of troughs. (See pl. 38, *B.*) Sharp but somewhat sinuate crests separate these troughs. The entire surface is vermiculate and resembles rather closely the surfaces of the type *Chlorellopsis* reefs. The under side of an eccentric shell of this type of pitted reef bears rounded, conoidal excrescences, each with a crater-like pit at the top which is the other end of a sand-filled tube or core of a surface pit.

The pits of the other kind are simply cone-shaped depressions with rounded bottoms. They may be very shallow or deep. Near the surface the cone flares, forming a sort of border for the pit. This collar and the inside of the cone have a granulose texture, which contrasts with the rather coarsely faveolate surface of the reef. (See pl. 38, *B.*) These pits differ widely in size and have no regular arrangement, although most of them are about equally spaced. The under side of a pitted reef of this type is marked with deep crater-like pits in the tops of low, steep-sided cones.

In cross section the pitted reefs show rather thick and porous or cellular growth layers. These consist of fine-grained buff calcite and are arched between the pit cores, being more highly arched the more closely the cores are spaced. Many pit cores extend through at least one "reef shell," 5 to 12 centimeters, but others go only about 1 centimeter below the bottom of the pit. (See pl. 38, *A.*) The writer does not know what the maximum length of these tubes may have been. The heads of some reefs are clearly fluted for 3 feet or more from the top, and these flutings end in ringed surface pits. (See pl. 40, *A.*) Broken fluted heads show that many of the tubes are both long and wide. Those shown in Plate 39, *B*, are 2 or 3 centimeters in diameter, only a little smaller than the surface pits.

The tubes of the ringed pits are filled with clean fine-grained sand compactly cemented with clear calcite. Small fishbones and a few ostracodes are scattered through these cores. The tubes of the conoidal pits are less distinct, having been largely overgrown by algal deposits from the sides and filled with small pellets of algal limestone and fine oolite grains.

Under the microscope the two kinds of pitted deposits appear to be essentially the same. They consist of superimposed long botryoidal layers of *Chlorellopsis coloniata* Reis separated by irregular layers and lunate zones of somewhat spongy microcrystalline calcite, which shows a network of radially arranged, interlacing fine lines of more coarsely crystalline calcite. (See pl. 34, *B.*) Scattered through this organic structure are many small pockets and stringers of

[28] Walcott, C. D., Pre-Cambrian Algonkian algal flora: Smithsonian Misc. Coll., vol. 64, pp. 108–110, pls. 17–19, 1914.

angular quartz and fresh orthoclase feldspar grains some of which are as much as 0.3 millimeter in diameter. These detrital grains are in a matrix of clear, finely granular calcite.

In certain zones in the reefs the colonies are more or less isolated, tall, columnar, and branched and give those zones a coarsely spongy aspect. This different habit was apparently caused by an accumulation of medium-grained sand and cyprid ostracode valves, in the hollows between colonies, which nearly kept pace with the algal growth.

In some reefs the algal deposits and also laminae of dense structureless limestone that coat them are considerably brecciated. The angular fragments, mixed with a generous proportion of fine sand and limy ostracode shells, form distinct layers within the reefs. Such structure indicates that the limestone of both kinds became hard and brittle comparatively soon after its deposition and that these reefs grew where at intervals waves and currents were active.

Clearly these deposits grew periodically by the addition of alternate layers of algae molds and precipitates of finely divided calcium carbonate. The algae grew freely, for their extensive layer-like colonies also expanded upward into comparatively broad domelike forms. Filamentous algae apparently also flourished and formed somewhat compressed hemispherical colonies among and on top of the *Chlorellopsis* colonies.

Toward the tubes the colonies thin very decidedly and in that way form the tube pits, for obviously the area immediately surrounding a tube built up much less rapidly than the other parts of the deposit. Consequently also the thinned edges of the colonies must dip more and more steeply into the pits as the deposit increases in thickness. In some reefs these edges dip inward at angles as large as 65° from the horizontal. The conclusion is inescapable that the immediate vicinity of these pit tubes was distinctly less favorable for the growth of the lime-depositing algae than areas more remote from the tubes. In fact, it appears that the growth of the algae was inversely proportional to the proximity of pit tubes.

The reasons for the greatly restricted growth of algae near the tubes are not clear. One possible explanation is offered. The tubes are all vertical or very nearly so, even though they emerge from the very steep sides of a large columnar head of a thick reef. (See pl. 39, *A*.) They are also fairly uniform in diameter, mostly 0.75 to 1.75 centimeters. None larger than 3 centimeters in diameter have been observed, but in places where they are rather closely spaced, as between two of normal size, there are tubes as small as 3 millimeters in diameter. This persistently vertical habit, the variation of size within fairly definite limits, and especially the spatial relations of small to large tubes, together with their fairly regular circular or slightly elliptical cross section, suggest that the tubes are molds of a large sedge such as *Scirpus lacustris*, the common bullrush that grows profusely in the shallow water along lake shores. If the tubes were formed in that way, then the zone around the sedge stems may have been less favorable to the algae by reason of the reduced illumination at all times except when the incident light was practically parallel to the sedge stalk. The most luxuriant growth of algae in the widest spaces between tubes accords with the suggestion of light control. Sand and other detrital material may well have filled the tubes after complete decay of the sedges when reef building ceased and the deposit was buried by the overlying sediment.

Although this explanation may serve to elucidate the distribution of the algae and consequently also the formation of the pits, it is not wholly convincing as to the origin of the tubes, because there is no trace of the stout rootstocks of a sedge. Further search might reveal them at the base of the reef, and yet it is inconceivable that a single stand of sedges could have persisted while more than 2 meters of algal limestone was formed around them. It is, however, barely possible that the rootstocks grew in the limy mud at many successive levels in the reefs, and that as they were horizontal and below the surface of the deposit they had little chance of being filled with sand, and therefore upon decay their molds collapsed and the limy mud settled in, thus obliterating all trace of them. Even the vertical tubes, where filled with microcrystalline calcite, are exceedingly obscure.

Although originally all conoidal, the surface pits have very probably been modified to the cup shape by solution, as they are excellent small water reservoirs. Moreover, the tops of some pitted reefs are so deeply weathered that the pits are nearly effaced. Only obscure rings show where the tubes end. (See pl. 39, *A*.) Because fine to medium grained, well-sorted sand occurs between the algal colonies, because there are layers of finely brecciated algal limestone mixed with sand at several levels within the reefs, and because many of the reefs rest on sandstone or beds of oolitic and ostracode limestone which contain coarse broken fragments of algal limestone it seems very likely that these reefs were formed in shallow water, where currents and waves were at least periodically active. As the origin of the tubes can not be conclusively demonstrated they do not assist in interpreting the reef ecology.

The thickest and best-exposed pitted reef was found near the top of a shore phase of the Green River formation in the NW. ¼ SE. ¼ sec. 26, T. 4 N., R. 96 W., Moffat County, Colo. (See pl. 40, *A*.) It rests upon a thin layer of ellipsoidal algal heads, which in turn rests upon a massive bed of light-gray clean medium-grained sandstone that is about 5.2 meters (17 feet) thick. This sandstone bed, together with two others below, makes a conspicuous cliff about 15 meters

(50 feet) high which is chiefly light gray but is locally banded with pink, mauve, and ocher. At approximately the same horizon and only 4 miles farther west, in the NE. ¼ SE. ¼ sec. 30, T. 4 N., R. 96 W., Moffat County, Colo., is another algae reef with very sharply defined pits. (See pl. 38, *B*.) This may have been formed contemporaneously with the reef in sec. 26 but is not a westward continuation. It is about 1.5 meters (5 feet) thick, but only the upper third is pitted, the lower part having smooth-surfaced shells. Soft shaly sandstone and siltstone underlie this reef, and fine-grained soft light-gray to buff sandstone overlies it.

Two other pitted reefs were found in the basal unit of the formation along the road from Fruita to Rangely, near the divide between Douglas and East Salt Creeks, Colo. One which is 51.6 meters (170 feet) above the base of the formation is only 5 centimeters thick and forms heads 7 to 15 centimeters in diameter. It rests upon ostracode limestone and is overlain by finely laminated dark-brown waxy shale, which contains some ostracodes and numerous small fishbone fragments and the skeletons of small fish. The other pitted reef is 162 meters (535 feet) above the base and ranges in thickness from 0.3 to 1 meter (1 to 3 feet). It forms hemispherical or puffball-shaped heads 15 to 60 centimeters in diameter and makes up a part of a compound algae reef 5.5 meters (18 feet) thick. (See pl. 29, *A*.)

A *Chlorellopsis* reef which is without pits but which in configuration and internal structure closely resembles the pitted reefs was found near the base of the formation in the SE. ¼ NE. ¼ sec. 18, T. 3 N., R. 95 W., Moffat County, Colo. It consists of much flattened cushion-shaped heads from 5 to about 20 centimeters in diameter, whose surfaces are smooth or only weakly faveolate, and is associated with regularly bedded ostracode limestone, oolite, sandstone, and shale. Each head of the reef is built up of many layers of *Chlorellopsis coloniata* separated by very thin layers of dense calcite. Thus the algal colonies are very extensive, some having areas of more than 1,000 square centimeters. Most of them are less than 5 millimeters thick, and none are more than 7 millimeters thick. Some consist of a single even layer of cells, but most of them are many cells deep and are minutely mammillate.

These colonies illustrate well the effect of contemporaneous accumulation of small amounts of detrital material and also indicate that the cells of *Chlorellopsis coloniata* were invested in a gelationus integument. Several algal layers, otherwise almost perfectly smooth, are deeply indented by pockets filled with subangular limestone pellets, fine sand, oolite grains, and ostracode valves. Some of the largest limestone fragments, about 4 millimeters long, stand with their major axes nearly vertical and their lower ends resting in sharp downfolds of algal colonies. (See pl. 40, *B*.) Evidently the investing medium of the algal cells was tough enough to bend sharply without breaking.

REEFS OF RECUMBENT COLONIES

Large recumbent *Chlorellopsis* colonies form reefs of closely appressed spheroidal heads which are 6 to 8 centimeters thick and 12 to 20 centimeters in diameter. Locally these heads have the form of short round-topped columns as much as 30 centimeters high. Moderately soft light chocolate-brown shale which weathers mouse-color underlies and overlies these reefs. The upper surface of each head bears closely spaced irregular cushion-shaped protuberances 0.5 to 3 centimeters in diameter and about 0.5 centimeter high. The sides have peripherial wrinkles or folds that vaguely resemble fabric, and the bottoms are practically smooth. A vertical section through a head shows that the deposit is built up of large recumbent colonies of *Chlorellopsis coloniata*. (See pl. 41, *A*.) These are exceedingly irregular, but most of them are discoid layers which range from about 1 to 6 centimeters in diameter. They average about 0.5 centimeter in thickness, but a few are as thick as 1 centimeter. Their eccentric growth lines are convex in the direction of the radii of the colonies except in those colonies that form the surface layer, in which the growth lamellae are convex upward. Most of the colonies are separated by very thin, mildly brecciated layers of light-buff dense calcite. Between some of them are thin irregular layers and lenses of contorted chocolate-brown shale similar to that upon which the reef rests.

Thin sections of these colonies show that many of the *Chlorellopsis* cells are ellipsoidal but apparently only because they are so densely packed. The cells are embedded in a microgranular matrix of calcite which was originally rather porous. Secondary quartz in small interlocking grains now fills the pores. Also the thin sections show that the thin buff layers consist of transversely arranged calcite crystals and that the brown shale contains enough organic matter to be regarded as a low-grade oil shale.

Why the algae in these reefs formed such unusual colonies is not wholly clear. So decided a tendency toward the formation of discoid colonies by peripheral growth seems to indicate that free vertical growth was inhibited. The inhibition may have been due to the deposition of a thin film of organic ooze or the precipitation of a thin layer of calcium carbonate on the upper surfaces of the colonies. Perhaps also the overlapping of contemporaneous colonies prevented upward growth. On the other hand, the mildly brecciated limy layers, together with the gently contorted organic shale, suggest that the basement yielded under the weight of the growing colonies so that they were unable to assume their normal cushion or puffball shape. A somewhat higher concentration of dissolved salts in the lake water of that stage might also have in part caused the peculiar habit of the algae in these reefs. They are associated with beds of sun-cracked shale and at least one bed of rather low-grade oil shale which contains many small calcite pseudomorphs after glauberite. Although the salinity of the water might have increased enough to modify the habit of the plants, the supposed change was probably not great, for the form and size of the cells remained unchanged. The bulbous colonies of the surface layer indicate more normal conditions of growth and also serve to demonstrate that the recumbent habit is not a character upon which to found another species of *Chlorellopsis*.

These algae reefs were obviously formed in quiet water, but at what depth it is impossible to say except that it must have been shallow enough to promote active photosynthesis in the algae. They were found at the base of the saline facies of the Green River formation in the composite section measured in Indian Canyon along the mail road from Duchesne to Price, approximately in sec. 28, T. 6 S., R. 7 W. Uinta meridian, Duchesne County, Utah. One reef is about 1,063 meters (3,830 feet) and the other about 1,185 meters (3,900 feet) above the base of the formation.

A thin partly silicified reef consisting of a few layers of recumbent *Chlorellopsis coloniata* colonies was found in the basal tongue of the Green River formation just north of Soldier Summit, Utah County, Utah. These colonies range in diameter from 0.5 to about 4 centimeters, but very few exceed 3 millimeters. They rest either upon a very uneven substratum apparently made up of heaps of plant detritus mixed with ostracodes and mollusk shells or upon thin irregular zones of spongy algal deposit whose interspaces have been filled with chalcedonic silica. Some of the *Chlorellopsis* molds are filled with silica, others with yellowish microcrystalline calcite. In the partly silicified débris which the algae incrusted were found large pieces of the tissues of higher plants, cuticles of leaves, various pollen grains, and numerous short fungal hyphae, some of which bear simple terminal conidia. Thin and somewhat contorted layers of yellowish-brown limy shale are also included in the deposit. Stems of *Chara*, but no fruits, are fairly plentiful in a silicified layer associated with the algae reef. Clearly this reef formed in quiet water, which was probably also shallow and close to a protected shore.

REEFS WITH SPONGY STRUCTURE

DIGITATE REEFS

A specimen representing an unusual type of reef occurs either as isolated spheroidal or potato-shaped heads or as large botryoidal intergrowths of these forms and is embedded in light-brown flaky or platy sandy shale whose bedding is somewhat contorted. (See pl. 41, *B*.) It is overlain by a bed of massive hard greenish-gray shale that contains many secondary gypsum partings. The upper surface bears many irregular mound or ridge shaped excrescences separated by rather deep depressions, which are partly filled with buff limy mudstone. In addition to these larger features the upper and lower surfaces are vigorously tuberculate or papillate. The steep sides are granular or pustulate. In its form and sculpturing it resembles closely a specimen of *Lithothamnium? ellisianum* described by Howe and Goldman.[29]

A polished vertical section of this specimen, however, shows that the heads of the reef consist of many digitate groups of interrupted cuneiform lobes of finely crystalline calcite which show fine arcuate growth lines delicately colored in tints that range from deep reddish brown to buff. (See pl. 42, *B*.) Very fine grained dark bluish-gray to cream-colored limy sandstone fills compactly the spaces between the calcite lobes or columns. Clear crystalline calcite fills some of the cavities that were apparently not open enough to permit the sand to enter.

A transverse section of this specimen shows that the lobes or columns are arranged in a roughly concentric manner and that although they are exceedingly irregular in cross section they show a marked tendency toward centrifugal thickening, especially in those near the periphery. (See pl. 42, *A*.) The smaller columns are simple and nearly circular in cross section, but the larger ones are deeply and complexly embayed.

The internal structure of this reef resembles rather closely an algal deposit from the north German Buntsandstein at Schlossenberg described by Kalkowsky.[30] It also resembles the algae reefs now being formed in Green Lake, N. Y.

Thin sections cut parallel to the columns reveal in them obscure algal forms. The plainest of these are several transverse zones of *Chlorellopsis coloniata* molds. Other parts of the columns or algal colonies consist mostly of microcrystalline calcite which locally has a spongy structure resembling that of certain recent algae reefs, but there are also areas of uniformly fine granular calcite that shows no other structure than vague growth layers. The obscurity of the plant structure in this specimen seems to be due chiefly to lack of differentiation in size of crystal grain between the plant molds or casts and the matrix.

This reef is peculiar not only in its complex, digitate habit of growth but also in its content and distribution of organic matter and limonite grains. Each algal colony and branch has just beneath its surface a thin layer of closely packed fine limonite granules, many of which are cubical. Locally the granules are also scattered sparsely through the interior of a colony. Associated with the limonite or distributed in skeleton

[29] Howe, M. A., and Goldman, M. I., *Lithothamnium? ellisianum*, sp. nov., from the Jurassic Ellis formation of Montana: Am. Jour. Sci., 5th ser., vol. 10, p. 316, 1925.

[30] Kalkowsky, Ernst, Oolith und Stromatolith in norddeutschen Buntsandstein: Deutsche geol. Gesell. Zeitschr., vol. 60, pp. 106–107, pl. 8, 1908.

forms of tall algal colonies within the limonite encasements is a considerable quantity of yellowish-brown organic matter. It is not homogeneous, but neither does it contain identifiable organisms. It resembles the organic matter of oil shale and is still further analogous to such matter because it is diffused through microgranular calcite. This reef derives its colors from the limonite and organic matter.

Apparently the limonite is secondary after pyrite that formed from decomposition products of the organic matter and iron salts dissolved in the lake water. Moreover, the organic matter is probably a residuum of the plants that built the reef, not only because it has the form of algal colonies but also because the deposition of an organic ooze upon the reef would hardly be expected in water continually transporting and depositing sand. Furthermore, the segregation of the limonite close to the peripheries of colonies suggests that the inclosed algae subsequently decayed and that as hydrogen sulphide from their decay migrated outward it precipitated pyrite where it came into contact with iron salts in the lake water. The occurrence of disseminated limonite granules within some colonies is also in harmony with this hypothesis.

This particular specimen shows two major stages in the history of the reef's development. At *a*, Plate 42, *B*, is an irregular nucleus of dense cream-colored calcite from which finely laminate colonies radiate. A buff band, shown in white in the photograph, circumscribes the nucleus and passes through the tips of the colonies that radiate from it. The colonies directed downward from the nucleus are much longer than those directed upward. Because they grew principally upward by accretion of calcite at their tips it is evident that the part of the reef circumscribed by the buff band was overturned when it had reached that stage of its development. A similar but less striking nodule cut so as to just miss the nucleus may be seen to the right of this one. (See pl. 42, *B*.) There are also small short colonies on what was the under side of the larger nodule. Whether these grew downward where the nodule did not actually rest on the bottom it is difficult to say. The absence of them on the originally lower side of the smaller nodule lends slight support to this idea.

The second stage in the developmental history of this specimen is represented by the tall flabellate colonies that make up the larger part of the specimen. They are oriented as they grew. (See pl. 42, *B*.)

This reef is so similar to those now being formed in Green Lake, N. Y., that it seems safe to infer for it a like origin. The tall flabellate and complexly branched protuberances whose tips are richly nodose are remarkably like those of the recent reefs and like them were probably formed through the agency of a dense felt of algae. The elongated protuberances of the recent deposits seem to be due to rapid growth and a struggle of the plants to acquire better illumination. Similar features in the fossil reefs seem properly to be explained in the same way. The overturning of these nodules when partly formed indicates at least periodic strong wave action, and the abundance of fine, well-sorted sand between the arborescent masses also indicates current or wave action. From these the writer concludes that this reef was formed in fairly shallow water.

This reef was found approximately in sec. 22, T. 10 S., R. 25 E., Uintah County, Utah, about 82 meters (270 feet) above the base of the Green River formation.

TABULATE REEFS

Tabulate reefs of essentially uniform thickness occur within beds of fine-grained and somewhat shaly oolite, which also contains numerous ostracodes. (See pl. 43, *B*.) At one locality a reef of this kind contains vertical molds of large deeply fluted *Equisetum* stems. The top consists of slightly arched, very irregular, and more or less closely appressed molariform or reniform protuberances, which are yellowish buff. Small oolite grains in a dense gray matrix occupy most of the depressions between these. The lower surface of the reef is practically flat.

As shown in the polished cross section the reef is built up of many rather thick layers of porous yellowish-gray calcite. These layers are only slightly sinuous near the base but become more and more irregular toward the top, where they form a series of flat-topped, steep-sided arches separated by deep channel-like depressions that are partly filled with fine oolite grains cemented by light-gray calcite. Such deep crooked channels give the cross section of the reef a crudely columnar aspect.

Vertical thin sections of a reef of this type show that the rather poorly defined layers consist of microcrystalline calcite and have a spongy structure. The microcrystalline calcite contains thin branching lines of slightly coarser grained calcite which have a prevailing radial habit. (See pl. 34, *B*.) Some of these may be the casts of filamentous algæ, but others clearly are not, for they fork downward as well as upward and form a continous network between the irregular microcrystalline masses. Furthermore they are not at all uniform and widen into comparatively large cavities, which differ greatly in size and have no definite form. These coarser-grained calcite lines seen rather to be cross sections of thin secondary fillings between the microcrystalline calcite masses. Moreover, thin sections cut normal to these fine radial lines that most resemble algae support this hypothesis, for none of them are circular or even elliptical in cross section. They entirely surround the transverse sections of columnar and globular microcrystalline masses that make up the reef.

The spongy but otherwise structureless aggregate of microcrystalline calcite is exactly comparable to the deposits of calcium carbonate localized by members of the Cyanophyceae at the present time in fresh-water lakes, and very probably it had a similar origin. Small calcite oolite grains which apparently formed where they are now found are associated with reefs of this kind and indicate that the water, for a time at least, was saturated with respect to calcium carbonate. Vertical molds of large *Equisetum* stems occur in one reef. These evidently grew contemporaneously with the reef and show that the deposit formed in very shallow lake margins, where a more or less sparse emergent vegetation prevented not only strong water movements but also the influx of much clastic material. Although shallow, the water was probably clear except at times of storm, when the limy mud was thrown into suspension. Such shallow and slow-moving water must also have been considerably warmed, a condition favoring the formation of the oolitic marl in which this type of reef occurs.

One reef of this kind was found at the base of the Laney shale member of the Green River formation in the NW. ¼ sec. 18, T. 25 N., R. 103 W., Sweetwater County, Wyo. A similar reef occurs in Colorado near the top of the basal unit of the formation, about 161 meters (530 feet) above the base, on the divide between East Salt and Douglas Creeks a few hundred feet east of the saddle through which the Fruita-Rangely road passes. This land has not been sectionized, but the locality is approximately where sec. 13, T. 5 S., R. 102 W., would fall.

COMPOUND REEFS

Reefs built up of more than one principal structural type have been grouped for convenience of exposition under the general term compound reefs. They may include not only *Chlorellopsis* colonies, *Confervites* filaments, and the less definite masses with spongy structure but also physico-chemical incrustations.

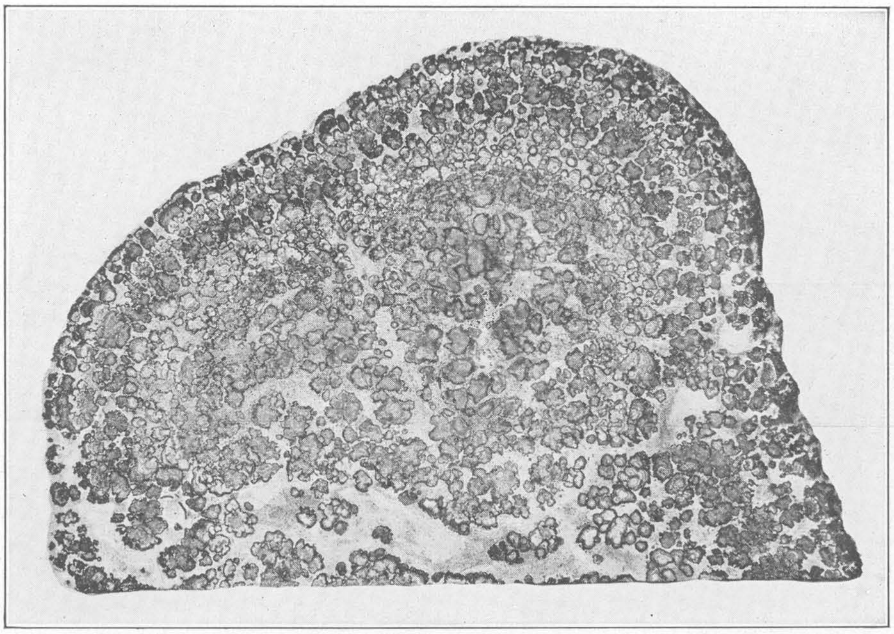
REEFS CHIEFLY ALGAL

Compound reefs that are chiefly algal were found in beds of limy shale as isolated, more or less widely spaced low circular heads that are somewhat biscuit or mushroom shaped, 3 to 8 centimeters high, and 5 to 18 centimeters in diameter. The upper surface and sides consist of a mosaic of smaller heads, which are irregularly rounded or elliptical but somewhat flattened or even concave on sides where they are closely appressed. Although the upper surface was worn nearly smooth by scour before burial, each minor head was originally bulbous and represents an individual algal colony. (See pl. 44, *B.*) Along the margins where abrasion was less these are now wartlike protuberances. The under surface has the form of an inverted irregular basin with a nearly flat bottom and steep or even overhanging sides.

A polished cross section of a specimen representing this type reveals four growth zones, each with a distinct structure. (See pl. 44, *A.*) The lowest zone has a spongy structure and consists of dense brownish-gray calcite. The interspaces are completely filled with clear coarsely crystalline calcite, which is evidently secondary. The second zone is considerably thinner and consists of dense calcite finely color banded in shades of red-brown, yellow, and gray. This zone is more compact than the others and closely resembles agate. Overlying the agate-like zone is a layer which has a spongy structure somewhat similar to that of the basal layer except that the areas of dense calcite are larger and light buff. In places they are radially elongated and give the zone a very crude columnar structure. Many of the elongated pieces are distinctly arborescent. Some of the interspaces of thin layers have been filled with clear calcite, but most of them are still open. The structure of both spongy zones is very much like the internal structure of the algae reefs now being formed in Green Lake, N. Y. The surface layer consists of rather large and irregular bulbous or puffball-shaped colonies of *Chlorellopsis coloniata* Reis, which rise from a nearly continuous substratum of the same organisms. (See pl. 44, *A.*) These colonies are about 1 centimeter high and range in diameter from 4 millimeters to 1.7 centimeters. Some are irregular sprawling forms, and a few are forked near the summit, but most of them are simple. All contain thin irregular stringers or clavate lobes of dense buff calcite in which the plant cells occur only sparingly.

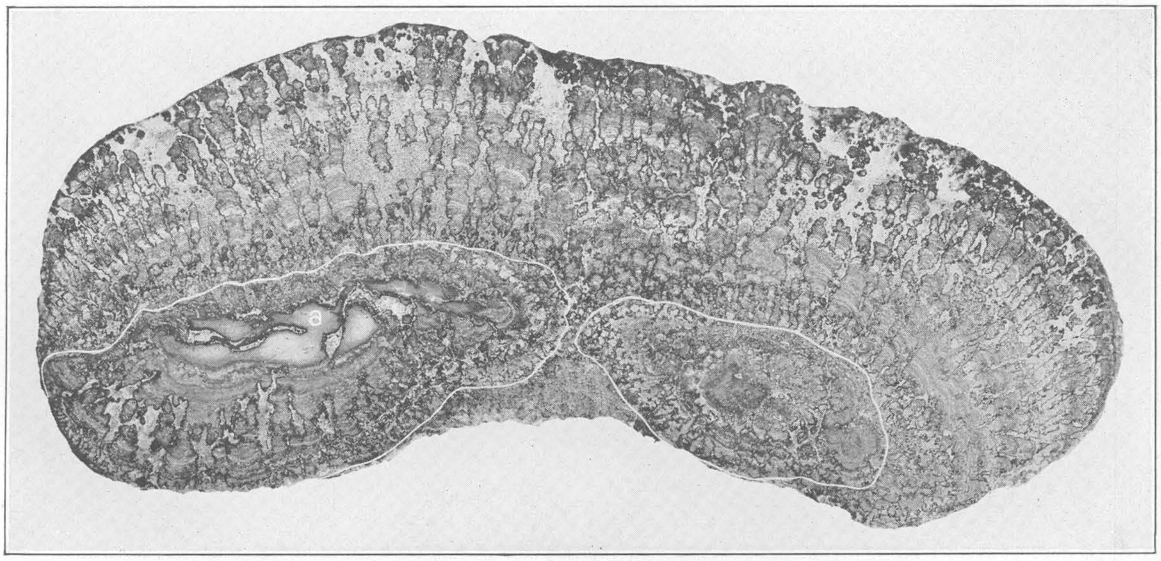
Areas between the algal colonies are filled with dense brownish calcite that shows fine laminae outlining the colonies. Between some colonies are pockets of fine sand mixed with a few small ostracode valves.

Under the microscope the two spongy layers separated by the agate-like zone appear to be identical except only that more interstices of the lower one contain coarsely crystalline secondary calcite. The irregular and somewhat arborescent masses that make up these layers consist of even-grained microcrystalline calcite, which locally contains a few fine interlacing lines of more coarsely crystalline calcite that may may be the casts of filamentous algae. The agate-like layers consist mostly of tiers of radially elongated calcite crystals, but locally the whole zone is made up of finely granular calcite. Minute granules of limonite are scattered through this zone or are arranged in definite layers. These layers, perhaps together with small quantities of organic matter, give to the zone its banded aspect and various shades of red, brown, and gray. Many of the limonite granules are cubical, and probably all are secondary after pyrite. In the micro-



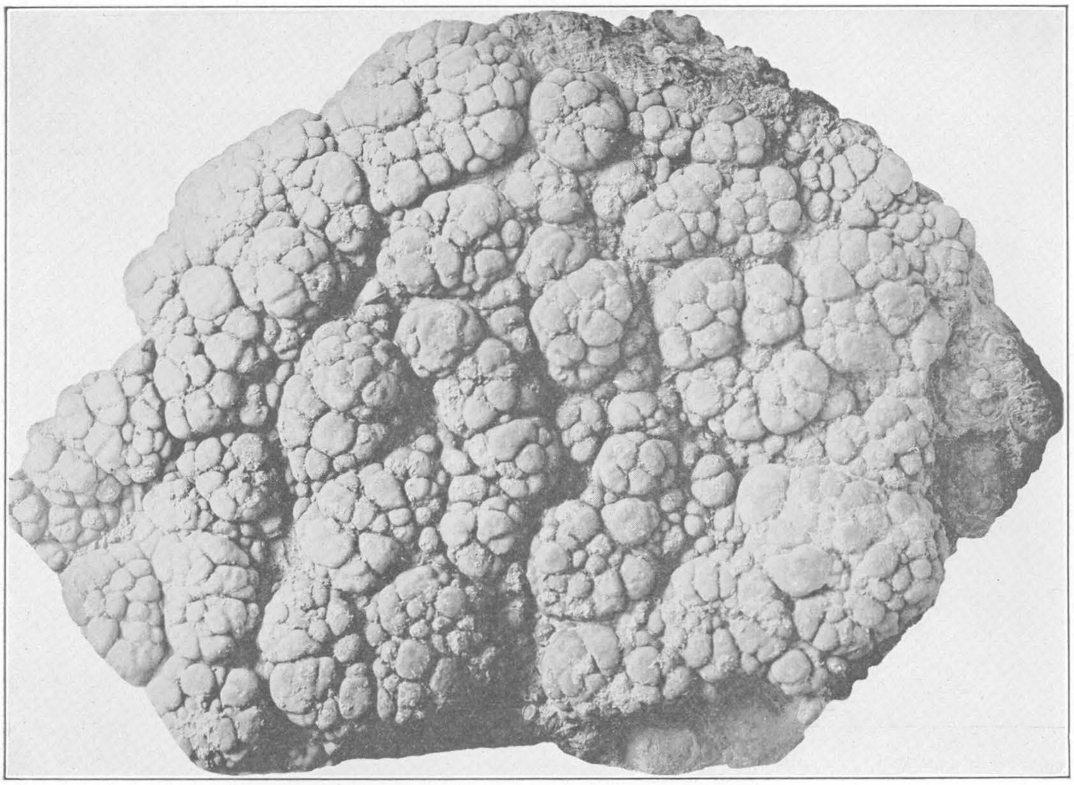
A. POLISHED TRANSVERSE SECTION OF THE DIGITATE REEF SHOWN IN *B*

Natural size



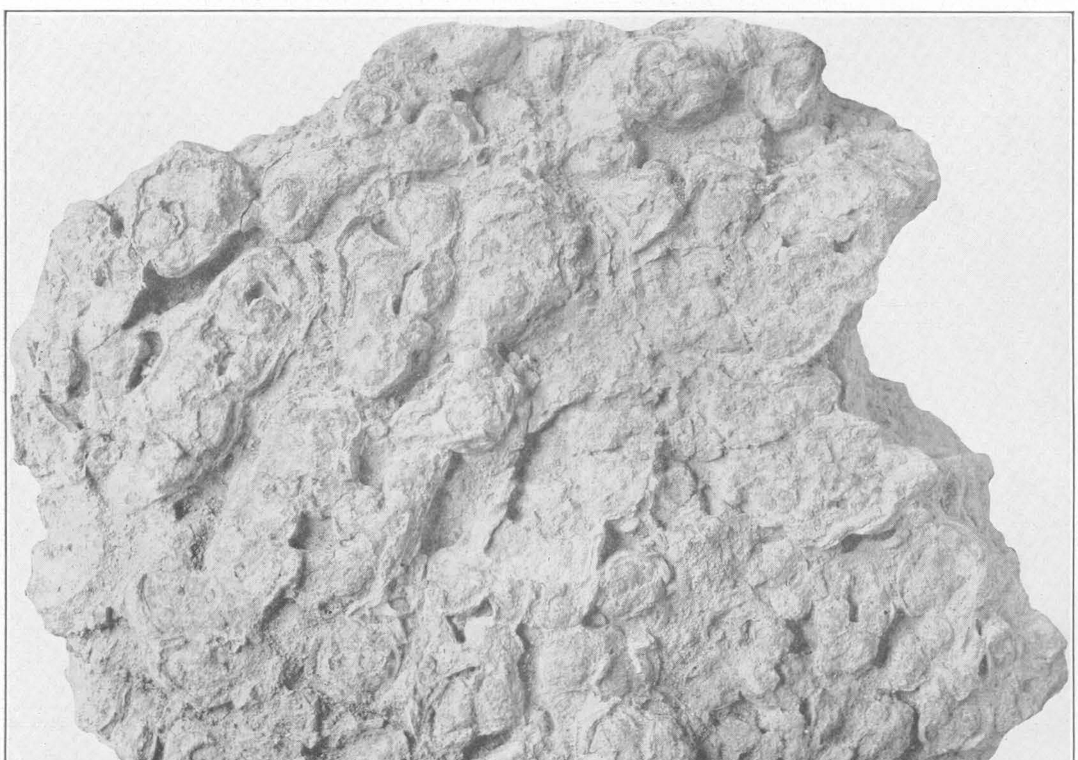
B. POLISHED VERTICAL SECTION OF A DIGITATE ALGAE REEF

Showing nuclei of dense cream-colored limestone (a) and two distinct stages of growth. The light-gray finely speckled material between the columns of algal deposit is fine-grained limy sandstone. Natural size



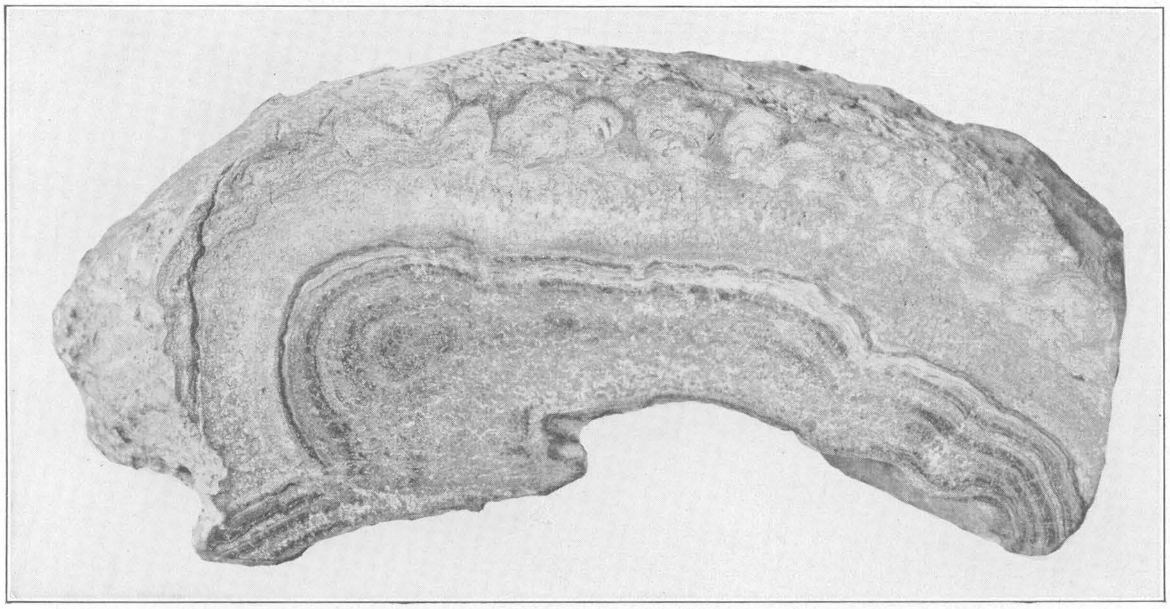
A. UPPER SURFACE OF A COMPOUND REEF WHICH CONSISTS OF ALTERNATING ZONES OF ALGAL AND INORGANIC LIMESTONE

Near base of Tipton tongue of Green River formation in NW. ¼ sec. 21, T. 24 N., R. 101 W., Sweetwater County, Wyo. Three-fourths natural size



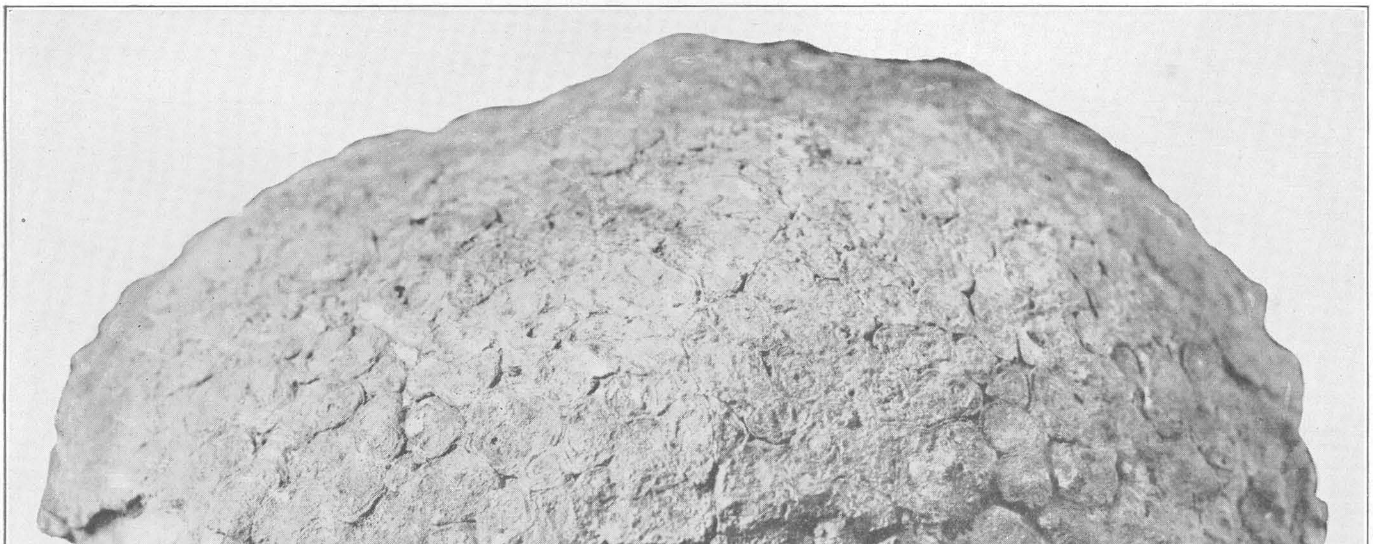
B. UPPER SURFACE OF A TABELLATE REEF WITH SPONGY STRUCTURE

Each molariform head is more or less columnar in section, though many of them are very irregular and complexly intergrown. Three-fourths natural size



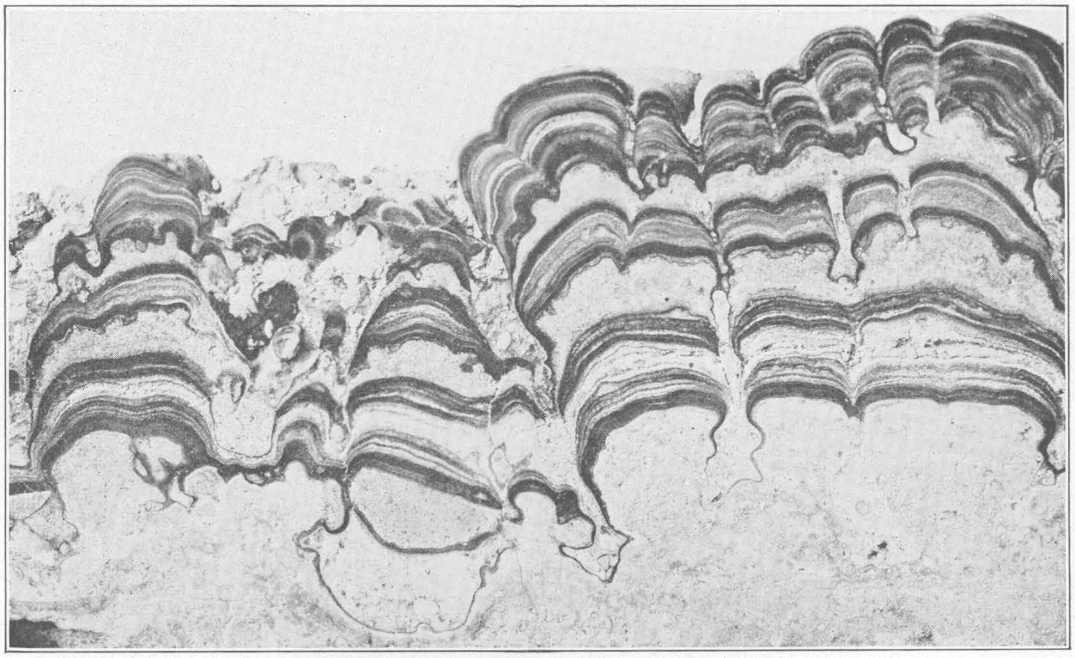
A. POLISHED VERTICAL SECTION OF A COMPOUND ALGAL HEAD CONSISTING OF MANY SMALL HEADS, EACH OF WHICH REPRESENTS A SINGLE COLONY OF CHLORELLOPSIS COLONIATA REIS

These minor heads rest upon a zone of spongy algal deposit, which is separated from another similar zone below by a finely banded inorganic agatelike zone. Natural size



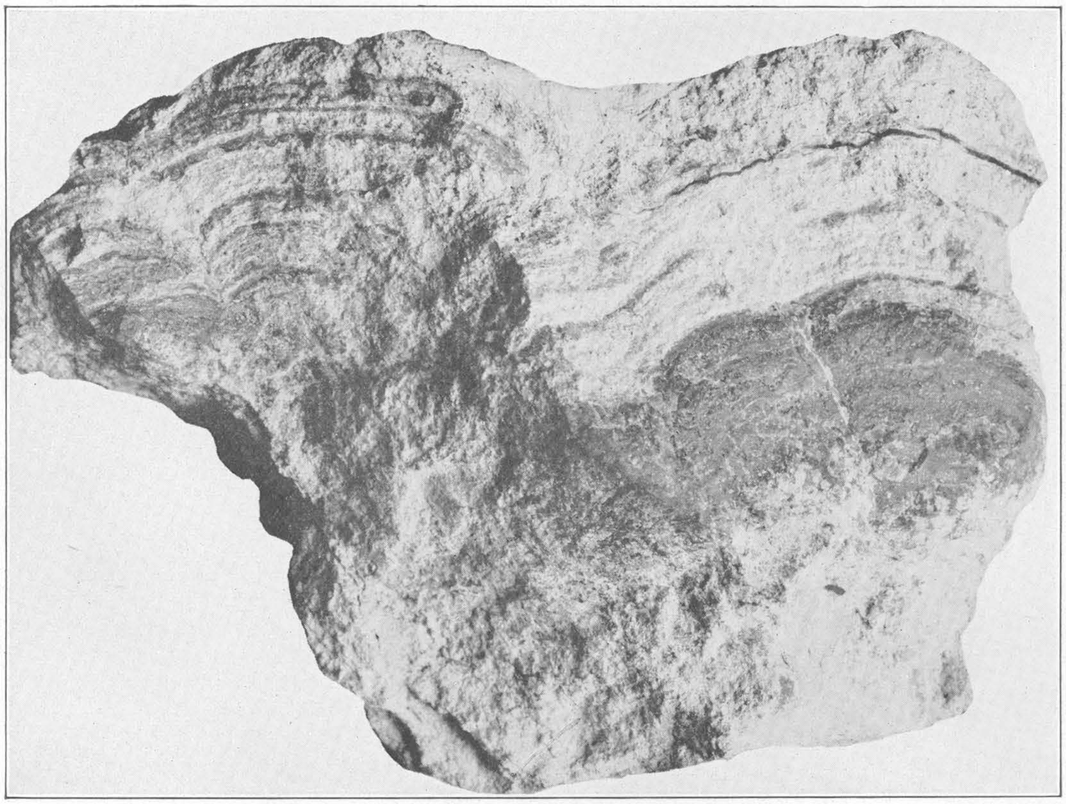
B. COMPOUND ALGAL HEAD CONSISTING OF MANY MINOR HEADS, EACH OF WHICH REPRESENTS A SINGLE COLONY OF ALGAE

Compare with *A*



A. POLISHED TRANSVERSE SECTION OF THE REEF SHOWN IN PLATE 43, *A*, SHOWING ALTERNATE ALGAL AND INORGANIC LAYERS

The irregular light-colored layers consist of the molds of *Chlorellopsis coloniata* and typical spongy algal deposit. The black and gray finely banded layers are of inorganic origin and owe their dark color to disseminated pyrite. Enlarged 3 diameters. Compare with the photomicrograph of a thin section of part of the same reef shown in Plate 34, *A*.

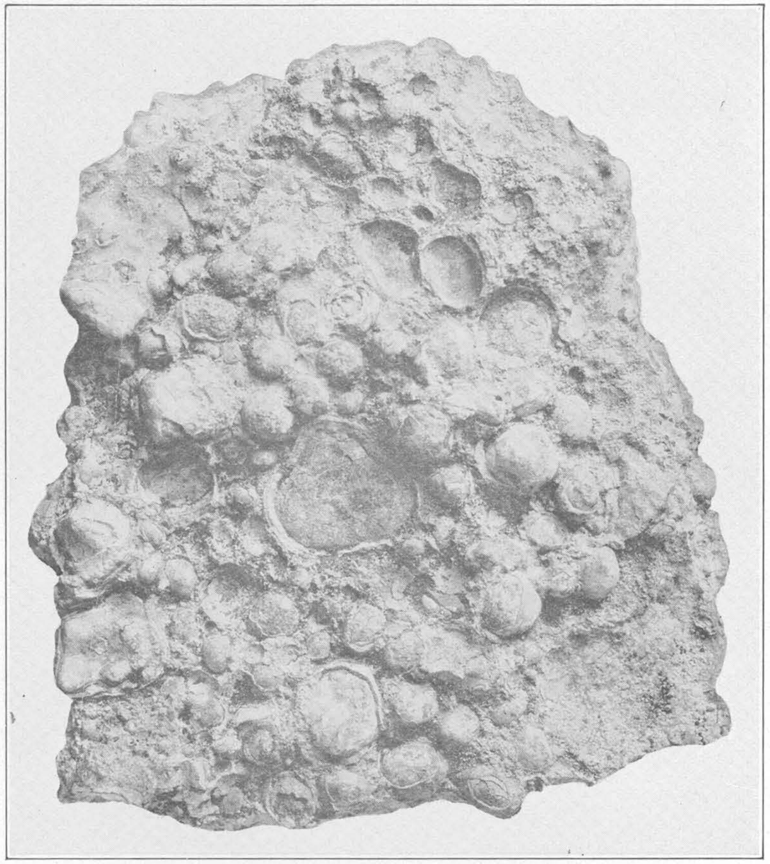


B. ALGAE REEF FROM THE "MANTI BEDS," MANTI, UTAH

The dark areas are partly silicified and contain the filamentous algae and coprolites shown in Plate 33. Natural size

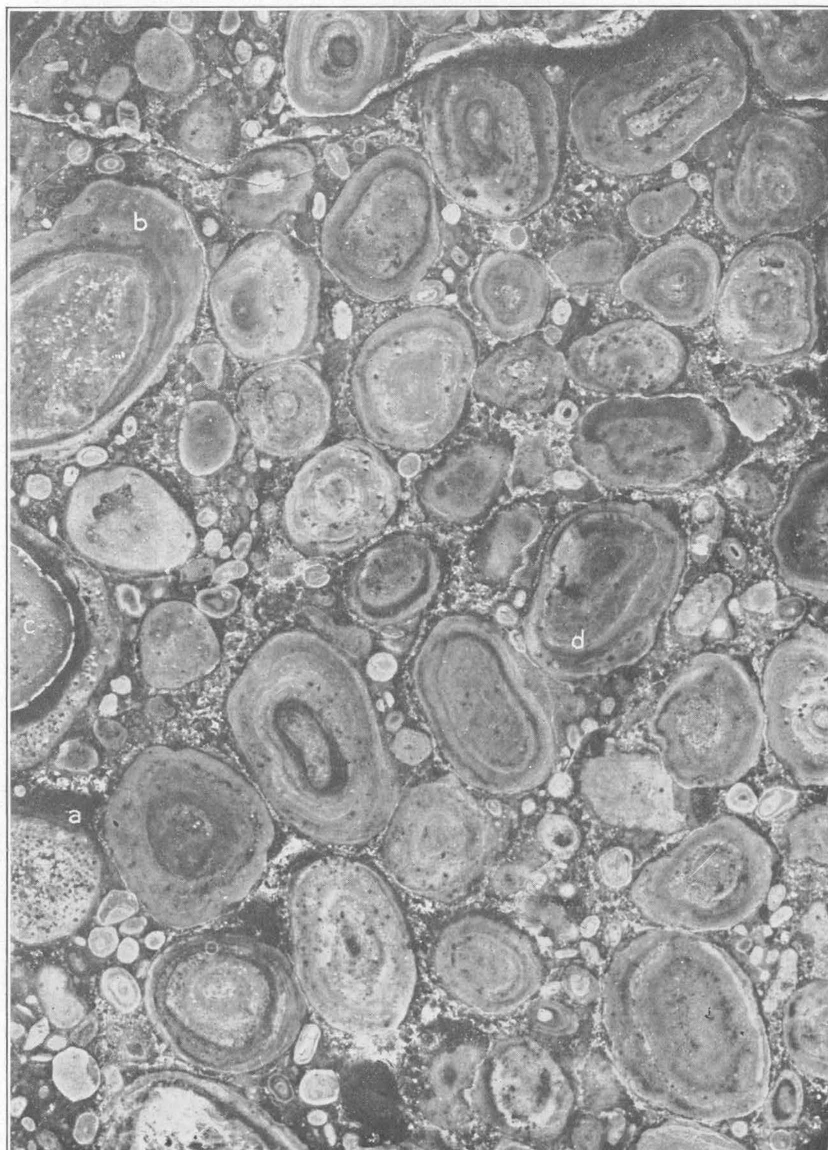
A. POLISHED SECTION OF AN ALGAL COBBLE

Showing a large subangular limestone nucleus and three distinct stages of growth. Natural size. See text, p. 219, for explanation of letters



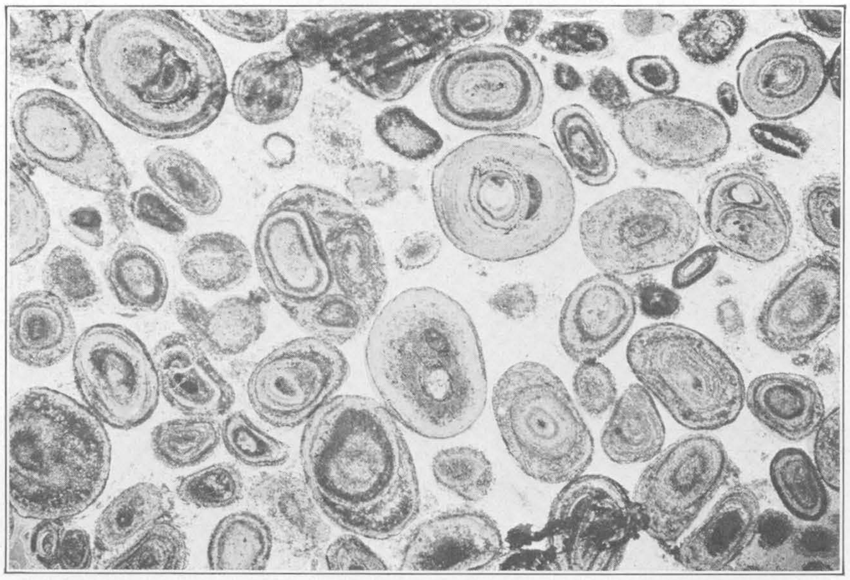
B. ALGAL PEBBLES FORMED CHIEFLY OF CHLORELLOPSIS COLONIATA REIS IN A MATRIX OF OSTRACODE LIMESTONE

Natural size



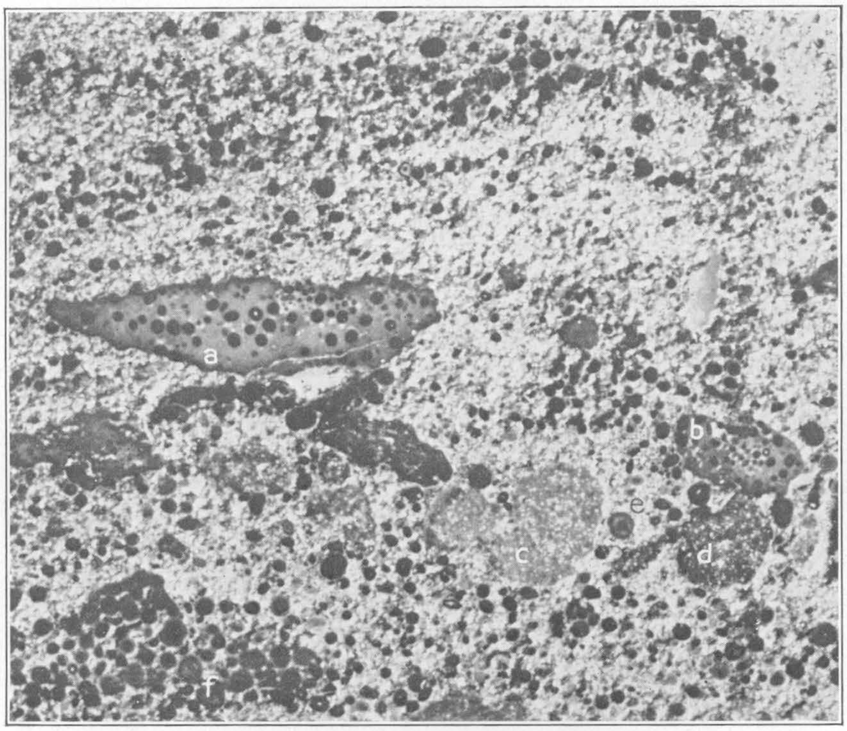
POLISHED SPECIMEN OF ALGAL PEBBLES SHOWING DETAILS OF INTERNAL STRUCTURE

At a is a pebble consisting wholly of *Chlorellopsis coloniata*, at b and c are pebbles made up chiefly of *Chlorellopsis* molds but containing also thin dense inorganic layers, and at d is a pebble consisting chiefly of spongy algal deposit with a few thin inorganic layers and a few *Chlorellopsis* molds. Between the algal pebbles are small oolite grains mixed with fine limy sand. Enlarged 5 diameters



A. THIN SECTION OF AN OOLITE FROM THE LANEY SHALE MEMBER OF THE GREEN RIVER FORMATION ON SHELL CREEK, SEC. 9, T. 12 N., R. 98 W., WYO.

Showing large oolite grains with eccentric growth zones. The darker granulose parts of these grains consist of mechanically enmeshed silt, and the clearer parts consist of fine-grained calcite partly replaced by chalcedonic silica. The groundmass consists of chalcedonic silica, with scattered microcrystals of calcite. Enlarged 11½ diameters



B. SMALL AREA OF THE POLISHED SPECIMEN SHOWN IN PLATE 35

This shows a part of the oolitic sandstone which contains at a and b fragments of microcrystalline calcite with ferruginous oolite grains suspended in the positions in which they formed, at c and d fragments of algal limestone consisting almost wholly of *Chlorellopsis*, and at e and f unusually large oolite grains that show the wide concentric banding characteristic of all the oolites in this bed. Enlarged 5 diameters crystalline calcite between the cells of some *Chlorellopsis* colonies are calcite casts of small filaments in fascicular groups. These resemble somewhat *Confervites mantiensis* but are not well enough preserved to be worth description.

This reef evidently had four distinct stages of growth, the first and third probably by means of filamentous algae which left only vague traces of themselves. The paucity of small angular grains of feldspar and quartz and the absence of limy mudstone in these two zones indicate that they were probably formed in quiet and also clear water. The agate-like layers between them are probably of inorganic origin, and the abundance of limonite grains, secondary after pyrite, suggests that decaying organic matter through its evolution of ammonia brought about their precipitation.

Chlorellopsis and probably also some filamentous algae formed the surface layer. During this stage the water was apparently more active and deposited some fine sand in pockets between the algal colonies. Small quantities of calcium carbonate in the form of mud were also deposited on and between the colonies during their growth.

The strongly abraded surface of the reef shows that after its complete solidification it was subjected to a rather potent scouring. It is not clear whether during that erosion it was exposed to the weather.

This reef was found in the lower part of the Tipton tongue of the Green River formation in the NE. ¼ NE. ¼ sec. 16, T. 24 N., R. 102 W., Sweetwater County, Wyo.

REEFS LARGELY INORGANIC

A thin discontinuous reef which is representative of a small class of similar deposits that are largely inorganic (see pls. 34, *C*; 43, *A*; 45, *A*) rests on ostracode limestone which contains limestone pebbles as much as 1 centimeter in diameter. In places the same bed contains small but distinct mud curls. A somewhat similar pebble conglomerate overlies the reef, but in addition to limestone fragments it contains well-rounded quartz, chert, and feldspar pebbles, some of which are nearly 1 centimeter in diameter, and also larger sharply angular fragments of a similar reef.

The reef itself is about 3 centimeters thick and makes an essentially continuous bed. The upper surface consists of somewhat flattened hemispherical heads of closely spaced wartlike protuberances, which resemble in shape, color, and even texture the thickened pads on the under side of a cat's paw. (See pl. 43, *A*.) The under surface is flat.

A polished cross section of the specimen shows that it consists of alternating black, dark grayish-buff, and light-buff complexly crenulated layers. The lowest buff layer has a flat base, but on its upper sides it bears relatively large, vigorously nodose flabellate or in places even arborescent *Chlorellopsis coloniata* colonies between which are pockets filled with ostracodes and small angular pebbles of algal limestone, all of which are so thickly incrusted with lime as to resemble irregular oolite grains. These are mixed with a little fine sand and cemented by clear calcite. Upon these colonies are built the hemispherical heads of wartlike protuberances, each of which consists of several short cushion-shaped buff layers like the basal layer except that they are thinner. These are separated by zones of thin dense black or gray layers which vary in thickness from place to place but which are continuous across the specimen. It is also significant for their proper interpretation that in places the black layers line cavities, fill cracks, and follow the reentrants below overhanging buff layers. (See pl. 45, *A*.) Moreover, their upper surfaces, except where interrupted by detrital material, are smooth curves and contrast sharply with the richly nodose upper surfaces of the buff layers.

Between the turbinate or puffball-shaped heads are pocket-like depressions filled with detrital material such as small ostracodes, angular fragments of dense buff calcite, small sand grains, and oolite grains some of which have an ostracode valve for a nucleus. Clear calcite forms the matrix of these pocket fillings. Pyrite now partly altered to limonite has completely replaced the fillings of a few such pockets near the top of the reef.

Thin sections of this specimen show that the upper part of the basal buff layer and also the other buff layers consist of spongy microcrystalline calcite which contains a network of algoid lines of coarser-grained calcite. They were very probably deposited by a felt of algae. (See pl. 34, *A*.) In thin section it becomes apparent that the black or dark-gray agate-like layers have been completely recrystallized, for their long acicular calcite crystals, some of which are more than 0.1 millimeter long, cross thin layers of yellowish organic matter and thin zones of limonite granules that probably mark successive stages of peripheral growth. The layers that separate the zones of long acicular crystals consist of granular calcite with a small quantity of organic matter and an abundance of small limonite grains, many of which are cubical.

Locally the limonite grains are so closely spaced that they appear as black bands, even though highly magnified. Much of the dark color of these layers is due to them. Yet vast numbers of irregular black particles, 3 microns or less in diameter, disseminated through the calcite crystals of the fibrous layers, also contribute to the black or dark-gray tones.

Apparently this reef grew under variable conditions, being built up now by means of algae and again by physico-chemical precipitation, and each process was modified somewhat by the sporadic accumulation of detrital grains. Moreover, the algal and inorganic deposits alternated in a periodic fashion.

The algal deposits contain pockets and lenses of detrital material in which angular limestone pebbles 1 to 3 millimeters in length are fairly plentiful. Therefore it seems probable that the algal layers were formed in shallow water when waves and currents were more or less active. The conditions under which the black and gray agate-like layers formed are not so clear. If the black particles disseminated through their crystals are organic matter they suggest that, in periods of quiet, layers of organic ooze were deposited on the algal deposits and that ammonia generated by the decay of this ooze localized the precipitation of calcium carbonate. This hypothesis is supported to some extent by the prevalence in these dark layers of cubical limonite grains which are probably secondary after pyrite. Then too, in harmony with this suggestion there are, in the upper part of the reef, masses as much as 1 centimeter in diameter of pyrite partly altered to limonite. Nevertheless, other physicochemical factors probably also operated to precipitate calcium carbonate, for ostracode valves and small fragments of limestone within this reef are incrusted with concentrically layered fibrous calcite that is entirely free from iron oxide, organic matter, and black particles.

This reef occurs about 5.5 meters (18 feet) above the base of the Tipton tongue of the Green River formation in sec. 21, T. 24 N., R. 101 W., Sweetwater County, Wyo.

REEF FROM THE "MANTI BEDS"

A reef from the "Manti beds" (pl. 45, *B*) has the form of elongate lenses about 25 centimeters in maximum thickness, rests upon thin-bedded white shaly limestone, and is overlain by laminated very limy shale. Its upper surface is botryoidal.

A polished vertical section through the reef shows that it is built up of many tiers of arched and finely tuberculated layers interspersed with thicker, coarsely spongy layers. The thinner layers that resemble agate are gently sinuous or arcuate and banded in shades of yellowish and brownish gray. Several of the spongy zones are minutely punctate. The dark areas shown in Plate 45, *B*, are partly silicified. This reef is unique among those of the collection because a small partly silicified area of it contains a network of the fossil filamentous alga *Confervites mantiensis*. (See pl. 33, *C*.)

Thin sections of the reef show that it consists almost wholly of microcrystalline calcite which has a spongy structure and is of algal origin. It also contains several colonies of *Chlorellopsis coloniata*. Further, some of the partly silicified zones consisted originally of microcrystalline calcite which shows no structure and is perhaps an inorganic deposit.

This reef is chiefly interesting for its fossil filamentous algae and the numerous coprolites that are associated with them. (See pl. 33, *B*.) It occurs near the top of the "Manti beds" in a quarry just east of the Mormon temple in Manti, San Pete County, Utah. The exact location is unknown, but it is approximately sec. 6, T. 18 S., R. 3 E. Salt Lake meridian.

ALGAL NODULES OR COBBLES

The algal nodule shown in Plate 46, *A*, came from a layer of similar isolated nodules or cobbles between two beds of hard gray-green sandy clay. It is irregularly rounded and has a minutely nodose surface. A transverse section shows that it is built up of three zones of algal deposit about an irregular nucleus of dense buff ostracode limestone surrounded by masses of closely packed small ostracode shells, which are cemented in some places by clear secondary calcite and in others by gray sandy limestone.

Under the microscope this specimen shows no fossil algae, but nevertheless its microstructure is predominantly algal. The greater part of the first and third zones consists of spongy-structured microcrystalline calcite in minutely mammillate layers with many small pockets of fine-grained, sharply angular sand. The intermediate zone consists of a succession of very thin and unusually regular layers. The thicker of these consist of spongy microcrystalline calcite with a few pockets of detrital grains and are entirely similar to the deposits of the first and third zones of the specimen. But the thinner layers consist of radially arranged coarse, somewhat elongated crystals of clear calcite. Although these layers have obviously been recrystallized and retain no algal structure, they are arcuate and resemble feltlike colonies of certain filamentous algae. Such layers may be recrystallized deposits of calcium carbonate precipitated rapidly upon the algal colonies—for example, by rapid loss of CO_2 from the surrounding water. But they are considerably different from the fibrous incrustations of acicular crystals described on pages 217–218 and also different from the concentric layers of oolites and similar thin incrustations upon ostracode shells and detrital grains. They are much less uniform, most of them vary rapidly in thickness from place to place, and their upper surfaces are very irregular and serrate, not smooth like the layers in agate structure. Furthermore, their crystals are not acicular but blunt, and in many layers the individual crystals are not strictly radial, but instead groups of them are canted in various directions. For such deposits Reis [31] proposed an explanation which to the writer seems plausible—namely, that for some reason the algae died off, and ammonia from their decay precipitated calcium carbonate in the interspaces of the spongy mass and at the same time coarsened the

[31] Reis, O. M., Kalkalgen und Seesinterkalk aus dem rheinpfalzischen Tertiär: Geognostische Jahresh., vol. 36, p. 125, 1923.

crystal grain so that the original spongy structure was obscured.

The nucleus of this specimen was probably a hard mud lump formed close to the place where it was found, for its reentrants and salients are all smoothly rounded, and as the cardinal salients are no more blunt and rounded than small and protected ones it presumably had not been rolled much before algae became attached to it. During the first stage of growth the nucleus rested upon the base *a-b*, Plate 46, *A*. Then the nodule was rolled over, and growth occurred on less than half its surface, probably because it rested against other nodules on the sides *c*, *a*, *d*, or because it was partly buried. The third zone of growth apparently formed after the nodule had been again rolled over so that it then rested on some part in front or behind the plane of the polished face.

Because these nodules or algal cobbles occur in massive sandy gray-green clay that is transitional between the Tipton tongue of the Green River formation and the Cathedral Bluffs tongue of the Wasatch formation and may be either fluviatile or lacustrine and because they contain so much fine sand and have obviously been rolled, it seems clear that they were formed in shallow, somewhat active water, perhaps near the mouth of a stream that fed the lake. Although smaller they are comparable to the layers of stream concretions described by Roddy.[32]

These nodules were found in the NE. ¼ SE. ¼ sec. 15, T. 25 N., R. 102 W., Sweetwater County, Wyo.

ALGAL PEBBLES

Algae of the Green River formation built not only extensive reefs and isolated heads and nodules but also rounded pebbles that range from 0.75 millimeter to about 5 centimeters in diameter. Those that are more nearly spherical closely resemble large oolite or pisolite grains; the others resemble ordinary subangular pebbles that have been incrusted with lime. (See pl. 46, *B*.) Both types and all gradations between them may occur in the same deposit. Furthermore, algal pebbles are almost invariably associated with true oolite grains, algae reefs or their broken fragments, and great quantities of small limy ostracode shells.

Nearly all algal pebbles of the Green River formation are smooth, and although some show a marked tendency to exfoliate thin concentric shells that resemble egg shells, others are more homogeneous and are weakly pustulose.

Under the microscope the algal pebbles show structure wholly analogous to that of the larger reefs and are clearly distinguishable from the inorganic oolites with which they occur. Most of them consist of a spongy aggregate of fine calcite grains that shows no fossil algae, but on the other hand some consist chiefly of layers of *Chlorellopsis coloniata*. (See pl. 47.) Others consist of uniformly microgranular calcite which gives no clue to their origin. These can be distinguished by their shape alone. Although some algal pebbles appear to have no nucleus, most of them are built around small subangular bits of limestone which were probably firm mud when the algae began incrusting them; a few contain ostracode shells or inorganic oolite grains as nuclei.

These fossil algal pebbles are closely similar to algal pebbles now being formed in some lime-rich fresh-water lakes of temperate North America. Those collected by the writer in 1925 from the shore near Squaw Island, at the north end of Canandaigua Lake, N. Y., range from 0.5 to about 2 centimeters in diameter, and although they vary greatly in shape, discoid pebbles are most plentiful. The outer crust of each pebble is hard and fairly smooth, but the interior is soft and exceedingly porous because it consists of minute irregular chalky granules held in a close mesh of dead algal filaments that have a vague radial arrangement. If the pores of these pebbles were filled with secondary calcite they would be strikingly like many of those from the Green River formation. Pollock [33] described the formation of similar algal pebbles in the shallow margins of Ore Lake, Mich.

Presumably the fossil pebbles were formed under similar conditions and in much the same way as the recent pebbles which they so much resemble. However, locally calcium carbonate seems to have been precipitated upon the pebbles without the aid of algae, for in some beds not only the pebbles but also groups of them and ostracode shells and small mud lumps are rather uniformly coated with one or more layers of calcite, which has a distinct fibrous structure with the greatly elongated crystals oriented radially. The writer regards deposits of this kind as resulting from a rapid incrustation due to physico-chemical causes identical with those that produce oolites.

Beds of algal pebbles occur at many places in both the Green River Basin of Wyoming and the Uinta Basin of Utah and Colorado, but the specimens studied came from two localities—one at the base of the Tipton tongue of the Green River formation in the SW. ¼ NE. ¼ sec. 27, T. 25 N., R. 103 W., Sweetwater County, Wyo., and the other about 161 meters (530 feet) above the base of the Green River formation in sec. 13, T. 5 S., R. 102 W., Colo.

POSSIBLE ANNUAL LAMINATION OF ALGAL DEPOSITS

Roddy [34] and Schmilde [35] attribute the lamination of certain fresh-water algal deposits to an annual peri-

[32] Roddy, H. J., Concretions in streams formed by the agency of blue-green algae and related plants: Am. Philos. Soc. Proc., vol. 54, pp. 246–248, 257–258, 1915.

[33] Pollock, J. B., Michigan Acad. Sci. Twentieth Ann. Rept., p. 249, 1918.

[34] Roddy, H. J., Concretions in streams formed by the agency of blue-green algae and related plants: Am. Philos. Soc. Proc., vol. 54, pp. 253–254, 1915.

[35] Schmilde, W., Postglaziale Ablagerungen im nordwestlichen Bodenseegebiet: Neues Jahrb., vol. 11, pp. 114–115, 1910.

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odicity in the growth of the plants, but each author gives a different cause for the periodicity. Roddy in describing algal deposits in a Pennsylvania stream says:

That periodic accretion alternates with a period of quiescence is shown plainly by the concentric laminations of nearly uniform thickness. The open porous nature of each lamina within and the more solid character without, like the concentric arrangement, is due without doubt to the seasonal conditions of the region. Since algae are essentially thermophilic plants, each winter destroys many of them and stops the growth of most of the rest, and thus at beginning of the plant year (spring) few and widely scattered algae at first produce slow and scattered accretion of the limy matter; later the plants become more abundant and by summer they are crowded over the surface of each mass. This distribution of the algae seasonally would naturally have its effect upon the structure and arrangement of the limy matter, giving a decided though rough coralline appearance to the inside portion and a more compact texture to the outer part. The theory just given has been confirmed by a study of the distribution of the algae on the concretionary bodies through the seasons.

Schmilde, on the other hand, described the lamination of small algal pebbles which are being formed in shallow bays of Unter See, Germany, below the outlet of the Lake of Constance. Each winter the water level is lowered, so that the deposits, unlike those described by Roddy, are left dry for several months, and at that time, he says,

the growth of the algae is interrupted or at any rate greatly restricted, while the life processes go on and therefore also the segregation of lime; thus it forms a hard, thin limy crust. In summer and spring, on the contrary, the plants grow up quickly; the precipitated lime therefore accumulates more loosely consolidated and so forms the more porous layers. It seems very much to me, therefore, that the zonal structure of the incrustation is correlated with the periodic growth in dry and wet habitats; it would be scarcely understandable otherwise that an assemblage of algae should be able to show a zonal growth.

The average annual deposit, which consists of a thin dense layer and a soft porous one, ranges in thickness from 1 to 2 millimeters. In the deposits described by Roddy [36] the annual deposit consists also of a dense and a porous layer, but these together range in thickness from 3 to 6 millimeters.

Not all fresh-water algal deposits, however, are laminated. Those in Green Lake, N. Y., studied by the writer are not, despite the cold winters of that region. Also some reefs in the Green River formation are not laminated. The presence or absence of distinct lamination in algal deposits might be accounted for by a hypothesis that differs slightly from either Roddy's or Schmild's—namely, that the thin dense layer is due to recrystallization in a thin zone at the surface of the deposit. If the rate of recrystallization is constant throughout the year or perhaps even lessened during the winter, then it will, nevertheless, have a considerably longer time to operate at one horizon of the deposit during the winter when the algae are either dead or relatively inactive and consequently not adding to the deposit. But several factors might operate to counteract the recrystallization during the winter. If the rate of recrystallization were slow and the algae mildly active, the deposit might grow so fast that the effects of recrystallization would be distributed through a thicker zone, as in the summer deposit, and so would not be discernible. A more probable factor, however, might be actual solution of the calcium carbonate at the surface of the deposit due to the greatly increased concentration of the carbon dioxide dissolved in the lake water. Chambers [37] and Powell [38] have observed that the carbon dioxide and bicarbonate content of pond and reservoir waters increases noticeably during the winter, owing largely to the lessened activity of submerged aquatic plants but also to the greater solubility of the carbon dioxide in cooler water. This perhaps accounts for the absence of lamination in the reefs from Green Lake, N. Y., although, so far as the writer is aware, no analyses of the water in Green Lake have been made to determine the relative quantities of dissolved carbon dioxide in summer and winter. Thin dense surface zones formed by recrystallization were found only in those parts of the algal deposits in Green Lake that are buried in limy mud and therefore necessarily barren of algae.

Many but not all the algae reefs from the Green River formation are distinctly laminated. Those whose lamination seems most likely to be annual are the pitted reefs built by *Chlorellopsis coloniata* Reis. Many layers consist of numerous individual algal colonies that rise uninterrupted from a common substratum to the top of the layer, which is marked by a thin, dense, and generally darker-brown layer. These algal layers vary greatly in thickness, even within the same reef. Of the 56 layers measured the thinnest is 1 millimeter, the thickest about 15 millimeters, and the average 6 millimeters. Although the writer realizes fully that these layers may not be annual and might possibly even represent many years, probably none of them represent less than one year. Consequently any estimates of time based on them will err in being too short.

According to this average rate of accumulation the large pitted reef shown in Plate 40, *A*, which is locally as much as 2.1 meters (7 feet) thick, must have required at least 355 years to form. Sernander [39] found at Benestad, in southern Sweden, varved postglacial algal tufas whose rate of growth is comparable to those of the Green River formation. The summer

[36] Roddy, H. J., op. cit., pp. 249–250.

[37] Chambers, C. O., The relation of algae to dissolved oxygen and carbon dioxide, with special reference to carbonates: Missouri Bot. Garden Ann. Rept., vol. 23, pp. 187–192, 1912.

[38] Powell, S. T., The effect of algae on bicarbonates in shallow reservoirs: Am. Waterworks Assoc. Jour., vol. 2. pp. 703–708, 1915.

[39] Sernander, Rutger, Exkursions fürher für Skåne: Vierte Internat. Pflanzengeog. Exkursion durch Skandnavien, 1925; cited by Antevs, Ernst, Varved sediments, in Twenhofel, W. H., and others, Researches in sedimentation in 1925–26, p. 83, National Research Council, 1926.

layers are loose, and the autumn layers, which contain leaf impressions, are thin and hard. A bed of that tufa 1.81 meters thick had 420 varves, which averaged 4 millimeters in thickness.

The pitted *Chlorellopsis* reefs are more coarsely laminated and hence presumably grew more rapidly than the other reefs of the Green River formation, but a direct comparison of the rates can not be made because the time value of the laminae in the other reefs is far too uncertain.

OOLITES

In an earlier paper [40] the writer stated his belief that the oolites so intimately associated with the algae reefs in northern Sweetwater County, Wyo., were formed by algae or bacteria. In this more critical study of several specimens of oolites from various parts of the Green River formation the writer not only found no reason to postulate a genetic relation between bacteria and the oolites but also was unable to find any conclusive evidence to support the hypothesis that they were formed by algae. On the contrary, it can be clearly demonstrated that the oolites of a few beds are of inorganic origin. One of these beds consists almost wholly of a gently cross-bedded mixture of small oolite grains and fine grains of quartz and feldspar, but it also contains several small flat mud lumps and mud curls. Some of the smaller lumps consist of calcite that is nearly cryptocrystalline. These contain a few oolite grains that do not touch and in general are widely spaced. Clearly they were suspended in the matrix when it was an ooze. (See pl. 48, *B*.) The oolite grains themselves have no fibrous or radial structure but are exceedingly fine grained and indisguishable from the matrix except for their perfect though rather wide concentric banding and noticeably darker color. They are dark yellowish brown, whereas the matrix is pale brownish gray. Evidently the color is due to iron, because the weathered oolite grains are coated with limonite. Moreover, the iron is clearly concentrated in them with respect to the matrix. Nuclei are rare, but some of the oolite grains contain minute quartz or feldspar grains at their centers.

Apparently these oolites in the dense matrix were formed in a similar manner to that elucidated by Schade.[41] The original ooze or gel in which the oolite grains formed consisted of colloidal ferric hydroxide with a large admixture of extremely finely divided calcium carbonate. From the facts that the calcite crystals in the oolites and matrix are now only 1 to 2.5 microns in diameter and that some crystal growth has probably occurred since the Eocene it is possible that the calcium carbonate may also have been in a colloidal state, though that would not have been necessary for the formation of oolites. Growth of the calcite crystals was perhaps inhibited by the protective action of the colloidal ferric hydroxide. Moreover, the complete absence of long acicular crystals forming radial structure strengthens this possibility, especially because the calcium carbonate or crystalloid component was large. The ferric hydroxide must have been coagulated by negative ions such as carbonate or chloride in the solution, and then because the minute coagulated particles are unstable in the presence of larger ones, and apparently also in the presence of any larger foreign particle such as a quartz or feldspar grain, they coalesced into spheres, mechanically enmeshing a considerable quantity of the suspended calcium carbonate. By that process the oolite grains grew. Apparently their growth was limited by the supply of ferric hydroxide, as they seem to have abstracted the greater part of it from the matrix. Their concentric lamination, as Schade's experiments [42] indicate, is a characteristic property of coagulated colloids that contain admixtures of foreign material and depends upon slight changes in the proportions of the constituents, upon concentration of the salt solution, and consequently also upon the rate of coagulation of the colloidal component and the viscosity of the fluid or gel.

Now, because all the isolated oolite grains, which made up a considerable part of the whole bed, are precisely identical with those in the small pieces of dense matrix it seems probable that they were also formed in the same way and, moreover, in the same medium or matrix, but that the matrix was washed away from them when the bottom deposits at that place were reworked by waves or currents. Only those parts of the matrix that were partly solidified, perhaps by incipient recrystallization after the abstraction of the ferric hydroxide to form the oolites, or perhaps only bound by some of the residual colloidal matter, were able to withstand the disturbance and thus form the small lumps containing the oolite grains still suspended as they were formed.

Both Bucher [43] and Twenhofel [44] state that for oolites to be formed through the change of at least one component from a colloidal to a solid state it is necessary that the oolite grains should grow suspended in an ooze or a jelly-like medium. Obviously some and perhaps most oolites are formed while suspended in gel or ooze, but is that a necessary factor? Schade's experiments [45] seem to indicate that it is not, for he states that only an imperceptible quantity of the colloidal component relative to the crystalloid pre-

[40] Bradley, W. H., Shore phases of the Green River formation in northern Sweetwater County, Wyo.; U. S. Geol. Survey Prof. Paper 140, p. 126, 1926.

[41] Schade, Heinrich, Zur Entstehung der Harnsteine und ähnlicher konzentrisch geschichteter Steine organischen und anorganischen Ursprungs: Zeitschr. Chemie u. Industrie der Kolloide, vol. 4, p. 265, 1909.

[42] Idem, pp. 262–264.

[43] Bucher, W. H., On oolites and spherulites: Jour. Geology, vol. 26, p. 603, 1918.

[44] Twenhofel, W. H., Treatise on sedimentation, p. 543, 1926.

[45] Schade, Heinrich, Zur Entstehung der Harnsteine und ähnlicher konzentrisch geschichteter Steine organischen und anorganischen Ursprungs: Zeitschr. Chemie u. Industrie der Kolloide, vol. 4, p. 263, 1909.

cipitate is necessary for the successful formation of artificial gallstones. Moreover, those gallstones, which are oolites, are formed in a mobile liquid and are not suspended in a gel. Furthermore, as natural gallstones are formed their liquid medium is almost continuously in motion. So also the oolites that were formed in the hot-water coil of a furnace as described by Twenhofel [46] must have been alternately at rest and in motion in a liquid far too fluid to hold them in suspension.

Furthermore, the vegetable pearls formed in the interior of a coconut as mentioned in another paper by Schade [47] probably rested on the bottom of the coconut and were occasionally moved about. These so-called pearls consist of $CaCO_3$ with a nitrogenous organic substance as the binding colloid. All that appears to be requisite for the formation of the oolites in Schade's experiments [48] was the coagulation of a very small amount of a colloidal substance with which may be admixed, in almost any proportions, one or more other components. In gallstones the other component is a crystalloid which precipitates out of a salt solution. Now Schade [49] further points out that the tendency of the minute droplets or globulites of coagulated fibrin to coalesce and form larger droplike particles with a netlike structure of intersecting needles thickened at their intersections and the subsequent shrinkage of the mass are not peculiar to fibrin but are common to other colloids.

Empirically, therefore, it seems wholly possible that calcareous oolites might be formed in natural environments that were quite as fluid as the media in which natural and artificial gallstones are formed. Lake water might be saturated with calcium carbonate and contain a colloidal component such as ferric hydroxide, silica, algal gelatine, or some of the products of decomposing organic matter so dispersed that it would not increase the viscosity of the solution enough to hold nuclei and small oolite grains suspended. Such conditions where the growing oolites rest one against the next or are only partly suspended in silty mud and are occasionally moved by storms seem to the writer better adapted to the formation of many of the oolites in the Green River formation, especially those larger than 1 millimeter in diameter, for they are unsymmetrical, are of various sizes, and show two or more zones of concentric growth that are eccentric with respect to one another and in some also to the nucleus. (See pl. 48, *A*.) Moreover, many of them contain layers in which clay and silt are generously admixed with the microcrystalline calcite.

Conditions in Pyramid Lake, Nev., perhaps approaching these have been described by Jones.[50] When the lake is clear and quiet the oolites, which are not suspended but rest against each other on the bottom, grow by the formation of minute aragonite needles that are radially oriented, but when the bottom is stirred up by storms the silt that is thrown into suspension is admixed with the aragonite, and granular stony layers that are concentric with those layers having radial fibrous structure are formed. In Pyramid Lake, however, the calcium carbonate is being precipitated from warm spring water, and so the conditions are somewhat different from those that must have prevailed in the ancient Green River lakes, where the beds of oolite are many square miles in area and an origin by warm springs is almost surely precluded. Yet probably the means by which the components are precipitated has little general effect upon the growth of the oolite grains, provided the material is in the proper state. Thus the precipitation of calcium carbonate from lake water by a change in temperature or by the gradual abstraction of carbon dioxide from the bicarbonates in solution by the growth of submerged aquatic plants, as described by Hassack,[51] Chambers,[52] and Powell,[53] together with the simultaneous coagulation of even a very small amount of a suitable binding colloid, might conceivably produce oolites over large areas of the lake bottom, even though the bottom was sandy or silty and the growing oolite grains were not suspended. Soft ooze bottoms would of course provide a medium in which oolite grains, at least while small, would be more or less completely suspended. Such an ooze might not necessarily contribute to the growth of the oolite grains except in so far as it was mechanically enmeshed.

SUMMARY

Certain but not all chlorophyll-bearing algae precipitate calcium carbonate from natural waters by their photosynthesis, a process by which they abstract not only the carbon dioxide that is dissolved in water but also that held in solution as bicarbonates. This process has for a long time been clearly established by laboratory experimentation and observation of algae in natural habitats. As this process depends directly upon sunlight it follows that the algae reefs in the Green River formation must have been produced in shallow water that was relatively clear, at least for the

[46] Twenhofel, W. H., Treatise on sedimentation, p. 540, 1926.

[47] Schade, Heinrich, Über Konkrementbildungen beim Vorgang der tropfigen Entmischung von Emulsions-kolloiden: Kolloidchemische Beihefte, Band 1, pp. 375–390, 1910.

[48] Schade, Heinrich, Zur Entstehung der Harnsteine und ähnlicher konzentrisch geschichteter Steine organischen und anorganischen Ursprungs: Zeitschr. Chemie u. Industrie der Kolloide, vol. 4, p. 263, 1909.

[49] Idem, p. 178.

[50] Jones, J. C., Quaternary climates; Geologic history of Lake Lahontan: Carnegie Inst. Washington Pub. 352, pp. 14–18, 1925.

[51] Hassack, Carl, Über das Verhältnis von Pflanzen zu Bicarbonaten und über Kalkincrustation: Untersuchungen aus dem Bot. Inst. Tübingen, vol. 2, pp. 467–473, 1888.

[52] Chambers, C. O., The relation of algae to dissolved oxygen and carbon dioxide with special reference to carbonates: Missouri Bot. Garden Ann. Rept., vol. 23, pp. 178–204, 1912.

[53] Powell, S. T., The effect of algae on bicarbonates in shallow reservoirs: Am. Waterworks Assoc. Jour., vol. 2, pp. 703–708, 1915.

greater part of the time. These two factors, however, are plainly interdependent, the depth at which the algae reefs could be formed varying directly as the clarity, or, stated better, inversely as the turbidity, which is the principal factor limiting light penetration in fresh water.[54] The depth may have been as much as 4.5 meters (15 feet), or perhaps even more, but probably most of the reefs and certainly some of them were formed in water less than 1.8 meters (6 feet) deep. One reef at least was formed in very shallow water, for it contains the molds of emergent plant stems in the position in which they grew.

In order that the limestone precipitated by the algae could persist, as Johnston and Williamson[55] have pointed out for limestone in general, the water surrounding them must have been saturated with respect to the normal carbonate of calcium. From this it follows that lime was continually being brought into the lake and that the water circulated, even though perhaps slowly, and thus replenished the lime precipitated by the algae. Rather vigorous circulation of the water around many of the reefs and beds of algal nodules and pebbles is, however, revealed by fragments of algal deposits, limy mud lumps, and transported sand and oolite grains either within the reefs or very intimately associated with them. Indeed pebbles as much as 1 centimeter in diameter are associated with one reef.

Algae reefs are most plentiful in shore phases of the Green River formation, where they are irregularly distributed through the entire thickness of the formation, but elsewhere they are confined almost wholly to the basal member, whose lithology is similar to that of the shore phases. At a few localities remote from shore phases, where those parts of the formation between the basal member and the lowest oil-shale zone and between the uppermost oil-shale zone and the top of the formation consist of hard limy or silty shale, there are a few thin algae reefs.

The reefs are nowhere closely associated with oil shale even of very low grade. Their absence from those parts of the formation that consist predominantly of oil shale is clearly due to the fact that the conditions necessary to the formation of oil shale are distinctly unfavorable to the formation of algae reefs. Where oil shale was formed stagnation of the water and putrefaction of great quantities of organic matter effectively inhibited the growth of algae, which were the most active reef builders. Furthermore, in those parts of the lake where decaying organic ooze was abundant the ammonia generated by the decay quickly precipitated the calcium carbonate, which in turn was buried in the ooze or formed thin layers upon it.

[54] Forel, F. A., Le Leman, vol. 2, pp. 426–427, 1895.

[55] Johnston, John, and Williamson, E. D., The rôle of inorganic agencies in the deposition of calcium carbonate: Jour. Geology, vol. 24, p. 735, 1916.

The scarcity of algae reefs in the uppermost member of the formation, even in deposits that were clearly laid down in shallow water, may be ascribed to one or more of three causes—(1) the increased concentration of sulphates in the lake, which at one stage became so great that a large quantity of glauberite crystallized out in the mud; (2) a lessened quantity of lime in solution available for the formation of algae reefs, either because lime was less soluble in the more saline lake water or because the supply brought to the lake was diminished; (3) periodic evaporation of the lake during the normal growing season of the algae.

From the distribution of the algae reefs, their bed-like shape, and their evident origin in very shallow water, the writer concludes that the shore phases of the Green River formation, some of which are as much as 40 kilometers (25 miles) wide, and also much of the whole basal member were deposited in water not more than 15 feet deep. The floors of the two great Eocene lakes, even from the beginning, were very smooth and had only gentle basinward slopes, for the original surface that each lake flooded was a nearly level plain of fluviatile aggradation, marking the top of the Wasatch formation. The wide lateral distribution of sun-cracked bedding planes and of mud curls at many horizons in the lacustrine deposits, moreover, indicates that during the greater part of their existence the lakes had nearly level bottoms.

The basal member of the Green River formation contains more algae reefs in the vicinity of the Douglas Creek anticline than on either side of it. From this the writer concludes that the lake was shallower there, although it is in the central part of the basin.

Algae reefs in parts of the formation above the basal member and remote from the shore phases represent a reversion of the ecologic conditions to those which prevailed at earlier stages of the lakes. Reefs in the upper parts of shore phases that are contemporaneous with the saline stages of the lakes were very probably formed close to the mouths of streams or perhaps in small, somewhat isolated basins fed by streams or fresh springs.

The abrupt change in lithology between the basal member and the upper part and the absence or scarcity of algae reefs from the upper part indicate a decided change in the ecology of the lakes, but a discussion of that subject is not germane to this report.

According to the writer's interpretation of the origin of calcareous oolites and of fresh-water algae reefs oolites may be intimately associated with algae reefs because the conditions favorable to the formation of oolites are in general also favorable to the growth of algal limestone deposits, though the converse is by no means true; or they may be intimately associated because the oolite grains were transported to the growing reef in the same way that clastic grains are carried to and inclosed in algae reefs.

A REVISION OF THE FLORA OF THE LATAH FORMATION

By Edward Wilber Berry

INTRODUCTION

A preliminary account of the flora of the Latah formation by F. H. Knowlton was published in January, 1926, in connection with an account of the geology by J. T. Pardee and Kirk Bryan.[1] The materials were largely contributed by local students. During the summer of 1926 Knowlton visited the area and made large additional collections, which had not been unpacked at the time of his death. It is much to be regretted that he did not live to work up this collection, for it contained many novelties, and its excellent preservation was a constant source of pleasure to him. It became my duty to identify this material in order to prepare a collection of duplicates for the Spokane Museum, and in this task I encountered so much that was new and important that it has seemed desirable to prepare the present report. During the course of the work I have received valuable additional material from Prof. T. A. Bonser and Messrs E. E. Alexander and C. O. Fernquist, of Spokane.

The region from which the Latah flora was collected has a present altitude in the neighborhood of 2,000 feet. The Spokane Weather Bureau station shows an average annual precipitation (for a 24-year period) of 18.23 inches. This drops to less than 10 inches a short distance to the southwest, but rises to around 75 inches on the Pacific-facing slopes of the mountains west of the Spokane area and to 90 inches on the Pacific coast. The Latah area is characterized by summer droughts. The normal annual mean temperature is 45.9° F., which is not low relatively, but the climate is marked by extremes of temperature, both in winter and summer. Consequently the nights are cool, and both late and early frosts result in a relatively short growing season.

It is beyond the scope of the present paper to discuss these climatic factors in their bearing on the existing flora of the region, and this has already been done in a general way by more competent botanists. My purpose is merely to hint at the present conditions as a background for discussing the conditions in Miocene time.

Floristically the Spokane region is in the transition zone between the northern extension of the Great Basin arid region (Sonoran) and the (in general) evergreen mesophytic forests of the Columbian region to the west and the Rocky Mountain ranges to the north and east—what is usually termed the Canadian zone. These forests consist largely of needle-leaved conifers, and the assemblage becomes more hygrophilous on the Pacific slopes of the mountains west of Spokane and on the corresponding slopes of the mountains of Montana and Idaho. There is a considerable admixture of broad-leaved deciduous trees, especially along streams. In the heavier stands of evergreens there is a relative scarcity of undershrubs and herbaceous species.

This transition zone is both forested and treeless in the immediate vicinity of Spokane. The somewhat less arid forested portion includes such arborescent and shrubby genera as *Abies*, *Acer*, *Pinus*, *Populus*, *Pseudotsuga*, *Rhamnus*, *Salix*, *Taxus*, *Thuya*, *Tsuga*, *Alnus*, *Amelanchier*, *Ceanothus*, *Chimaphila*, *Linnaea*, *Lonicera*, *Menziesia*, *Opulaster*, *Pachystima*, *Ribes*, *Rosa*, *Rubus*, *Salix*, and *Vaccinium*. Of these the genera *Acer*, *Pinus*, *Populus*, *Salix*, *Alnus*, *Amelanchier*, *Ceanothus*, *Menziesia*, and *Vaccinium* were present in the region in upper or middle Miocene (Latah) time.

The present account of the Latah flora contains 152 species, as against 95 in Knowlton's preliminary account. Of this number 6 are referred to *Phyllites*, 6 to *Carpites*, and 1 to *Carpolithus*, all but the *Carpolithus* under names proposed in Knowlton's paper. I have not named a considerable number of new forms represented by poor material in the present collection.

The notable additions to the flora comprise a characteristic new fern of the genus *Asplenium;* a large and diversified representation of seeds and leaves of *Pinus;* two species of sweet fern, *Comptonia;* the leaves of several hardwoods hitherto unknown in the Latah flora, such as the hickory (*Hicoria*), beech (*Fagopsis*), sycamore (*Platanus*), horse chestnut (*Aesculus*), and linden (*Tilia*); or tree genera hitherto unknown in the western Miocene, such as the tulip tree (*Liriodendron*) and sassafras (*Sassafras*).

There is of course some duplication involved in giving separate names to leaves and fruits, especially in the genera *Pinus*, *Alnus*, *Acer*, *Ulmus*, *Liquidambar*, and *Quercus*. There are also undoubtedly too many species recognized among the poplars, birches, and

[1] U. S. Geol. Survey Prof. Paper 140, pp. 1-81, 1926.

oaks. These have been retained for the most part, out of respect for Knowlton's opinion and partly because of the impossibility of drawing satisfactory specific lines among the leaves of these trees, although I have indicated my opinions on these points in the systematic discussion.

The Latah flora now contains 75 genera in 51 families and 29 orders. The largest order is the Fagales, with 25 nominal species; next come the Sapindales, with 14; the Pinales and Salicales, with 13 each; the Ericales, with 8; and the Laurales, with 7.

Similarly the largest family is the Fagaceae, with 16 nominal species; next in specific representation is the family Salicaceae, with 13; followed by the Betulaceae, with 9; the Lauraceae, with 7; the Pinaceae, Cupressinaceae, and Papilionaceae, with 6 each; and the Aceraceae, with 5. The largest genus is *Quercus*, with 13 nominal species; next come *Phyllites* and *Carpites*, with 6 each; and *Pinus*, *Salix*, *Acer*, and *Vaccinium*, with 5 each. Most numerous individually are the leaves of the oaks, poplars, *Sequoia*, and bald cypress.

As probably the largest and best-preserved western Miocene flora except that from Florissant, Colo., the Latah flora is of especial interest. In addition to the plants the scales, rays, and vertebrae of a small cyprinoid fish are not uncommon in these deposits. These remains are not sufficiently complete for precise identification, but they probably represent the genus *Leuciscus* and may be identical with *Leuciscus turneri* Lucas, of the Esmeralda formation of western Nevada. I have illustrated two of the characteristic scales in the present paper. (See pl. 49, figs. 1, 2.)

In Knowlton's account of the Latah flora he remarks on the rarity of insect remains, an anomalous feature because of the fine-grained texture and lacustrine character of the sediments. Only one species, a carabid beetle, *Calosoma fernquisti* Cockerell, was recorded. The more recent collections bid fair to remedy this situation, containing several other beetles, flies, dragon flies, etc. These will be described in a separate contribution.

Flora of the Latah formation

Bryophyta:
- Musci—
  - Mniaceae—
    - Archaeomnium patens E. G. Britton.
  - Polytrichaceae—
    - Polytrichites spokanensis E. G. Britton.
    - Moss, unnamed.

Lepidophyta:
- Lycopodiales—
  - Lycopodiaceae—
    - Lycopodium hesperium Knowlton (fertile spike).

Arthrophyta:
- Equisetales—
  - Equisetaceae—
    - Equisetum, rhizome with tubers.

Pteridophyta:
- Polypodiales—
  - Polypodiaceae—
    - Asplenium occidentale Berry.
    - Woodwardia praeradicans Berry.
    - Woodsia bonseri Berry.
    - Pteris sp. Berry.

Coniferophyta:
- Ginkgoales—
  - Ginkgoaceae—
    - Ginkgo adiantoides (Unger) Heer.
- Pinales—
  - Taxaceae—
    - Tumion bonseri Knowlton.
  - Cupressinaceae—
    - Sequoia langsdorfii (Brongniart) Heer.
    - Sequoia sp. Knowlton, wood.
    - Taxodium dubium (Sternberg) Heer.
    - Taxodium, staminate ament.
    - Libocedrus praedecurrens Knowlton.
    - Glyptostrobus?, staminate aments.
  - Pinaceae—
    - Pinus latahensis Berry.
    - Pinus macrophylla Berry.
    - Pinus monticolensis Berry.
    - Pinus tetrafolia Berry
    - Pinus sp. Knowlton.
    - Tsuga latahensis Berry.

Spermatophyta:
- Angiospermae—
  - Monocotyledonae—
    - Pandanales—
      - Typhaceae—
        - Typha? sp. Knowlton.
    - Naiadales—
      - Naiadaceae—
        - Potamogeton heterophylloides Berry.
        - Palaeopotamogeton florissanti Knowlton.
    - Arales—
      - Araceae—
        - Arisaema hesperia Knowlton.
    - Graminales—
      - Poaceae—
        - Grass, unnamed.
    - Liliales—
      - Smilaceae—
        - Smilax lamarensis Knowlton.
      - Juncaceae?—
        - Juncus? crassulus Cockerell.
  - Dicotyledonae—
    - Choripetalae—
      - Juglandales—
        - Juglandaceae—
          - Hicoria juglandiformis (Sternberg) Knowlton.
      - Myricales—
        - Myricaceae—
          - Comptonia hesperia Berry.
          - Comptonia insignis (Lesquereux) Cockerell.
      - Salicales—
        - Salicaceae—
          - Salix florissanti Knowlton and Cockerell.
          - Salix inquirenda Knowlton.
          - Salix perplexa Knowlton.
          - Salix remotidens Knowlton.
          - Salix? sp. Knowlton.
          - Salix, pistillate flower.
          - Salix, stipule.

Spermatophyta—Continued.
Angiospermae—Continued.
Dicotyledonae—Continued.
Choripetalae—Continued.
Salicales—Continued.
Salicaceae—Continued.
Populus heteromorpha Knowlton.
Populus lindgreni Knowlton.
Populus washingtonensis Knowlton.
Populus, amentiferous bract.
Populus, bud scales.
Populus, pistillate ament.
Fagales—
Betulaceae—
Betula fairii Knowlton.
Betula heteromorpha Knowlton.
Betula largei Knowlton.
Betula, winged fruit.
Alnus elliptica Berry.
Alnus prerhombifolia Berry.
Alnus sp. Knowlton, cones.
Alnus or Betula, staminate catkin.
Carpinus sp. Knowlton.
Fagaceae—
Castanea castaneaefolia (Unger) Knowlton.
Castanea orientalis Chaney.
Fagopsis longifolia (Lesquereux) Hollick.
Quercus bonseri Knowlton.
Quercus cognatus Knowlton.
Quercus merriami Knowlton.
Quercus obtusa Knowlton.
Quercus payettensis Knowlton.
Quercus rustii Knowlton.
Quercus simulata Knowlton.
Quercus spokanensis Knowlton.
Quercus treleasii Berry.
Quercus ursina Knowlton?
Quercus cf. Q. pseudolyrata Lesquereux.
Quercus, acorn.
Quercus, cupule.
Urticales—
Ulmaceae—
Ulmus fernquisti Knowlton.
Ulmus speciosa Newberry.
Ulmus, fruit.
Moraceae—
Ficus? washingtonensis Knowlton.
Platanales—
Platanaceae—
Platanus aspera Newberry.
Platanus dissecta Lesquereux.
Platanus appendiculata Lesquereux?
Ranales—
Menispermaceae—
Menispermites latahensis Berry.
Magnoliaceae—
Liriodendron hesperia Berry.
Magnolia californica Lesquereux.
Magnolia dayana Cockerell.
Magnolia sp. Knowlton.
Rosales—
Grossulariaceae—
Ribes fernquisti Berry.
Hamamelidaceae—
Liquidambar californicum Lesquereux.
Liquidambar, fruit.
Saxifragaceae—
Hydrangea bendirei (Ward) Knowlton.

Spermatophyta—Continued.
Angiospermae—Continued.
Dicotyledonae—Continued.
Choripetalae—Continued.
Rosales—Continued.
Drupaceae—
Prunus rustii Knowlton.
Rosaceae—
Amelanchier scudderi Cockerell.
Cercocarpus praeledifolius Berry.
Caesalpiniaceae—
Cassia idahoensis Knowlton
Cassia spokanensis Berry.
Cassia sophoroides (Knowlton) Berry.
Cercis? spokanensis Knowlton.
Papilionaceae—
Sophora alexanderi Knowlton.
Sophora spokanensis Knowlton.
Meibomites knowltoni Berry.
Meibomites lucens Knowlton.
Leguminosites bonseri Berry.
Leguminosites alexanderi Berry.
Sapindales—
Sapindaceae—
Sapindus spokanensis Berry.
Sapindus armstrongi Berry.
Celastraceae—
Celastrus lacoei Lesquereux.
Celastrus fernquisti Knowlton.
Celastrus spokanensis Berry.
Euonymus knowltoni Berry.
Anacardiaceae—
Rhus typhinoides Lesquereux.
Rhus merrilli Chaney.
Hippocastanaceae—
Aesculus hesperia Berry.
Aceraceae—
Acer bendirei Lesquereux.
Acer chaneyi Knowlton.
Acer merriami Knowlton.
Acer minor Knowlton.
Acer oregonianum Knowlton.
Rhamnales—
Rhamnaceae—
Rhamnus spokanensis Berry.
Paliurus hesperius Berry.
Malvales—
Tiliaceae—
Tilia hesperia Berry.
Malvaceae?—
Malva? hesperia Knowlton.
Hibiscus? occidentalis Berry
Parietales—
Ternstroemiaceae—
Ternstroemites idahoensis (Knowlton) Berry.
Laurales—
Lauraceae—
Laurus californica Lesquereux.
Laurus grandis Lesquereux.
Laurus princeps Heer.
Laurus similis Knowlton.
Sassafras hesperia Berry.
Umbellularia dayana (Knowlton) Berry.
Umbellularia lanceolata Berry.
Umbellales—
Araliaceae—
Aralia whitneyi Lesquereux.

Spermatophyta—Continued.
Angiospermae—Continued.
Dicotyledonae—Continued.
Choripetalae—Continued.
Umbellales—Continued.
Cornaceae—
Cornus acuminata Berry.
Nyssa knowltoni Berry.
Nyssa magnifica (Knowlton) Berry.
Umbelliferae—
Umbelliferospermum latahense Berry.
Gamopetalae—
Ericales—
Ericaceae—
Menziesia knowltoni Berry.
Arctostaphylos spatulata Berry.
Arctostaphylos knowltoni Berry.
Vacciniaceae—
Vaccinium americanum (Lesquereux) Berry.
Vaccinium bonseri Berry.
Vaccinium bonseri serrulatum Berry.
Vaccinium salicoides Knowlton.
Vaccinium spokanense Berry.
Ebenales—
Ebenaceae—
Diospyros princetoniana Cockerell.
Diospyros andersonae Knowlton.
Gentianales—
Apocynaceae—
Apocynophyllum latahense Berry.
Polemoniales—
Convolvulaceae—
Porana microcalyx (Knowlton) Berry.
Rubiales—
Caprifoliaceae—
Viburnum lantanafolium Berry.
Viburnum fernquisti Berry.
Position uncertain—
Phyllites amplexicaulis Knowlton.
Phyllites crustacea Knowlton.
Phyllites pardeei Knowlton.
Phyllites peculiaris Knowlton.
Phyllites relatus Knowlton.
Phyllites sp. Knowlton.
Carpolithus pteraformis Berry.
Carpites boraginoides Knowlton.
Carpites ginkgoides Knowlton.
Carpites menthoides Knowlton.
Carpites paulownia Knowlton.
Carpites polygonoides Knowlton.
Carpites spokanensis Knowlton.

LOCAL DISTRIBUTION

Anyone taking the trouble to tabulate the local occurrences of the members of the Latah flora will find the same facies and much the same species at each fossiliferous outcrop. The species recorded from only a single locality are usually represented by a single or but a few specimens.

All but one of the plant localities are within a few miles of one another in the vicinity of Spokane; the only remote locality is that at Stanley Hill, 2 miles northeast of Coeur d'Alene, Idaho, and this is only 25 miles distant.

Such contrasts between localities as appeared in the collections studied by Knowlton have tended to disappear when the later collections were studied. Twenty-two species were named from the Coeur d'Alene district by Knowlton, and but six of these were common to the Spokane area. The subsequent collections show quite as many oaks, poplars, and sequoias around Spokane as at Coeur d'Alene. The following 16 species, representing over 72 per cent of the identified species from Coeur d'Alene, are now represented in the collections from Spokane, so the plants from the two areas can not be said to differ appreciably, either botanically or in the indicated environmental conditions:

Sequoia langsdorfii.	Quercus simulata.
Taxodium dubium.	Betula fairii.
Populus lindgreni.	Betula heteromorpha.
Alnus, pistillate cones.	Ficus washingtonensis.
Quercus cognatus.	Prunus rustii.
Quercus merriami.	Sophora alexanderi.
Quercus payettensis.	Cassia sophoroides.
Quercus rustii.	Umbellularia dayana.

RELATIONSHIPS

The following 39 genera out of a total of 75 in the Latah flora are not represented in the existing flora of the State of Washington as described by Piper:[2]

Archaeomnium.	Carpinus.	Sapindus.
Polytrichites.	Ficus	Celastrus.
Ginkgo.	Platanus.	Aesculus.
Tumion.	Menispermites.	Paliurus.
Sequoia.	Liriodendron.	Tilia.
Taxodium.	Magnolia.	Ternstroemites.
Libocedrus.	Liquidambar.	Laurus.
Arisaema.	Hydrangea.	Sassafras.
Hicoria.	Cassia.	Umbellularia.
Comptonia.	Cercis.	Nyssa.
Castanea.	Sophora.	Diospyros.
Fagopsis (Fagus).	Meibomites.	Apocynophyllum.
Ulmus.	Leguminosites.	Porana.

Disregarding the form genera *Archaeomnium*, *Polytrichites*, *Meibomites*, *Leguminosites*, *Laurus*, and *Apocynophyllum*, we may note that of the 39 genera found in the Latah flora which are not present in the existing flora of the State of Washington the following 26 are no longer represented in the existing flora of western America:

Ginkgo.	Ficus.	Celastrus.
Taxodium.	Menispermites.	Aesculus.
Arisaema.	Liriodendron.	Tilia.
Hicoria.	Magnolia.	Ternstroemites.
Comptonia.	Liquidambar.	Sassafras.
Castanea.	Hydrangea.	Nyssa.
Fagus (Fagopsis).	Sophora.	Diospyros.
Ulmus.	Sapindus.	Porana.
Carpinus.	Paliurus.	

[2] Piper, C. V., Flora of the State of Washington: Contr. U. S. Nat. Herbarium, vol. 11, 1906.

The majority of these are well-known arborescent genera of the mixed hardwood forests of the mesophytic region of southeastern North America, although many are not confined to that region.

The following genera of the Latah flora are still represented in western North America: *Tumion*, *Libocedrus*, *Platanus*, and *Cercis* in California; *Sequoia* and *Umbellularia* in Oregon and California. These all represent genera of once general distribution in western North America, which because of changing climatic conditions, chief of which was the progressive increase in aridity due to the geologically recent elevation of the Sierra Nevada and Cascade Range, became extinct in the region east of the mountains and now survive only in favored situations west of them.

The following genera of the Latah flora no longer represented in western North America occur in the existing flora of eastern Asia:

Ginkgo.	Carpinus.	Aesculus.
Glyptostrobus.	Menispermites.	Paliūrus.
Arisaema.	Liriodendron.	Tilia.
Hicoria.	Magnolia.	Ternstroemites.
Castanea.	Liquidambar.	Sassafras.
Fagus (Fagopsis).	Hydrangea.	Nyssa.
Ulmus.	Celastrus.	Porana.

Several of these, such as *Liriodendron*, *Hicoria*, and *Sassafras*, are relatively recent discoveries in the flora of China, whose presence in that region is not generally known. All the genera in the foregoing list of Asiatic occurrences except *Ginkgo*, *Paliurus*, and *Porana* are common to the mesophytic region of southeastern North America.

It is of great interest to comment in somewhat more detail on the features above set forth.

The genus *Ginkgo*, whose single existing species was aptly termed a living fossil by Darwin and which survived to modern times only in eastern Asia and is now a prized ornamental tree in all temperate countries, has an ancestral history that goes back to remote geologic time. It was present over practically all of North America, as well as on all the other continents except Africa and South America, during the Mesozoic era. The Tertiary found it still present in the floras of Europe, Asia, the Arctic region, and western North America. To-day, through the care of man—temple gardeners in eastern Asia and arboriculturists elsewhere—this unique tree has been preserved from total extinction, greatly to our enjoyment and profit.

The genus *Taxodium*, the bald cypress of the southeastern United States, has an ancestral history quite as romantic though shorter than that of the maidenhair tree (*Ginkgo*). It grew on all three of the continents of the Northern Hemisphere, commencing with the Eocene, and maintained its holarctic distribution well into Miocene time, contributing to the browncoal deposits of both America and Europe. Its restriction of range began in the late Tertiary, and its existing species are three—two slightly differentiated forms in the southeastern United States and the third or Mexican cypress, separated from the other two by the arid country of our Southwestern States and northern Mexico, furnishing some of the historic trees associated with Cortez's conquest of Mexico, and as old as the big trees of California, if not older.

The genus *Sequoia*, represented by the familiar redwood and the still more restricted big trees of California, has been the subject of so much comment that the theme is well-nigh threadbare. Its ancestry goes back to the Mesozoic, and it was present throughout the whole Northern Hemisphere well into Tertiary time. Large standing silicified trunks may be seen in the upper Miocene deposits at Florissant, Colo., and in the celebrated fossil forests of Yellowstone Park, and its wood is found with the foliage in the Latah formation, in which its twigs are so abundant. The main facts of its history have long been well known, but it has not been realized how recently was the great elevation of the mountains, which was the main factor in the ecologic rearrangement and extinctions among the Miocene forests of our Pacific States.

The genus *Tumion* (or *Torreya*, as it is more generally called) is another example of an old line of trees, practically cosmopolitan in Cretaceous time, which has single existing survivors in such geographically remote regions as Florida, California, and eastern Asia, standing, as it were, on the brink of extinction.

The so-called incense cedar, *Libocedrus*, represents another Latah type, quite as rare as *Tumion*, although its history is not so completely known, which was evidently widely distributed in former times, as it survives in such remote regions as California, eastern Asia, Chile, New Zealand, and New Caledonia.

Arisaema, a herbaceous genus with an unknown history, survives in the mesophytic regions of eastern Asia and southeastern North America.

The hickories, long supposed to have survived only in southeastern North America, have recently been discovered in that great natural floral preserve of central China. Their range was holarctic during the early Tertiary, and they survived until late Tertiary time in both the western United States and Europe.

The sweet fern (*Comptonia*) has a single modern species in southeastern North America. There were numerous fossil species on all the northern continents, and some survived until the late Tertiary in Eurasia and western America. *Comptonia* was especially abundant around the Miocene Lake Florissant in Colorado, and one of the Florissant species occurs in the Latah flora. Late Eocene species are found northward through the present Rocky Mountain region to Alaska.

The chestnut (*Castanea*), no longer found in western North America, has three existing species in southeastern North America, a Mediterranean species ranging from Spain eastward to southwestern Asia, and a fifth species in China and Japan. Its geologic history goes back to the Eocene, and it was not uncommon in the West and in Alaska during most of the Tertiary.

As I have pointed out in the systematic descriptions, the genus *Fagopsis* is believed to be referable to *Fagus*, which comprises the beeches found to-day in Europe, eastern Asia, and southeastern North America. Their cousins, the evergreen beeches of Chile, Australia, and New Zealand, are now segregated in the separate genus *Nothofagus*. The oldest known fossil beeches are found in the Upper Cretaceous of Europe and North America. They were certainly holarctic in their range during the Tertiary period, about 30 species from the Miocene having been described, as compared with but 4 in existing floras.

The elm is widely distributed over the North Temperate Zone except in western North America. Although there are six species of elms in our present forests, none occur west of the Rocky Mountains, where they were so abundant before the rising Sierra Nevada and Coast Ranges interrupted the moisture-laden winds from the Pacific. The elms, like the beeches, probably reached the maximum of variety and distribution during the Miocene epoch.

The hornbeam (*Carpinus*), doubtfully represented in the Latah flora, occurs to-day, like so many other of the Latah hardwoods, in Europe, southeastern Asia, and southeastern North America. Its ancestors are not certainly known at horizons earlier than the "Paleocene," but there are more fossil than recent species, especially in the later Tertiary.

What appears to be an undoubted fig leaf is rather common in the Latah formation. The genus *Ficus* is an exceedingly large one, with hundreds of living and fossil species of a great variety of habitats, though confined in the existing flora to warm temperate and tropical regions. Its ancestry goes back to the Cretaceous, and it was particularly abundant in western North America during Upper Cretaceous and Eocene time. It was not out of place in the strictly temperate humid environment that prevailed in Washington in Latah time, because many modern species live under comparable climatic conditions, the cultivated fig normally ripening its fruit in Maryland and at altitudes of 8,000 feet in Bolivia.

The genus *Platanus*, which has three nominal species in the Latah flora contains the existing sycamore, buttonball, or plane tree, with six or seven species of southwestern Asia, southeastern and western North America, Mexico, and Central America. With its numerous fossil species and several extinct genera it constitutes a separate order of flowering plants related to the order Urticales, which includes the elm and fig families. *Platanus* was exceedingly abundant in the Upper Cretaceous and Eocene in western North America, as well as throughout Eurasia, became more restricted but was still abundant during the Miocene, and survived in that region in a single species—*Platanus racemosa* Nuttall—which finally has become restricted to stream valleys in California as the climate of the region became drier.

Although the genus *Menispermites* is a form genus of the family Menispermaceae, as I have explained in the systematic descriptions, the Latah species probably represents the genus *Cebatha* or *Menispermum*—the latter with but two existing species of climbers, one in eastern Asia and the other in eastern North America. *Menispermites* is common in the Upper Cretaceous of the West, and a species of *Cebatha* is present in the latest Tertiary of British Columbia.

The genus *Liriodendron*, the familiar tulip tree of southeastern North America, has one of the most interesting geologic histories of all our forest trees. Exceedingly varied and wide ranging during the Upper Cretaceous, its ancestors have been found in the Arctic, in eastern and western North America, and in Europe. The Eocene records include British Columbia, Greenland, Iceland, and Europe. Well-marked forms grew in Europe through the Miocene and late Pliocene, but no certainly identified Miocene form has been found in western North America prior to the discovery of characteristic fruits in the Latah formation. The existing species are but two in number—the common southeastern American *Liriodendron tulipifera* and an almost identical form in China, separated by half the circumference of the globe—the sole survivors of this ancient and once holarctic line.

The magnolias to-day have about a score of species, one-third of which occur in southeastern North America and the rest in the region from the Himalayas eastward to southeastern Asia. Their ancestral line goes back to the Upper Cretaceous, and they once had a continuous range over the lands of the Northern Hemisphere. They were abundant along the west coast as late as Miocene time and continued to flourish in Europe until the advent of the Pleistocene glaciation.

Another tree, common in western North America as late as the Miocene, is the *Liquidambar*, now represented in southeastern North America by the familiar red or sweet gum, also present in eastern Asia, Asia Minor, and Central America. It is not certainly known in deposits earlier than the Eocene, but during that epoch it grew in Greenland, Alaska, and Oregon; and it survived in Europe as late as the Pliocene.

Hydrangea, more familiar as a cultivated shrub than as a wild plant, is a genus with about 35 existing species of shrubs or small trees found in southeastern North America, South America, and eastern Asia. One of its peculiarities is the tendency for some of the small flowers of the flower cluster (corymb) to become sterile and consist merely of three, four, or five enlarged and showy sepals. The selection of this feature by gardeners has resulted in the completely sterile large single or double clusters of the favorite cultivated forms. The geologic history of *Hydrangea* is unknown, but its discovery in this intermediate geographic position in the Miocene is interesting, as is also its representation in the Latah formation by large sterile flowers with four or five calyx lobes.

The genus *Cercis*, the redbud or Judas tree, contains five or six existing species. One of these is found in southeastern North America, a second in Texas, a third in the humid part of the Pacific coast region, and the others in Mediterranean Europe and southwestern, central, and eastern Asia. Its geologic history is imperfectly known, but characteristic forms have been discovered in the Eocene of North America and Europe and are rather common in the Miocene of Holarctica.

The genus *Sapindus*, including the soapberry, is no longer found in western America, although it was practically cosmopolitan in the Upper Cretaceous and throughout much of the Tertiary. It belongs to a large and mostly tropical family and in the existing flora is not found nearer Washington than southern Arizona. It is especially common in southeastern Asia.

Celastrus, whose sole living North American representative is the shrubby or climbing bittersweet of the eastern part of the continent, belongs to a genus with an extended geologic history, during which it attained a cosmopolitan range. There are about 30 other existing species in eastern Asia, Australia, and Madagascar. It was common in western North America in the late Cretaceous and Eocene, and three species are represented in the Latah flora, one of which is also found at Florissant, Colo.

The genus *Paliurus* of Jussieu contains two or three existing species of shrubs or small trees with cordate or ovate, palmately three-veined, and usually small leaves with stipular thorns. The fruits are coriaceous, peltate, and umbonate, with a horizontal marginal, radiately veined wing. In existing floras they are restricted to dry-soil habitats from Spain on the west to Japan on the east. *Paliurus aculeatus* Lamarck extends from Spain through southern Europe, Asia Minor, Crimea, the Caucasus, and Persia to China (Szechwan). *Paliurus ramosissimus* Poiret extends from about 27° north latitude in Kiangsi to Japan, and *Paliurus orientalis* Franchet, sometimes united with the preceding, reaches the stature of a thin tree sometimes 50 feet tall in eastern Szechwan and Shensi, China.

Whatever the taxonomic distinction of the three, their ranges overlap, and the geologic record is sufficiently complete to show that their present range is a restricted one and that they represent relict species.

Turning now to the geologic record we may note that a considerable number of fossil species have been described, based for the most part on leaves and therefore subject to the uncertainties attending the identification of this class of remains.

The oldest records embrace about a dozen species, so called, of leaves, from the Upper Cretaceous. These include four from the Dakota sandstone of Kansas, one from the Patoot beds of Greenland, two from the Mill Creek beds of western Canada, one from Vancouver Island, one from the Eutaw formation of Georgia, three from the Magothy formation of New Jersey, Staten Island, and Long Island, and one from the so-called Laramie of Yellowstone Park, which is of Montana age. Many of these are very similar to the leaves of the existing species but lack the corroboration of associated fruits or structural remains.

The Eocene has furnished at least 10 nominal species, including occurrences in western Greenland, Spitsbergen, Siberia, and Alaska on the north, and in British Columbia, Montana, Colorado, and Wyoming in the western part of North America. I have described three species from the Wilcox group (lower Eocene) of the Mississippi embayment, and one of these is represented by characteristic fruits. Seward has described a large fruit from the supposed Eocene of southeastern Nigeria which has the appearance of a *Paliurus* but is not certainly so assigned.

The Oligocene contains at least three species—one from Louisiana represented by very characteristic leaves and thorny stems, and two from southeastern France represented by both leaves and fruit.

There are at least 13 nominal species recorded from the Miocene. These include identifications based upon leaves in Alsace, Switzerland, Bohemia, Italy, France, Silesia, and two from Florissant, Colo., the last not conclusive in themselves but highly probable in view of the occurrence of typical fruits at the same Miocene horizon in the State of Washington. Miocene species based upon fruits include occurrences in Bohemia, Styria, Switzerland, and southern Russia. The last, which comes from the Sarmatian stage, is scarcely if at all distinguished from the existing *Paliurus aculeatus*. The Pliocene record consists of a typical fruit from central France (Cantal), which is also indistinguishable from the existing *Paliurus aculeatus*.

In view of what we know of the plant history of the Tertiary it is surely of interest that the Miocene species from Washington should be most similar to the restricted species of south-central China (*P. orientalis*), as are also the leaves associated with the fruit, and that there should be earlier (late Eocene) species in the intervening region in Alaska and Siberia.

The horse-chestnuts or buckeyes, highly ornamental small trees or shrubs, constitute the genus *Aesculus*, with about a dozen existing species in Europe, Asia, and North America. Four of these are found in North America, all eastern except *Aesculus californica* Nuttall, a small tree surviving along stream borders in California. It is not without significance that the handsome Latah species is more like the existing widely cultivated *Aesculus hippocastanum* Linné than it is like any of the surviving American species. The geologic history of the genus is very imperfectly known.

The genus *Tilia*, comprising the lindens, basswood, and limes, is the north temperate representative of a prevailingly tropical family of trees, and its score of existing species range over the north temperate zone except western North America and Central Asia. A considerable number of fossil species are known, extending back to Eocene time, when it grew in western America, Alaska, and eastern Asia. It is exceedingly common in the Miocene of Europe but in western American is known from only Washington, Colorado, and Yellowstone Park.

Ternstroemites is a form genus for members of the tea family (Ternstroemiaceae or Theaceae) of the warmer parts of America and southern and eastern Asia. The geologic history goes back to the Upper Cretaceous, when *Ternstroemites* was represented on all the northern continents. The characteristic Latah species, the only known Miocene form in western North America, is probably closely related to the genus *Gordonia*, which has two species of showy-flowered shrubs or trees in our South Atlantic States and eight or nine species in southeastern Asia and the Malay Archipelago.

The genus *Sassafras*, whose single existing species was until recently the unique possession of southeastern North America, as almost the sole temperate representative of the large and chiefly tropical family Lauraceae, has two additional species in central China, thus paralleling the distribution of the tulip tree and hickory. No ancestral tree history is more interesting. It occurred in both eastern North America and western Europe toward the end of the Lower Cretaceous and became varied and wide ranging during the Upper Cretaceous. The Eocene American records are confined to Greenland and British Columbia. It continued to be abundant in Europe as late as the Pliocene, but until the discovery of characteristic leaves in the Latah deposits its occurrence in North America during the long interval represented by the Oligocene, Miocene, Pliocene, and Pleistocene epochs had been entirely unknown.

The genus *Umbellularia*, with a single existing species—the California laurel or spice tree, *Umbellularia californica* Nuttall of low, moist valleys in Oregon and northern California west of the Sierra Nevada—evidently had a wider and more varied existence in the Miocene and is not uncommon in the Latah flora.

The sour, cotton, or tupelo gums of the genus *Nyssa* were given the Latin name of a water nymph because of their marked preference for a palustrine or at least wet environment. There are six or seven existing species, all confined to southeastern North America except a single species of southeastern Asia. There are numerous fossil species, many of them based upon the characteristic stones of their drupaceous fruits. They occur in Europe, Asia, North America, and the Arctic in either the Upper Cretaceous or Tertiary deposits, and the existing forms are evidently relics of a once holarctic distribution. They disappear from the European record at the end of the Miocene, and the Latah species, comprising both leaves and stones, represents their latest known appearance in western North America.

The genus *Diospyros* represents the mostly tropical family Ebenaceae and includes very many species, both fossil and recent—the former going back to the Upper Cretaceous. In the modern flora of North America it is represented by the well-known persimmon of the southeastern United States and a smaller species in the Texas region. Other related species occur in eastern Asia, and these furnish the large edible so-called Japanese persimmons, now well known to consumers. *Diospyros* was common in western North America from the Upper Cretaceous to the Miocene, and the Latah species or closely related forms occur at Florissant, Colo., in Yellowstone Park, in western Oklahoma, in the John Day Basin of Oregon, in California, and in the Ellensburg formation of Washington.

The genus *Porana*, represented by capsular fruits of which the persistent calyx lobes constitute a parachute, is no longer present in North America and apparently was never common on this continent. Although its geologic history is imperfectly known, its absence in North America except in the middle or upper Miocene of eastern Washington and the Florissant lake beds of Colorado suggests a late Tertiary introduction into North America from Asia by way of the Bering land bridge. It also occurs in the European Tertiary but in the modern flora is restricted to southeastern Asia and Australia.

It has seemed important to give in some detail the geologic history and existing distribution of the genera of the Latah formation which no longer occur in the State of Washington. The remaining genera, which are still present in the State, may be passed over as of less interest. It would seem that the conclusions to be legitimately drawn from this survey are obvious, and I will therefore not dwell upon them at any length.

There are in this Latah flora many elements representing what may, to speak broadly, be called the holarctic Miocene flora, although I do not mean to imply that this was at all uniform over all the northern continents. It did, however, contain numerous similar generic types. After the climatic changes due mainly to the uplift of the Sierra Nevada and the Cascade and Coast Ranges the distribution of these generic types was altered. Some survived in locally favorable situations on the western mountain slopes, along streams, or in the humid western part of the State or the adjacent region to the south. Others disappeared entirely from western North America, and, as we have seen, their nearest relatives have a remarkably consistent distribution. Some few still survive in Europe, but the great majority are now extinct on that continent. A considerable number survive in either eastern Asia or southeastern North America, but the majority are represented in both of these mesophytic Tertiary floral preserves. The remarkable pairing of eastern America and eastern Asia, first emphasized by Asa Gray in 1872, thus becomes understandable, and we have in the Latah and similar western floras the record of a time before the changes due chiefly to extinction of species or restriction of their ranges brought about the contrasts between the existing floras of Europe, Asia, and eastern and western North America and the correlative resemblance between the floras of eastern Asia and eastern North America.

The cause is not far to seek and has been frequently emphasized: The continent of Europe, lying as a whole poleward as compared with America or Asia, was extensively glaciated during Pleistocene time, not only by the continental ice sheet from the Scandinavian center but by mountain glaciers in the Pyrenees, Alps, Carpathians, Urals, and Caucasus. Its Tertiary flora, with magnolias, gums, walnuts, hickories, sassafras, tulip trees, etc., during the climatic stress of glacial time had its southward retreat cut off by a continuous barrier of high mountains or open seas from the Bay of Biscay eastward to the expanded Caspian Sea. Consequently many plant species became extinct, and the modern flora of Europe has an impoverished aspect when compared either with the Miocene flora of Europe or with the Recent flora of eastern Asia or eastern North America.

In western America the history is somewhat different but with a similar ending. The gradual elevation of the mountain systems and the changes in geographic pattern governing wind circulation resulted in developing rain shadows or inappropriately seasoned rains over areas of great extent, producing prairies like the great belt of country bordering the Rocky Mountains on the east, the grass lands of southeastern Washington, the semiarid to desert region east of the Sierra Nevada and west of the Rockies in the present Great Basin, or the arid to desert country of southern California, Arizona, and New Mexico. With these progressive changes, accompanied by regional uplift, the mesophytic plants—and the Miocene flora of Holarctica, as a whole, was a mesophytic one—were obliged to retire to the humid region around Puget Sound, to the westward-facing wetter slopes of the mountains, or to stream borders and canyon bottoms. This restriction of suitable areas and the vicissitudes of topographic and resulting climatic change resulted in the extinction of many forms and their replacement by high mountain species from the north and xerophytic species from the south.

In southeastern North America and southeastern Asia, in marked contrast to western North America and Europe, the relation of land and sea assured abundant precipitation, there was plenty of country unglaciated, and, in particular, the orientation of the moderately elevated mountains afforded every variety of temperate habitat over wide areas. Plants could readily find their accustomed environmental requirements either laterally or vertically. Consequently there were no extensive extinctions, most of the more widely ranging Miocene genera survived, and new local species were evolved. In the main these factors are adequate to account for the observed facts.

ENVIRONMENTAL CONDITIONS

The general history of the Latah region has been given in considerable detail by Pardee and Bryan in the paper already cited. In Knowlton's account of the flora several paragraphs are devoted to the probable ecologic conditions. Chaney in his account of the climatic relations of the Mascall flora[3] considers it to represent an assemblage like that of the oak-madrono forest of the present in California,[4] with an indicated annual rainfall of 30 inches. It seems to me that it is highly hazardous to exclude from consideration, as Chaney does, those species which are no longer represented in Pacific floras, for their absence in the recent flora is the most conclusive evidence that the Miocene physical conditions differed from those of the present in that region. Otherwise there is no reason to account for their lack of survival.

I would also dispute the assertion of a progressive trend toward aridity throughout the Tertiary. There is certainly no indication of such a trend as late as the middle or upper Miocene Latah epoch. Possibly there was such a trend during the Pliocene.

The Latah flora is overwhelmingly mesophytic in its facies. I can not name a single genus of the 75 enumerated that can be unquestionably considered to have been xerophytic, although it is quite possible that some of the pines and oaks were. Omitting such obviously water-side plants as *Alnus*, *Typha*, and *Salix*, we have the bald cypress, chestnut, beech, hornbeam, fig, sycamore, *Menispermites*, tulip tree,

[3] Chaney, R. W., The Mascall flora—its distribution and climatic relation: Carnegie Inst. Washington Pub. 349, 1925.

[4] See Cooper, W. S., The broad-sclerophyll vegetation of California: Carnegie Inst. Washington Pub. 319, 1922.

magnolia, sassafras, sweet gum, horse-chestnut, linden, *Ternstroemites*, persimmon, *Asplenium*, *Arisaema*, hickory, poplar, birch, elm, hydrangea, maple, exceedingly large-leaved Lauraceæ, and *Nyssa*, which are all forms of deep, fertile, well-watered soils, humid atmospheric conditions, and equable summer temperatures. I would hesitate to give a quantitative estimate of either the rainfall or the temperature, as in our eastern hardwood forests or those of Asia, where the modern representatives of these Latah genera still exist, they occupy situations of considerable diversity as to altitude and latitude and consequently as to climate. Furthermore, so much depends upon the availability of soil water, the distribution of precipitation throughout the year, the evaporating power of the air, and the influence of water vapor in preventing extremes of temperature, and still other factors that dogmatism is to be deprecated.

The Latah flora is an overwhelmingly temperate flora entirely appropriate to the latitude where it is found and indicative of an ample, well-distributed rainfall of possibly between 30 and 40 inches annually. It is rather closely paralleled among existing floras by those of such a Middle Atlantic State as Maryland.

AGE

In the present contribution 152 species are recorded from the Latah formation. This by no means exhausts the flora, for the local students are constantly collecting new forms, and I have not attempted to determine a considerable number of forms that are obviously new but are represented so far by inadequate material. Of the 152 species 105 are not yet known from other regions and are therefore peculiar to the Latah flora and lack precise correlation value, except as this is indicated by their general facies and degree of relationship to known forms from other localities.

Our knowledge of the Tertiary floras of the Pacific border is still in the formative stage, and there exists considerable uncèrtainty regarding the exact age of a number of these floras. The present study throws considerable light on some of these.

On the 42 species found in the Latah that occur in other formations, all except the widely ranging and probably botanically composite *Ginkgo adiantoides*, *Sequoia langsdorfii*, and *Taxodium dubium* have a rather short chronologic range. The *Ginkgo* occurs in the Eagle Creek and Mascall formations, the *Sequoia* in the upper part of the Clarno, in the Mascall, and at Florissant, Colo., Blue Mountain, Oreg., and Pit River, Calif., and the *Taxodium* in the Mascall. Of the remaining and more significant species 4 occur in the upper part of the Clarno of the John Day Basin in Oregon, 21 in the Mascall formation of the same region, 9 in the Eagle Creek formation of the Columbia gorge, on both sides of the river, 4 at Ellensburg, Wash., 7 in the Payette formation of Idaho, 4 in the Miocene of Yellowstone National Park, 13 at Florissant, Colo., 11 in the so-called auriferous gravel of California, 2 in the Puente formation of California, 3 at Blue Mountain, Oreg., 2 at Trout Creek, Oreg., and 2 at Fortynine Camp, Nev.[5]

The predominance of Mascall, Florissant, and California species in the Latah flora, despite the uncertainty regarding the age of some of the California forms, and the ascertained relationships of the Mascall and Florissant floras as a whole are conclusive evidence, in my opinion, that the Latah flora is not older than middle Miocene. Whether it may be younger depends partly on the age of other western plant beds about which no general agreement has yet been reached. In Knowlton's preliminary paper the Latah flora was stated to be "not younger than middle Miocene and not older than lower Miocene." In the same paper it was stated that the Payette and Eagle Creek floras and probably the flora of Bridge Creek, in the John Day Basin, were Miocene, and that the flora from Ellensburg, Wash., and the Mascall formation of the John Day Basin was very definitely middle Miocene. The resemblance between the Latah flora and that found at Florissant, Colo., was not recognized by Knowlton, as it was not especially pronounced in the material which he studied. The subsequent collections from the Latah emphasize this resemblance, and the preliminary accounts of studies made by Chaney show the presence of certain characteristic species such as *Populus lindgreni*, *Fagopsis longifolia*, and *Platanus dissecta* at numerous localities in the West and tend to give them an especial stratigraphic value.

The Florissant flora was considered for a number of years, after Cockerell's work to be middle Miocene. Knowlton's latest expressed opinion (not published) was that the Florissant flora was of upper Miocene age. In this opinion I concur most heartily. If the Florissant flora is upper Miocene, the Mascall, Payette, and Ellensburg floras are probably upper instead of middle Miocene. The Latah flora, as Knowlton recognized in his preliminary account of it, has a very modern facies, and it seems to me that the lateness of mountain uplift in the Pacific region, which presumably was the major factor in bringing about the changes of distribution and the extinction of species in the Tertiary floras of western North America, strongly favors an upper Miocene rather than a middle Miocene age.

This probability of the Latah flora being upper rather than middle Miocene and the tendency among students of west-coast geology to consider the formations involved younger than they were formerly thought to be has considerable bearing on the age of other Tertiary plant beds in the West. Thus the

[5] These localities are taken from incomplete lists published by Chaney in 1925.

upper part of the Clarno formation of Oregon seems to me to be clearly younger than Eocene and may well be as young as Miocene; the Eagle Creek formation, which Chaney considers Oligocene, I would consider Miocene; the Payette formation of Idaho is clearly Miocene, as Chaney has already announced,[6] is certainly not older than middle Miocene, and is probably upper Miocene. If the Payette flora is upper Miocene then the plant-bearing part of the Esmeralda formation of western Nevada, a collection from which I have studied recently and found to be very similar to the Payette flora, is also upper Miocene. These conclusions bring the Payette and Esmeralda formations more nearly in accord with the age determinations of the vertebrate paleontologists. I hesitate to be dogmatic about the age of the Mascall flora, because I have never worked it over systematically, but I do believe it to be somewhat younger than middle Miocene. There is much in common between the Latah and Mascall floras, and if the Latah flora is upper Miocene it furnishes additional evidence tending to prove that the Mascall flora is younger than middle Miocene and also has a significant bearing on the age of the Columbia River lava flows, because the only decisive means of dating these flows is that of the fossil plants contained in the associated sedimentary beds.

[6] Chaney, R. W., Notes on the flora of the Payette formation [Idaho and Oregon]: Am. Jour. Sci., 5th ser., vol. 4, pp. 214-222, 1922.

Outside distribution of the Latah flora

	Upper part of Clarno formation, Oregon	Mascall formation, Oregon	Eagle Creek formation, Oregon and Washington	Ellensburg formation, Washington	Payette formation, Idaho	Miocene, Yellowstone Park	Florissant lake beds, Colorado	Auriferous gravel, California	Puente formation, California	Blue Mountains, Oregon	Trout Creek, Oregon	49 Camp, Nevada
Ginkgo adiantoides [a]		×	×									
Sequoia langsdorfii [a]	×	×					×			×		
Taxodium dubium [a]		×										
Palaeopotamogeton florissanti							×					
Smilax lamarensis						×						
Juncus? crassulus							×					
Hicoria juglandiformis							×					
Comptonia insignis							×					
Salix perplexa		×			×							
Salix florissanti		×					×					
Populus lindgreni		×		×	×					×		
Betula heteromorpha	×		×									
Castanea castaneaefolia		×						×				
Fagopsis longifolia		×					×		×			
Quercus payettensis					×							
Quercus merriami		×	×									
Quercus ursina		×										
Quercus simulata			×		×							
Ulmus speciosa	×		×									
Platanus aspera	×		×									
Platanus dissecta		×		×	×			×		×	×	×
Platanus appendiculata								×				
Magnolia californica						×		×				
Magnolia dayana	×			×				×				
Liquidambar californicum		×	×				×	×				
Hydrangea bendirei		×										
Amelanchier scudderi							×					
Cassia idahoensis					×							
Sapindus spokanensis		×					×	×				
Celastrus lacoei							×					
Rhus typhinoides			×					×				
Acer oregonianum		×									×	×
Acer merriami		×										
Acer bendirei		×						×				
Acer minor		×										
Laurus princeps					×	×		×				
Laurus similis			×									
Umbellularia dayana		×										
Aralia whitneyi		?				×		×	×			
Vaccinium americanum		×		×			×					
Diospyros princetoniana							×					
41 species	5	21	9	4	7	4	13	11	2	3	2	2

[a] Recorded from many other localities and horizons.

SYSTEMATIC DESCRIPTIONS

Phylum BRYOPHYTA

Class MUSCI

Family POLYTRICHACEAE

Genus POLYTRICHITES E. G. Britton

Polytrichites spokanensis E. G. Britton

Polytrichites spokanensis E. G. Britton in Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 24, pl. 8, figs. 3, 4, 1926.

This characteristic species is represented in the present collection by good material from a new locality.

Occurrence: Deep Creek, northwest of Spokane; Spokane, Portland & Seattle Railway cut No. 4, Spokane, Wash.

Phylum PTERIDOPHYTA

Order POLYPODIALES

Family POLYPODIACEAE

Genus ASPLENIUM Linné

Asplenium occidentale Berry, n. sp.

Plate 49, Figures 3, 4

Habit of frond unknown, as only the detached pinnules are preserved. Pinnules lanceolate, slightly falcate, tapering from point near the base to the acute tip. Base abruptly contracted and obliquely truncated, fuller on one side (apparently the proximal) than on the other. Margin with regular closely spaced teeth ranging from crenate to serrate and slightly more prominent and acute in the tip. Midvein fairly stout and prominent. Lateral veins well marked, diverging from the midvein at angles of 45° or more, the basal pair several times dichotomous; above the basal pair there are several pairs of twice dichotomous laterals, above which this type alternates with a lateral, the proximal fork of which is simple and the distal fork is once dichotomous. Higher up the veins are once dichotomous, and the distal four or five pairs are simple. Length about 6.25 centimeters. Maximum width about 1.2 centimeters. One specimen from Vera shows the somewhat poorly preserved parts of five pinnules and a stout winged rachis.

Occurrence: Vera, Wash.; Spokane, Portland & Seattle Railway cut No. 1 and brickyard at Spokane, Wash.

Genus WOODWARDIA J. E. Smith

Woodwardia praeradicans Berry, n. sp.

Plate 64, Figures 22, 23

Although the specimens thus far collected from the Latah formation are fragments of sterile pinnae, the venation leaves no doubt that they represent the genus *Woodwardia*.

The pinnae are long and lanceolate, suboppositely to alternately cut by narrow ultimately rounded sinuses two-thirds inward toward the rachis, forming relatively short, pronouncedly falcate segments, whose margins are minutely serrulate. The venation shows a row of long, narrow areoles on each side and parallel to the midvein of the pinna and similar areoles on each side of the midvein of the segments; outside of these there is a row of shorter, oblique, nearly isodiametric areoles, and outside of these a series of veinlets running to the marginal teeth. The veins except the midveins are thin. The texture is distinctly subcoriaceous.

The only other Miocene species of *Woodwardia* known to me is *Woodwardia florissanti* Cockerell,[7] both figure and description of which are so vague that it is unrecognizable. The Latah form may represent the same species, but as the Florissant form is said to be entire-margined, shows no venation, and has the segments (the so-called long linear pinnae of Cockerell) longer and straighter than in the Latah form, and also long stipitate, I believe the two are distinct.

The present species is remarkably like the living *Woodwardia radicans*, our most magnificent species, which occurs in shaded environments along streams in the Sierra Nevada and Coast Ranges from California to Mexico and Guatemala. The same or a related species occurs throughout the Mediterranean region of the Old World and in South America and Australia. The genus contains about six existing species, of which three are North American. Seven well-characterized fossil species have been reported from North America, including two from the late Upper Cretaceous, three from the early Eocene, one from Florissant, and one from the supposed Pliocene of Oregon.

The Latah species differs from all of these, being perhaps most similar to the last, *Woodwardia columbiana* Knowlton.[8] The genus is represented in the present flora of Washington by *Woodwardia spinulosa* Martens and Galeotti, a quite different species of the humid transition zone.

Occurrence: Brickyard at Spokane, Wash.

Genus WOODSIA R. Brown

Woodsia bonseri Berry, n. sp.

Plate 64, Figures 20, 21

Frond small, pinnate. Pinnules thin, small, ovate, incised marginally in the lower two-thirds by narrow pointed sinuses to form two or three ligulate lobes. The upper entire part is slightly crenulate. The apex is roundly pointed. The base is broad and almost

[7] Cockerell, T. D. A., The fossil flora of Florissant, Colo.: Am. Mus. Nat. Hist. Bull., vol. 24, p. 77, pl. 6, fig. 2, 1908.

[8] Knowlton, F. H., Two new fossil chain ferns (*Woodwardia*) from Oregon and Wyoming: Smithsonian Misc. Coll., vol. 52, p. 491, pl. 63, figs. 1, 2, 1910.

truncate and appears to have been sessile. The midvein is flexuous and not stronger than the laterals except at its extreme base. There are five or six pairs of thin alternating laterals, the lower ones once forked and extending into the marginal lobes, the upper ones simple.

The material is sterile but has all the vegetative features of *Woodsia* and does not resemble any other temperate North American genus, so that the identification is conclusive. *Woodsia* is a small genus of about 15 existing species of temperate and cold temperate regions. Seven of these are found in the United States and Canada. The genus has not been found fossil in North America heretofore.

The present species is similar to all the North American forms and is especially like *Woodsia alpina* (Bolton) S. F. Gray, a species of moist rocky environments, ranging from Labrador and Maine to Alaska and southward to or slightly south of the Canadian border. *W. alpina* does not, so far as I know, occur in Washington, where the genus is represented by *Woodsia scopulina* Eaton and *Woodsia oregana* Eaton, of the transition zone.

Occurrence: Brickyard at Spokane, Wash.

Genus PTERIS Linné

Pteris sp.

Fern, fragment, Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 24, pl. 9, fig. 10, 1926.

This very incomplete fragment figured by Knowlton has not been recognized in subsequent collections. It undoubtedly represents a part of a *Pteris* pinnule and is closely related to the existing widespread *Pteris aquilina* Linné.

Occurrence: Cut No. 2 on Oregon-Washington Railroad & Navigation Co.'s line, Spokane, Wash.

Phylum CONIFEROPHYTA

Order PINALES

Family TAXACEAE

Genus TUMION Rafinesque

Tumion bonseri Knowlton

Tumion bonseri Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 25, pl. 10, fig. 3, 1926.

A single specimen in the recent collections from Republic is rather more complete than Knowlton's type from Spokane.

Occurrence: Spokane and Republic, Wash.

Family CUPRESSINACEAE

Genus SEQUOIA Endlicher

Sequoia langsdorfii (Brongniart) Heer

Sequoia langsdorfii (Brongniart) Heer. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 26, pl. 9, figs. 3–6. 1926.

The occurrence of this species in the Latah formation has been fully described and illustrated by Knowlton in the paper cited. It is a common form, somewhat variable, and liable to be confused with the associated *Taxodium dubium*. Knowlton referred all the material from the immediate vicinity of Spokane to *Taxodium dubium*, but in the later collections which I have studied a considerable proportion of the specimens appear to me to represent the present species. This species has recently been recorded by Chaney from the Blue Mountains, Oregon, and Pit River, California.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Deep Creek northwest of Spokane, Wash.; cut 1 mile west of Shelley Lake, about 10 miles east of Spokane, Wash.; well at Mica, Wash.; Vera, Wash.; Chicago, Milwaukee & St. Paul Railway cut, Deep Creek Canyon, Spokane, Portland & Seattle Railway cut, and brickyard at Spokane, Wash.

Genus TAXODIUM L. C. Richard

Taxodium dubium (Sternberg) Heer

Taxodium dubium (Sternberg) Heer. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 27. pl. 9, figs. 2, 7–9; pl. 10, fig. 2, 1926.

Taxodium nevadensis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept., 1873, p. 272, 1874.

Mason, Carnegie Inst. Washington Pub. 346, p. 154, pl. 5, figs. 2, 5, 6, 1927.

The occurrence of this species in the Latah formation has been fully described and illustrated by Knowlton in the paper cited. The species is abundant in the recent collections and shows considerable variation in size. It is readily confused with the associated *Sequoia langsdorfii* unless the material is excellently preserved.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Deep Creek northwest of Spokane, Wash.; cut 1 mile west of Shelley Lake, 10 miles east of Spokane, Wash.; Vera, Wash.; Republic, Wash.; cut along Spokane, Portland & Seattle Railway; and brickyard at Spokane, Wash.

Taxodium, staminate ament

Plate 63, Figure 2

Knowlton[9] described and figured the staminate flowers of *Taxodium* from the Latah formation at Deep Creek, but his specimen is not nearly so typical as the one here figured from the later collections. This agrees exactly with the aments of the existing species, and there can not be the slightest doubt regarding the relationship of the fossil.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander.

Genus LIBOCEDRUS Endlicher

Libocedrus praedecurrens Knowlton

Libocedrus praedecurrens Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 28, pl. 8, fig. 8, 1926.

Fragmentary specimens of this species are represented at several localities in the present collections.

[9] Knowlton, F. H., Flora of the Latah formation of Spokane, Wash., and Coeur d'Alene, Idaho: U. S. Geol. Survey Prof. Paper 140, p. 28, pl. 10, fig. 4, 1926.

The type and only specimen previously known came from the Spokane, Portland & Seattle Railway cut at Spokane. It is of interest to note that a specifically unnamed *Libocedrus* is recorded by Chaney from the Mascall and Payette formations and from Trout Creek, Oregon.

Occurrence: Chicago, Milwaukee & St. Paul Railway cut No. 2, brickyard, and Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash.

Family PINACEAE

Genus PINUS Linné

Pinus macrophylla Berry, n. sp.[9a]

Plate 49, Figure 9

This species is based upon the single specimen figured showing elongated slender leaves quite unlike the associated forms or any previously described.

Leaves in threes, with long persistent leaf sheaths. Slender, about 1 millimeter or slightly over in diameter, and with a minimum length of 21 centimeters; the tips are all broken away, so that their maximum length remains unknown.

This interesting form may be compared with several existing pines of the Pacific slope, such as the western yellow pine (*Pinus ponderosa* Lawson), the Jeffrey pine (*Pinus jeffreyi* Vasey), the Digger pine (*Pinus sabiniana* Douglas), and the Torrey pine (*Pinus torreyana* Parry). In the character of the sheath and the slenderness of the leaves the fossil approaches most closely *P. ponderosa*, which, however, has 2-faced leaves.

Occurrence: Republic, Wash.

Pinus latahensis Berry, n. sp.

Plate 49, Figure 7

Leaves in fives, 2-faced, pointed, about 9 centimeters long and 1 millimeter broad. Sheath clearly deciduous; hence it belongs to the so-called white or hard pines.

These leaves in arrangement and size are very close to those of the existing western white pine (*Pinus monticola* Douglas) and sugar pine (*Pinus lambertiana* Douglas) and are most similar to those of the sugar pine. However, as the associated seeds are unlike those of the sugar pine and are, on the other hand, almost identical with the seeds of the western white pine, it is possible that the leaves and seeds, described separately, represent a single botanic species that may have been the Miocene ancestor of *Pinus monticola*. *P. monticola* has a wide range and is adapted to a variety of soils. It is found west of the Continental Divide in the mountains from northern Montana and southern British Columbia to Washington, Oregon, and California. At the north it is most common and largest in moist valleys, and in northern Idaho it reaches its greatest development on gentle north slopes and flats.

Occurrence: Republic, Wash.

Pinus monticolensis Berry, n. sp.

Plate 49, Figures 5, 8

In the collections from the Latah formation studied by Knowlton *Pinus* was represented by a single foliar specimen. The untrustworthy character of negative evidence is illustrated by the abundance of this genus in the later collections, where the pines are represented by four different kinds of leaves and by equally characteristic seeds.

The present species, which undoubtedly represents one or the other of the species based upon leaves, is represented by four specimens. These vary considerably in size and outline, but the alternative to regarding them as belonging to a single species is to consider them to represent four distinct species, which is not worthy of consideration. They agree in the form of the seed but differ in the size and shape of the wing. They may be described as follows:

Whole fruit of medium size, ranging in length from 17 to 26 millimeters and in maximum width from 4 to 9 millimeters. The inner margin is nearly straight, with the seed at the base. The seed is about twice as long as it is wide and but moderately elevated. The tip of the wing may be almost evenly rounded, as in the narrower specimen figured, or it may be subtruncate, as in the wider specimen figured. The outer wing margin may be but slightly rounded and subparallel with the inner margin, or it may flare at the top and narrow downward, in all specimens forming an outer margin nearly or quite to the base of the seed.

These seeds are very close to those of the existing western white or silver pine, *Pinus monticola* Douglas, whose distribution has been discussed under *Pinus latahensis*. They are also comparable to the seeds of *Pinus ponderosa* Lawson, the widespread western yellow pine, which is of some interest because the Latah collections contain a long-leafed pine that might represent a similar fossil form. However, the fossil leaves are two-faced instead of three-faced, as in the existing western yellow pine.

Occurrence: Republic and Spokane, Wash.

Pinus tetrafolia Berry, n. sp.

Plate 49, Figure 6

Leaves coriaceous, with a single bundle and two-faced, in fours, about 6 centimeters long and less than a millimeter in diameter. Sheaths persistent.

It is highly improbable that this should represent a distinct botanic species, not only because of the well-known variability among three-leaved and five-leaved forms but also because the present species is based

[9a] In a publication that appeared after the present paper was written Mason has made an interesting contribution to our knowledge of the fossil conifers of western America (Mason, H. L., Carnegie Inst. Washington Pub. 346, pp. 139-158, 1927). It is impossible to discuss Mason's conclusions here.

upon a single specimen. However, I have given it a name rather than multiply the already numerous unnamed pines in the literature. The leaves are more slender than in the associated *Pinus* sp. Knowlton.

Occurrence: Republic, Wash.

Pinus sp. Knowlton

Pinus sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 26, pl. 8, fig. 9, 1926.

Based by Knowlton on a single specimen from a well near Mica, southeast of Spokane, which may be identical with *Pinus knowltoni* Chaney,[10] from the Eagle Creek formation of Oregon. There are three specimens in the more recent collections. The leaves are short, and one specimen distinctly shows the sheath, so that it can not be one of the soft pines, as Knowlton inferred.

Occurrence: Well near Mica, Wash.; brickyard, Spokane, Wash.

Pinus, staminate aments

Plate 64, Figures 17–19

The staminate aments of a conifer are relatively common at the brickyard locality, as I have six rather well preserved specimens, which is a large number for such accidental fossils. They are about 2½ centimeters long and 5 millimeters in diameter, are slightly pedunculate, and consist of spirally arranged thick scales on a stout axis with ends turned up and imbricated. At the base there is a mass or involucre of flat pointed imbricated bracts.

I at first thought these basal bracts represented a gall of some gall midge and have to thank Dr. E. P. Felt for looking at them for me and giving me his opinion. I have compared them with various coniferous catkins, and they agree best with those of *Pinus*. As several species of *Pinus* are represented by foliage and seeds in the Latah formation, I have attached no name to the catkins.

Occurrence: Brickyard at Spokane, Wash.

Genus TSUGA Endlicher

Tsuga latahensis Berry, n. sp.

Plate 63, Figures 3, 4

Cone scales detached, thin, ovate to nearly orbicular. These vary considerably in size and form and presumably represent scales from different parts of the cone.

It might be expected that the deciduous cone scales of *Tsuga* would be of common occurrence in the later Tertiary deposits, but such has not been the case, and the only American occurrence known to me is the record (nomen nudum) of a member of this genus in the Bridge Creek beds of the John Day Basin in Oregon,[11] which is based on a twig and not a cone scale. One or two Tertiary species have been recorded from Eurasia, and this sparseness again disappoints one's expectation.

The existing species number seven, of temperate North America, Japan, central and western China, and the Himalayan region.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander and C. O. Fernquist.

Glyptostrobus?, staminate aments

Plate 63, Figure 1

The present object represents what in the United States have been considered the staminate aments sometimes called *Glyptostrobus europaeus ungeri* Heer [12] and sometimes *Glyptostrobus ungeri* Heer [13] and by European paleobotanists referred to either of these or to *Glyptostrobus europaeus* Heer. The last has been identified all over the world from almost every possible Tertiary horizon and is unquestionably a composite. I think that there can be no question but that the Latah specimen is homologous with Heer's numerous records of staminate aments of *Glyptostrobus*, but the idea that they can be specifically determined is preposterous, and it is by no means certain that the present specimen even represents *Glyptostrobus*. Its chief interest in the present connection is that similar remains occur in the Mascall formation of Oregon.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Phylum SPERMATOPHYTA

Class ANGIOSPERMAE

Subclass MONOCOTYLEDONAE

Order PANDANALES

Family TYPHACEAE

Genus TYPHA Linné

Typha? sp. Knowlton

Typha? sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 28, pl. 9, fig. 11, 1926.

Fragments of linear monocotyledonous leaves similar to the small fragment from Spokane which Knowlton tentatively referred to the genus *Typha* are common in the recent collections. Beyond their monocotyledonous nature their affinity is entirely problematic, although they might well represent the genus *Typha*.

Occurrence: Deep Creek Canyon and brickyard at Spokane, Wash.

[10] Chaney, R. W., The flora of the Eagle Creek formation: Walker Mus. Contr., vol. 2, No. 5, p. 160, pl. 5, figs. 3, 4, 1920.

[11] Chaney, R. W., Quantitative studies of the Bridge Creek flora: Am. Jour. Sci., 5th ser., vol. 8, p. 129, 1924.

[12] Lesquereux, Leo, The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 222, pl. 46, figs. 1–1c, 1883.

[13] Knowlton, F. H., Fossil flora of the John Day Basin, Oreg.: U. S. Geol. Survey Bull. 204, p. 26, 1902.

Order NAIADALES

Family NAIADACEAE

Genus POTAMOGETON Linné

Potamogeton heterophylloides Berry, n. sp.

Plate 50, Figures 1–3

Potamogeton sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 29, pl. 10, figs. 5, 6, 1926.

The fragment from the Spokane, Portland & Seattle Railway cut which Knowlton described is represented by 11 specimens in the recent collection, most of which are complete. They are slightly smaller than the type but vary considerably in size, ranging from 3 to 8 centimeters in length. The tip, absent in the type, is abruptly narrowed to a point.

I have ventured to give it a specific name in allusion to its resemblance to *Potamogeton heterophyllus* Schreber, which is found nearly all over North America as well as in Europe. Our eastern *Potamogeton nuttallii* Chamisso and Schlechtendal has submerged leaves even more like the fossil.

Occurrence: Cut on Spokane, Portland & Seattle Railway, Chicago, Milwaukee & St. Paul Railway cut No. 2, and brickyard at Spokane, Wash.

Genus PALAEOPOTAMOGETON Knowlton

Palaeopotamogeton florissanti Knowlton

Palaeopotamogeton florissanti Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 251, pl. 16, fig. 1; pl. 17, fig. 3, 1916.

Fruits exactly like those described by Knowlton for this species occur in the Latah formation, where they are found detached and unaccompanied by the foliage. There can be no doubt of their identity with the fruits from Florissant. I can see no evidence from either the fruits or foliage that there is any relationship with the Potamogetonaceae, but I have no suggestions to offer regarding their botanic affinity. Under the circumstances I would have ignored these small hard spherical fruits of the Latah formation except for the fact that they are an additional element in synchronizing the floras from Florissant, Colo., and those in the vicinity of Spokane.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist

Order LILIALES

Family SMILACEAE

Genus SMILAX Linné

Smilax lamarensis Knowlton

Plate 63, Figure 15

Smilax lamarensis Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 685, pl. 121, figs. 3, 4, 1899.

The single specimen figured is referred to this species with some hesitation. It approaches the minimum size of the leaves from Yellowstone Park and appears to be of a less firm texture, but in view of the well-known variability in the leaves of this genus it seems undesirable to multiply fossil species unless really distinctive specific characters are present. The Latah specimen indicates an ovate leaf about 8 centimeters long, with a maximum width in the lower half of slightly over 4 centimeters. The base is rounded and cordate. There are three principal primaries; the midvein is slightly more prominent than the laterals which are acrodrome. There is a second thinner pair of acrodrome primaries about 3 millimeters inside the margins which they parallel. The secondary venation is thin but well marked consisting of rather closely spaced obliquely somewhat sinuate transverse veins, forking or inosculating or connected by cross branches, and perfectly characteristic of the genus. The leaf texture is thin and soft, as is indicated by the way the veins stand out above the lamina and the somewhat crumpled character of the lamina.

The type came from the supposed Miocene of Yellowstone Park and was compared by its describer with the existing *Smilax rotundifolia* Linné and *Smilax pseudochina* Linné. It might equally well be compared with *Smilax hispida* Muhlenberg, *Smilax walteri* Pursh, or still other existing species. Such comparisons, however, have but slight ecologic or geographic significance.

Smilax is new to the Latah flora but has been recorded from the upper Miocene at Florissant, Colo., and the Eagle Creek and Mascall of Oregon. The species at Florissant is *Smilax labidurommae* Cockerell,[14] a considerably smaller deltoid form with a truncate base. The Mascall species is *Smilax wardii* Lesquereux,[15] an elongated hastate-sagittate leaf. Both are very different from the Latah species.

The genus, with well-defined characters, goes back certainly as far as the early Eocene and probably to the later Cretaceous. The existing species number about 200 widely distributed and for the most part in moist environments, most abundantly in tropical America and Asia. There are about 20 species in temperate North America, several extending as far northward as southern Canada.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander.

Family JUNCACEAE?

Genus JUNCUS? Linné

Juncus? crassulus Cockerell

Juncus crassulus Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 79, pl. 10, figs. 44, 45, 1908.

There are several specimens from the Latah formation which I am unable to distinguish from the so-

[14] Cockerell, T. D. A., Two new plants from the Tertiary rocks of the West: Torreya, vol. 14, p. 135, text fig. 1, 1914.

[15] Lesquereux, Leo, Recent determinations of fossil plants from Kentucky, Louisiana, Oregon, California, Alaska, Greenland, etc.: U. S. Nat. Mus. Proc., vol. 11, p. 19, pl. 13, fig. 1, 1888.

called flowers from Florissant, Colo., described by Cockerell as those of *Juncus*. I have queried the generic name, as I am by no means convinced that they can be conclusively shown to be referable to that genus.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Subclass DICOTYLEDONAE

Series CHORIPETALAE

Order JUGLANDALES

Family JUGLANDACEAE

Genus HICORIA Rafinesque

Hicoria juglandiformis (Sternberg) Knowlton

Phyllites juglandiformis Sternberg, Versuch einer geognostich-botanischen Darstellungder Flora der Vorwelt, Band 4, index, p. 40, pl. 35, fig. 1, 1825.

Carya bilinica Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 191, pl. 39, figs. 1, 2, 13, 1883.

Hicoria juglandiformis Knowlton, U. S. Geol. Survey Bull. 152, p. 117, 1898.

Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 80, 1908.

A typical large leaf of this species is present in the recent Latah collections. It is altogether improbable that this represents the same botanic species as that described from Europe, and it would probably be proper to take up Kirchner's *Juglans affinis* from Florissant as the proper name for the American fossil. It has hitherto not been found outside the Florissant Miocene.

Occurrence: Brickyard at Spokane, Wash.

Order MYRICALES

Family MYRICACEAE

Genus COMPTONIA Banks

Comptonia insignis (Lesquereux) Cockerell

Plate 50, Figure 5

Comptonia insignis Cockerell, Colorado Univ. Studies, vol. 3, p. 173, 1906; Am. Mus. Nat. Hist. Bull., vol. 24, p. 81. 1908.

Berry, Am. Naturalist, vol. 40, p. 499, 1906.

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 260, 1916.

Myrica insignis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 312, 1876; U. S. Geol. Survey Terr. Rept., vol. 7, p. 135, pl. 65, figs. 7, 8, 1878.

Myrica alkalina Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 149, pl. 65–A, figs. 10–15, 1883.

This handsome species, abundant at Florissant, Colo., is represented in the recent collections from the Latah formation by the fine and characteristic specimen figured.

Occurrence: Republic, Wash.

Comptonia hesperia Berry, n. sp.

Plate 50, Figure 6

It is certainly exasperating that the more rare the type generally the more scanty the material. The present species is based upon a tiny fragment showing the parts of but seven lobes. Fortunately these are characteristic enough to permit recognition of the genus but hardly sufficient to define the species accurately. However, as nothing else of the kind is known it may be made the type of a distinct species and may be described as follows:

Leaf lanceolate, dimensions unknown. Midvein stout. Lamina rather regularly divided nearly to the midvein into relatively narrow, falcate-pointed lobes about 7 millimeters long and 4 millimeters in maximum width. There are two relatively stout lateral veins in each lobe—the upper running to the tip, the lower camptodrome; a third and thinner lateral runs close to and subparallel with the lower arched margin until it disappears by inosculating distad; all are connected by fine oblique veinlets and camptodrome marginal arches. The margins of lobes are entire. The sinuses between them are evenly rounded. Texture subcoriaceous.

The only other plant with comparable foliage is the monotypic rosaceous genus *Lyonothamnus* Gray, of the southern California islands. In this the normal as well as the ancestral leaf is entire, becoming lobulate below and finally irregularly pinnately parted into numerous segments which are themselves lobulate as in *Comptonia*. *Lyonothamnus* is more coriaceous, less regularly lobate, and with more numerous veins than *Comptonia*.

The present specimen is evidently from the middle region of a leaf and may be readily matched among the rather variable leaves of the existing sweet fern, *Comptonia peregrina* (Linné) Coulter. The genus *Comptonia* is now a monotypic genus of dry and rocky hillsides from Nova Scotia to Manitoba and southward to North Carolina in the Appalachian region, although it had a holarctic range in the later Tertiary, and includes numerous fossil species from the Upper Cretaceous onward. Eight other fossil species are known from the Tertiary of western North America. There are at least two characteristic species at Florissant, and a third from the Miocene of Elko station, Nevada—all unlike the present fossil. There are two upper Eocene species in Alaska (Kenai formation), and two or three additional in the upper Eocene or Oligocene of British Columbia. Of these both *Comptonia diforme* (Sternberg) Berry (*C. columbiana* Dawson) and *Comptonia predryandroides* Berry (*C. cuspidata* Dawson, not Lesquereux) are similar to the Latah form but are smaller and differ in specific features such as the shape and division of the lobes, the character of the margin, and minor features of the venation. *Comptonia predryandroides* may well stand in an ancestral relationship to *Comptonia hesperia*.

Although the genus has failed to perpetuate itself in the existing less arid regions of the Pacific slope, it was evidently endemic there, as well as in eastern Asia, throughout the later Tertiary. That it can not be considered indicative of other than mesophytic conditions during Latah time is shown by its associates in the past in that general region and by the range of the sole surviving species. It was not a denizen of the Latah bottoms but of more or less rocky slopes with lessened ground water and a somewhat thinned cover.

Occurrence: Brickyard at Spokane, Wash

Order SALICALES

Family SALICACEAE

Genus SALIX Linné

Salix florissanti Knowlton and Cockerell

Plate 64, Figure 16

Salix florissanti Knowlton and Cockerell, U. S. Geol. Survey Bull. 696, p. 566, 1919.
Salix amygdalaefolia Lesquereux, Cretaceous and Tertiary floras, p. 156, pl. 3, figs. 1, 2, 1883. (Not Gilib, 1792.)
Knowlton, U. S. Geol. Survey Bull. 204, p. 30, 1902.
Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 17, 1888.
Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 82,1908.
Salix bryani Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 33, pl. 12, fig. 6, 1926.

This, the smaller of the two more typical willows of the Latah formation, occurs also at Florissant, Colo., and in the Mascall formation at Van Horn's ranch in the John Day Basin of Oregon. Knowlton described the Latah remains as a new species, but it is obviously identical with the *Salix amygdalaefolia* of Lesquereux.

Occurrence: Cut on Chicago, Milwaukee & St. Paul Railway and brickyard at Spokane, Wash.

Salix inquirenda Knowlton

Salix inquirenda Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 11, figs. 1, 2, 1926.

This fine and characteristic *Salix* is not uncommon in the recent collections from the Latah formation. It varies considerably in size, the largest specimen having a maximum width of 4.5 centimeters, but preserves the marginal and venation features throughout. The petiole is complete in two specimens and is 2 and 3 centimeters long, respectively. The new occurrences are given below.

Among existing species this appears to me to be closest to some of the forms of *Salix lasiandra* Bentham, a wet-soil type of middle altitudes found west of the Sierra Nevada in California, western Oregon, Washington, and southern British Columbia.

Occurrence: Vera, Wash.; Twelfth Avenue and Thor Street and brickyard, Spokane, Wash.

Salix remotidens Knowlton

Salix remotidens Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, fig. 7, 1926.

Although it shows some minor differences, especially in the more rounded base and less conspicuous teeth, it is doubtfully distinct from the associated *Salix inquirenda* Knowlton.

Occurrence: Spokane, Portland & Seattle Railway cut and brickyard at Spokane, Wash.

Salix, pistillate flower

Plate 63, Figure 5

Ovary slenderly fusiform, short stipitate, about 45 millimeters long and 1.25 millimeters in maximum diameter. Stipe about 1 millimeter long. Style practically nonexistent. Stigmas two, short and spreading. Scale small and narrow, about half the length of the ovary, villous distad.

This unique fossil is naturally represented by a single specimen, which was preserved by some lucky accident. That it is a willow can not be doubted, as the stigmas of *Populus* are dilated, parted, or lobed and are frequently three and more rarely four in number, whereas in *Salix* they are always two in number, although in some species these may be parted. Among recent species that I have seen the fossil is most like the pistillate flowers of *Salix cordata* Muhlenberg, a wet-soil shrub ranging from New Brunswick to British Columbia and south to Virginia, Missouri, Colorado, and California.

It is an unusual pleasure to find such a flower in association with the fossil foliage, and the present occurrence is, so far as I am aware, the first to be recorded, although poorly preserved catkins and the valved capsules have been found fossil.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Salix sp., stipule

Plate 52, Figure 6; Plate 64, Figure 9

In addition to the leaves of three species of *Salix* recorded from the Latah formation there are several specimens of remarkably well preserved stipules which might belong to one or the other of these leaf species. Detached stipules, when nonfugaceous, are exceedingly rare as fossils. The present specimens range from 0.8 to 2.5 centimeters long and 4 to 12 millimeters wide, sheathing at the basal side, pointed, and with numerous serrate teeth and a characteristic venation. The fossil can be exactly matched by selected stipules from the living tree.

Occurrence: Brickyard at Spokane, Wash.

Genus POPULUS Linné

Populus heteromorpha Knowlton

Populus heteromorpha Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 30, pl. 12, figs. 8–10; pl. 13, figs. 1–7; pl. 14, figs. 1–3; pl. 15, figs. 3–5, 1926.
Populus fairii Knowlton, idem, pl. 15, fig. 2; pl. 16, figs. 1–3.

This exceedingly protean species is the most abundant form in the Latah collections. It occurs in all sizes and shapes and shows a corresponding range of variation in its marginal characters. These have been sufficiently illustrated in the large suite of specimens figured by Knowlton. As he suspected, the forms called *fairii* are not distinct from the type, but every gradation is represented, and leaves with three, four, or five primaries are not distinctive. Every locality in the recent collections that contains one contains the other.

Occurrence: Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cuts Nos. 1 and 4, Spokane, Wash.

Populus lindgreni Knowlton

Populus lindgreni Knowlton, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 725, pl. 100, fig. 3, 1898; U. S. Geol. Survey Bull. 204, p. 29, pl. 2, fig. 1, 1902; U. S. Geol. Survey Prof. Paper 140, p. 31, pl. 14, figs. 4–7, 1926.

This species, described originally from the Payette formation of Idaho, was subsequently recorded from the Mascall and Latah formations. Recently Chaney has reported it from the Blue Mountains, Oregon, and Ellensburg, Wash.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Vera, Bigelow Gulch near Hillyard, and Republic, Wash.

Populus, bud scales

Plate 50, Figure 4; Plate 63, Figure 8

Characteristic bud scales of *Populus* are not uncommon in the present collection. They are truncate at the base, acute at the tip, 1.25 to 2 centimeters long, longitudinally veined, and of considerable consistency. They are involute, as shown by the splitting of specimens that have been flattened during fossilization. They are in every way comparable with the large and more or less resinous outer winter bud scales of the existing species and presumably belong to one of the species represented by leaves in the Latah formation.

Occurrence: Brickyard at Spokane, Wash

Populus, pistillate ament

Plate 63, Figure 7

A segment of fruit-bearing catkin of some species of *Populus*, presumably belonging to one of the named leaf species of the Latah formation, is contained in the collection. The axis is stout, the capsules are well spaced and small, ovate conical, about as wide as long and two-valved; some are open and others closed.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander.

Populus, amentiferous bract

Plate 63, Figure 6

A single specimen undoubtedly represents a bract from the catkin of a *Populus*, presumably one of the species so prolifically represented by leaves in the Latah formation. This bract is about 5 millimeters long, truncate or slightly excavated at the base, expanding upward, the substance thickened in its upper half and lacerate. The details of the specimen are not clear throughout, but it is obviously flat and not tubular as it would be if it were a sympetalous calyx or corolla, and it agrees closely with the bracts of various existing species of *Populus*, in which the bracts are characteristic.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Order FAGALES

Family BETULACEAE

Genus BETULA Linné

Betula heteromorpha Knowlton

Betula heteromorpha Knowlton, U. S. Geol. Survey Bull. 204, p. 39, pl. 3, figs. 6, 7; pl. 5, fig. 1, 1902; U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 17, figs. 5, 6, 1926.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 165, 1920.
Betula bryani Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 18, fig. 1, 1926.
Betula thor Knowlton, idem, p. 35, pl. 17, fig. 3.

This species, described originally from the upper part of the Clarno formation of the John Day Basin in Oregon, is very common in the Latah formation and occurs also in the Eagle Creek formation. The forms that Knowlton described as *Betula bryani* and *Betula thor* are nothing but variants of *Betula heteromorpha*, with which they are connected by insensible gradations. These leaves are separated with difficulty from some of the existing western leaves of *Alnus*. The variations of this Latah species of *Betula* can be matched among the leaves of the existing *Betula occidentalis*, which it closely resembles and which occurs along stream borders in rich soil through British Columbia, Washington, Idaho, and Montana.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Vera, Wash.; Bigelow Gulch below Hillyard, Wash.; Republic, Wash.; Deep Creek Canyon, brickyard, and cuts on Spokane, Portland & Seattle Railway and Chicago, Milwaukee & St. Paul Railway, at Spokane, Wash.

Betula fairii Knowlton

Betula fairii Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 33, pl. 17, fig. 4, 1926.
Betula nanoides Knowlton, idem, p. 34, pl. 18, fig. 2.

I can not see any adequate features distinguishing what Knowlton referred to the two species cited above; in fact, I imagine that both represent merely small leaves of the associated and more abundant *Betula heteromorpha* Knowlton.

Occurrence: Cuts on Chicago, Milwaukee & St. Paul Railway and Spokane, Portland & Seattle Railway and brickyard at Spokane, Wash.

Betula largei Knowlton

Plate 50, Figure 12

Betula? largei Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 17, figs. 1, 2, 1926.

This species was queried by Knowlton because he thought it might be an *Alnus* or *Corylus*. There are five specimens in the recent collections, including the perfect minimum-sized leaf figured. It is very similar to the existing *Betula luminifera* Winkler, of central China, which it resembles much more closely than it does any existing North American birches.

Occurrence: Cut on Spokane, Portland & Seattle Railway and brickyard at Spokane, Wash.; well at Mica, Wash.

Betula, winged fruit

Plate 63, Figure 9

Winged nutlets (samara), roundly obcordate, 6.75 millimeters in width, thus relatively large. The nut is fusiform, compressed, widest and fullest above the middle, with basal scar, 4.5 millimeters long and 1.75 millimeters in maximum width. It is crowned with two slender persistent curved styles 1 millimeter in length. The wings are very delicate, full and rounded, and very faintly and openly reticulate-veined.

This beautiful and characteristic fruit very probably represents the genus *Betula*, the leaves of which are among the commonest fossils in the Latah formation. It does not seem wise to multiply specific names by naming it, as it almost certainly represents the fruit of one of the forms represented by leaves which have already been named. It can not be conclusively proved that *Alnus* should be excluded from consideration, but as the leaves of *Betula* are so exceedingly common in this deposit, as all the existing species of *Betula* have winged nuts, whereas in the existing species of *Alnus* the wing is greatly reduced or entirely absent, and as the leaves of *Alnus* are less common in these beds, it seems probable that the reference to *Betula* is correct.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Genus ALNUS Gaertner

Alnus elliptica Berry, n. sp.

Plate 50, Figures 8–10

Leaves of small size, elliptical in general outline. Margin with close-set, prominently crenate teeth. Length 1.5 to 2.5 centimeters; maximum width 9 to 14 millimeters. Petiole very stout, about 4 millimeters long. Midvein stout, prominent. Secondaries relatively stout, regularly spaced, subparallel; they diverge from the midvein at angles of about 45°, pursue relatively straight ascending courses, and are craspedodrome. The tertiaries are obsolete.

As no larger leaves with these characters occur in the collections it is assumed that these small specimens were mature. This species is much like what Winkler calls *Alnus alnobetula* var. *crispa* in his monograph of the *Betulaceae*.[16] That variety ranges from Newfoundland to Alaska and south to New York, Michigan, and British Columbia.

Occurrence: Republic, near Spokane, Wash.

Alnus prerhombifolia Berry, n. sp.

Plate 50, Figure 11

Leaves of medium size; broadly elliptical, almost orbicular in general outline, with a shortly pointed tip and a rounded or truncate base. Texture subcoriaceous. Margin variously toothed, entire proximad. Teeth crenate or serrate and dimorphic. Length 4 to 6 centimeters; maximum width 2.5 to 4.5 centimeters. Petiole stout, of unknown length. Midvein stout, prominent. Secondaries relatively stout and straight, subparallel, regularly spaced. Tertiaries well marked, craspedodrome from outer distal part of secondaries; percurrent between them.

I have associated as this new species a somewhat variable series of leaves, some of which suggest *Betula* but which appear to me to represent *Alnus*, especially as undoubted cones of *Alnus* are not uncommon in these deposits. They are quite similar to the leaves of the existing *Alnus rhombifolia* Nuttall, a tree of stream borders, found from Idaho and Washington to southern California. The genus has a considerable geologic history and is abundant in the present Canadian and Hudsonian life zones.

Eight normal species from the western Miocene in California, Oregon, Washington, and Colorado have been described. These all differ decidedly from the present fossil form.

Occurrence: Vera, Deep Creek Canyon, and brickyard at Spokane, Wash.

Alnus sp. Knowlton

Alnus sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 33, pl. 18, figs. 3–5 a, 1926.

Pistillate cones of *Alnus*, identical with those figured by Knowlton from Coeur d'Alene, Idaho, are contained in the present collections from around Spokane, where leaves of this genus have also been recognized.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Deep Creek Canyon, Spokane, Wash.

Alnus or Betula, staminate catkin

The collection contains a single specimen of a cylindrical staminate catkin about 3.5 centimeters in length and about 6 millimeters in diameter which almost certainly represents *Alnus* or *Betula*.

Occurrence: Brickyard at Spokane, Wash.

[16] Winkler, C., in Engler, A., Betulaceae: Pflanzenreich, IV, vol. 61, p. 107, 1904.

Family FAGACEAE

Genus CASTANEA Adanson

Castanea castaneaefolia (Unger) Knowlton

Fagus castaneaefolia Unger, Chloris Protogaea, p. 104, pl. 28, fig. 1, 1847.
Castanea ungeri Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 246, pl. 52, figs. 3–7, 1883.
Castanea castaneaefolia Knowlton, U. S. Geol. Survey Bull. 152, p. 60, 1898; U. S. Geol. Survey Prof. Paper 140, p. 35, pl. 18, figs. 7, 8; pl. 19, fig. 1, 1926.

This species is not uncommon in the more recent collection from the Latah formation. As noted by Lesquereux in the material from California, the present material shows considerable variation in size and proportions, the largest leaf seen having a length of 24 centimeters and a maximum width of 5.5 centimeters. It is highly doubtful if these western North American leaves represent the same botanic species as the European form to which they have been referred.

Occurrence: Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cuts Nos. 1 and 4, Spokane, Wash.

Castanea orientalis Chaney

Plate 51, Figures 4, 5

Castanea orientalis Chaney, Carnegie Inst. Washington Pub. 346, p. 110, pl. 12, figs. 1, 4, 1927.

Among the leaves from the Latah formation which both Knowlton and I have referred to *Castanea castaneaefolia* (Unger) Knowlton are several in which the marginal teeth are very narrow and long. These agree with the species from the Bridge Creek formation of the Crooked River Basin, in eastern Oregon, recently described by Chaney. For the present I have retained both species, but it is highly improbable that there were two botanic species of chestnut at Spokane, and it is equally improbable that these western American chestnuts should belong to the same botanic species as that from the European Miocene described by Unger.

More material of *Castanea orientalis* may demonstrate that it varies from the typical form sufficiently to include *Castanea castaneaefolia*, but the two are best kept separate for the present. In the character of the type material of *Castanea orientalis* there is a considerable resemblance to the existing *Castanea henryi* Rehder, of central China.

Occurrence: Brickyard at Spokane, Wash.

Genus FAGOPSIS Hollick

Fagopsis longifolia (Lesquereux) Hollick

Plate 50, Figure 7

Fagopsis longifolia Hollick, Torreya, vol. 9, p. 2, text figs. 1, 2, 1909.
Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 265, pl. 20, fig. 5, 1916.
Chaney, Am. Jour. Sci., 5th ser., vol. 2, p. 90, 1921.
Planera longifolia Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 371, 1873; U. S. Geol. Survey Terr. Rept., vol. 7, p. 189, pl. 27, figs. 4–6, 1878.
Newberry, U. S. Geol. Survey Mon. 35, p. 81, pl. 58, fig. 3, 1898.
Penhallow, Roy. Soc. Canada Trans., 2d ser., vol. 8, p. 70, 1902; Report on Tertiary plants of British Columbia, p. 73, 1908.
Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 712, 1899.
Quercus semielliptica Goeppert. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 286, 1872.
Fagus longifolia (Lesquereux) Hollick and Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 88 (footnote), 1908.
Zelkowa longifolia (Lesquereux) Engler, in Engler and Prantl, Natürlichen Pflanzenfamilien, Teil 3, Abt. 1, p. 65, 1888.
Myrica oregoniana Knowlton, U. S. Geol. Survey Bull. 204, p. 33, pl. 3, fig. 4, 1902.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 163, 1920.

The finding of attached fruits by Hollick in 1909 conclusively showed these leaves to be referable to the Fagaceae, and it is difficult to see any reason for not referring them directly to the modern genus *Fagus*. Not having examined the fruits personally, I have retained Hollick's genus *Fagopsis* for the present.

The species is represented in the Latah formation by small leaves, which depart from the type merely in having the base somewhat more oblique than in most of the Florissant leaves. To the same species belongs the form from the Mascall formation referred by Knowlton to the genus *Myrica*.

The species as now conceived is an abundant and widely ranging Miocene type in western North America occurring in British Columbia; at Elko station, Nev.; in the Yellowstone Park; in the Mascall formation of Oregon; in the Puente formation of California; and in the Eagle Creek formation of Oregon. If the rarity of this form in the Latah formation is of any significance, which is by no means certain, it was not a common element in the Latah flora.

Occurrence: Brickyard and Spokane, Portland & Seattle Railway cut No. 4, Spokane, Wash.

Genus QUERCUS Linné

Quercus cognatus Knowlton

Quercus cognatus Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 20, figs. 1–4; pl. 21, figs. 1, 2, 1926.

The form of oak to which Knowlton gave this name is one of the commonest types in the Latah formation. As Knowlton has pointed out, it approaches very closely *Quercus pseudolyrata* Lesquereux,[17] of the Mascall formation of Oregon, and *Quercus merriami* Knowlton,[18] of the Mascall and Latah formations.

I can see no valid reason for discriminating *Quercus cognatus* and *Quercus merriami*, and both *Quercus*

[17] Lesquereux, Leo, Report on the fossil plants of the auriferous gravel deposits of the Sierra Nevada: Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 8, pl. 2, figs. 1, 2, 1878.

[18] Knowlton, F. H., Fossil flora of the John Day Basin, Oreg.: U. S. Geol. Survey Bull. 204, p. 49, pl. 6, figs. 6, 7, pl. 7: figs. 4, 5, 1902.

payettensis Knowlton[19] and *Quercus rustii* Knowlton[20] are, I believe, variants of the same botanic species. The leaves of the lobate species of oaks are always variable, and the Miocene forms of this series differ in relative width, number of lobes, and extent to which the lobes are incised or extended. It is also most improbable that there should have been so many Latah species of *Quercus*. I have not, however, made these suggested combinations in the present paper—first, because I do not wish to do any injustice to Knowlton's opinion, and, second, because if they represent a single botanic species, this can not be conclusively demonstrated, and their description and illustration serve to show the variations, which might be ignored if they were definitely considered one species.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Bigelow Gulch, near Hillyard, Wash.; Vera, Wash.; brickyard (very common) and Spokane, Portland & Seattle Railway cut No. 4, Spokane, Wash.

Quercus payettensis Knowlton

Quercus payettensis Knowlton, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 730, pl. 102, fig. 9, 1898; U. S. Geol. Survey Prof. Paper 140, p. 37, pl. 21, figs. 5–7, 1926.

As stated in the account of *Quercus cognatus*, this form is probably a variant of the same botanic species. It was described originally from the Payette formation of Idaho. It was recorded by Knowlton from the Latah formation at the Edwards ranch, Coeur d'Alene, Idaho What I regard as identical material occurs at two localities near Spokane.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Vera, Wash.; brickyard at Spokane, Wash. (10 specimens).

Quercus rustii Knowlton

Quercus rustii Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 21, figs. 3, 4, 1926.

As stated in my account of *Quercus cognatus* I regard the form to which Knowlton gave the name *Quercus rustii* as another variant of a single botanic species. Knowlton points out its affinity with what he called *Quercus payettensis* and *Quercus merriami*. It is not so common around Spokane as the other variants but occurs at two localities.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Vera, Wash.; brickyard at Spokane, Wash.

Quercus merriami Knowlton

Quercus merriami Knowlton, U. S. Geol. Survey Bull. 204, p. 49, pl. 6, figs. 6, 7; pl. 7, figs. 4, 5, 1902; U. S. Geol. Survey Prof. Paper 140, p. 35, pl. 19, figs. 4, 5, 1926.

This form represents leaves like *Quercus cognatus*, *Q. rustii*, and *Q. payettensis*, in which the lobes are extended and become narrowly conical and cuspidate, often bristle-tipped. Leaves with very slightly incised lobes have the same texture, venation, and tips, and these serve to connect the extremes represented by the nominal species named above. The present form occurs at several hitherto unrecorded outcrops around Spokane.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Chicago, Milwaukee & St. Paul Railway cut No. 2, brickyard, and Spokane, Portland & Seattle Railway cut, Spokane, Wash.

Quercus ursina Knowlton?

Quercus ursina Knowlton, U. S. Geol. Survey Bull. 204, p. 51, pl. 7, figs. 2, 3, 1902.

There are a few specimens from the brickyard at Spokane which, by their small size, obovate general outline, extended conical bristle-tipped lobes, with an accessory tooth, are indistinguishable from this species.

Quercus ursina has hitherto been known only from the Mascall formation of Oregon, where it is associated with *Quercus pseudolyrata* Lesquereux and *Quercus merriami* Knowlton—the former doubtfully and the latter positively identified by Knowlton in the Latah formation. *Quercus ursina* is probably an extreme variant of *Quercus merriami*.

Occurrence: Brickyard at Spokane, Wash.

Quercus simulata Knowlton, emended

Plate 51, Figures 6, 7, 9–11

Quercus simulata Knowlton, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 728, pl. 101, figs. 3, 4; pl. 102, figs. 1, 2, 1898; U. S. Geol. Survey Prof. Paper 140, p. 38, pl. 22, figs. 3, 4, 1926.

Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 168, pl. 12, fig. 1, 1920.

Salix elongata Knowlton [not O. Weber], U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, fig. 4, 1926.

Quercus chaneyi Knowlton, idem, p. 38, pl. 22, fig. 1, 1926.

Quercus praenigra Knowlton, idem, p. 37, pl. 19, fig. 6, 1926.

This species was described by Knowlton from the Payette formation of Idaho and was identified by the same author from the Latah formation and by Chaney from the Eagle Creek formation. I have recently detected it in the Esmeralda formation of Nevada.

There are a large number of specimens of a simple, prevailingly entire oak in the recent collections made around Spokane. These exhibit considerable variation in both size and form, ranging from narrowly to broadly lanceolate, with entire or sparingly toothed margins; the apex may be acuminate or bluntly pointed; the base ranges from narrowly cuneate to rounded, like the original Payette type and like the single Latah specimen which Knowlton described as *Quercus praenigra*. The similarity in texture and venation have convinced me that the citations in the above synonymy represent nothing more than the variants of a single Miocene species, comparable with

[19] Knowlton, F. H., The fossil plants of the Payette formation: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 730, pl. 102, fig. 9, 1898.

[20] Knowlton, F. H., Flora of the Latah formation of Spokane, Wash., and Coeur d'Alene, Idaho: U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 21, figs. 3, 4, 1926.

and showing less variation than such a recent species as *Quercus chrysolepis* Liebmann. The fossil is not especially close to the canyon live oak but is more like the recent *Quercus hypoleuca* Engelmann or our eastern willow oak, *Quercus phellos* Linné. Whatever the relationship between the fossil and recent species I am sure that anyone who has handled a series of specimens of the latter will agree that these Latah leaves represent a single botanic species.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Vera, Wash.; brickyard, Spokane, Portland & Seattle Railway cut, and Deep Creek Canyon, near Spokane, Wash.

Quercus treleasii Berry, n. sp.

Plate 52, Figures 1–3

Leaves of relatively small but variable size, ovate or subelliptical, somewhat narrowed distad to the obtusely pointed tip. Base rounded. Margins entire. Texture coriaceous. Length from 3.25 to 9 centimeters; maximum width from 1.5 to 3 centimeters. Petiole short and stout. Midvein stout and prominent. Secondaries stout, prominent; five to seven pairs diverge from the midvein at wide angles, pursue rather angular courses, and are camptodrome in the marginal region. The areolation consists of stout nervilles in a fine mesh.

These leaves, which are abundant, have the outline of several unrelated genera, but their venation and characteristic facies, easily seen but difficult to define, stamp them as belonging to *Quercus*. They are named for Prof. William Trelease, our most eminent student of the existing oaks.

Occurrence: Vera and brickyard at Spokane, Wash.

Quercus sp. Knowlton

Quercus, cup, Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 39, pl. 21, fig. 10, 1926.

A cupule of an oak from the Latah formation at Coeur d'Alene was figured by Knowlton. The recent collections contain many more or less crushed specimens, doubtless representing more than a single botanic species, but the preservation is such that no sharp differences can be made out.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash.

Order URTICALES

Family ULMACEAE

Genus ULMUS Linné

Ulmus speciosa Newberry

Ulmus speciosa Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 507, 1883; U. S. Geol. Survey Mon. 26, p. 80, pl. 45, figs. 3–4, 7 (not figs. 2, 5, 8), 1895 [1896].

Knowlton, U. S. Geol. Survey Bull. 204, p. 53, 1902; U. S. Geol. Survey Prof. Paper 140, p. 39, pl. 18, fig. 6, 1926.

Penhallow, Report on Tertiary plants of British Columbia p. 94, 1908.

Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 171, 1920.

Knowlton in his preliminary account of the Latah flora regards the large leaves (Newberry's figs. 3 and 4) as typical for this species. The smaller leaves described by Newberry are referred by Chaney [21] to his Eagle Creek species, *Ulmus tanneri*. Newberry's Figure 2 and *Quercus pseudoamericana* Lesquereux,[22] which Knowlton united with *Ulmus speciosa*, differ from the others in the very highly developed dimorphic teeth and are here excluded from that species.

Only one specimen of *Ulmus speciosa* was contained in the collections from the Latah formation studied by Knowlton, but it is abundant in the recent collections and occurs in all sizes and also exhibits great variations in marginal characters. Dentate and serrate teeth occur on the same leaf, and although there is a tendency for them to be simple they usually show some subordinate teeth, and individual specimens will have such teeth well developed.

The type came from the upper part of the Clarno formation of Oregon, and it is doubtfully recorded from supposed Oligocene beds in British Columbia and occurs also in the Eagle Creek formation of Oregon. It is associated in the Latah with *Ulmus* fruits which differ from any previously described.

Occurrence: Republic, Wash.; Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cuts Nos. 1 and 4, near Spokane, Wash.

Ulmus, fruit

Plate 51, Figure 1; Plate 64, Figures 3, 4

Fruit a samara, long stipitate, broadly lanceolate, with an acuminate decurrent base and a deeply cleft apex. Texture diaphanous, margin thickened. Finely reticulate veined. Length 1.5 to 2 centimeters; maximum width 6 to 8 millimeters; carpellary area 6 by 3, 4 by 4, 5 by 4, and 7 by 4 millimeters; the slender curved stipe 1 centimeter.

This very characteristic fruit is represented by six specimens, of which the most perfect are figured. In several specimens the rather large calyx is preserved about midway of the stipe.

Among existing American elms the one most similar to the fossils is the white elm, *Ulmus americana* Linné, a widely ranging species extending from Newfoundland to the eastern base of the Rocky Mountains and southward to Florida and Texas and reaching its maximum of size and abundance in the northern part of this range. The samaras of *Ulmus americana* are relatively wider, and the apical auricles are less produced.

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[21] Chaney, R. W., The flora of the Eagle Creek formation: Walker Mus. Contr., vol. 2, No. 5, p. 172, pl. 14, figs. 1, 2, 1920.

[22] Lesquereux, Leo, Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 249, pl. 54, fig. 10, 1883.

The present fruit very probably belongs to the same botanic species which is represented by leaves in the Latah formation. It is quite distinct from previously described *Ulmus* fruits. *Ulmus* with more than a score of existing species is widely distributed in the Northern Hemisphere except in western North America, reaching southward to the Sikkim Himalayas in Asia and to the mountains of southern Mexico in America. Despite its absence in the modern flora of western North America the genus is well represented throughout the Tertiary of that region and in the Miocene has four species in California and at Florissant, two in Oregon (Mascall formation), and one in the Yellowstone Park.

Occurrence: Brickyard at Spokane, Wash.

Family MORACEAE

Genus FICUS Linné

Ficus? washingtonensis Knowlton, emended

Plate 54, Figures 1–3; Plate 55, Figures 5, 6; Plate 62

Ficus? washingtonensis Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 40, pl. 25; pl. 26, figs. 1–3, 1926.

This species, as described by Knowlton, was based upon four incomplete specimens, only one of which came from the Spokane area, the other three coming from Coeur d'Alene, Idaho. In the recent collections there are a large number of specimens, several of which are complete—all of the same species, in my opinion, and some not to be distinguished from Knowlton's type. I am inclined to think that they represent the genus *Ficus*, and I agree with Knowlton that they are specifically distinct from *Ficus sordida* Lesquereux, of the California Miocene, although the two are closely related.

The present specimens greatly extend our conception of the species and show it to have been exceedingly variable in size and form. The petiole is long (over 4.5 centimeters) and exceedingly stout. The base may be rounded, truncate, or cuneate. The primaries in the narrower and more elongated forms are frequently three instead of five in number and sometimes diverge from above the base, although they are normally basal.

A large specimen (pl. 62), collected by E. E. Alexander after this manuscript was submitted for publication, still further widens its limits of variation. The specimen, which is nearly complete, indicates a length of 18 centimeters and a maximum width of 11.5 centimeters. About 2 centimeters of the long petiole is preserved, and this adds an unsuspected feature—that is, for a distance of about 1 centimeter immediately below the leaf it is conspicuously alate. The total maximum width of this lanceolate affair is 5 millimeters, of which two-thirds consists of marginal wings. An additional peculiarity is that the normal full rounded leaf margin on one side about two-thirds of the distance above the base is interrupted by an acute conical lobe subtending an open rounded sinus. There can be no question but that this specimen represents the same botanic species to which Knowlton first applied this name. The present specimen comes from the brickyard at Spokane.

A representative series of specimens, illustrating the variations, are figured herewith.

Occurrence: Republic, Wash.; Vera, Wash.; Spokane, Portland & Seattle Railway cut No. 1 and brickyard, Spokane, Wash.

Order PLATANALES

Family PLATANACEAE

Genus PLATANUS Linné

Platanus aspera Newberry

Platanus aspera Newberry, U. S. Nat. Mus. Proc., vol. 5, 1882, p. 509, 1883; U. S. Geol. Survey Mon. 35, p. 102, pl. 42, figs. 1–3; pl. 44, fig. 5; pl. 59, fig. 3, 1898.
Knowlton, U. S. Geol. Survey Bull. 204, p. 64, 1902.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 175, 1920.

This somewhat protean species was described by Newberry from the upper part of the Clarno formation at Bridge Creek, Oreg. It has also been recorded by Chaney from the Eagle Creek formation of Oregon. A single specimen in the Latah is unquestionably identical with the type in its long, stout petiole, numerous prominent marginal teeth, and closely spaced subparallel secondaries. A second specimen, less well preserved, from cut No. 1 also probably represents this species. It is very distinct from the associated leaves of *Platanus* and could not possibly represent a variant of any of these.

Occurrence: Spokane, Portland & Seattle Railway cuts No. 1 and 4, Spokane, Wash.

Platanus dissecta Lesquereux

Plate 53, Figures 1, 2; Plate 61

Platanus dissecta Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 13, pl. 7, fig. 12; pl. 10, figs. 4, 5, 1878; U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 249, pl. 56, fig. 4; pl. 57, figs. 1, 2, 1883.
Knowlton, in Smith, U. S. Geol. Survey Geol. Atlas, Folio 86 (Ellensburg, Wash.), p. 3, 1903.
Chaney, Carnegie Inst. Washington Pub. 349, p. 27, 1925.
Acer trilobatum productum (Al. Braun) Heer. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 253, pl. 59, fig. 3, 1883.

This species, described originally from the auriferous gravel (Miocene) of California and subsequently recorded from Ellensburg, Wash., was apparently a common element in the Latah flora, although no specimens were contained in the collections studied by Knowlton. *Platanus dissecta* Lesquereux does not differ appreciably from the leaves of the existing *Platanus racemosa* Nuttall, a large tree of the canyon bottoms and alluvial stream benches from Shasta County on the north to Lower California on the south and from the foothills of the southern Sierra Nevada to the coast. It has evidently retreated to streams with the progressive aridity of the region and must have undoubtedly enjoyed a less restricted range in its early history. It may be a descendant of the Miocene *Platanus dissecta*. Recently Chaney has recorded *Platanus dissecta* from the Mascall formation and from the Blue Mountains and Trout Creek in Oregon; from Ellensburg, Wash.; and from 49 camp, Nevada.

Occurrence: Deep Creek Canyon and Spokane, Portland & Seattle Railway cut near Spokane, Wash.

Platanus appendiculata Lesquereux?

Plate 52, Figure 5

Platanus appendiculata Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 12, pl. 3, figs. 1–6; pl. 6, fig. 7b, 1878.

This species, described by Lesquereux from Nevada and Placer Counties, Calif., was doubtfully recorded by Knowlton [23] from the Ione formation (upper Eocene) of that State.

A single incomplete specimen of a *Platanus* leaf from Republic, Wash., differs conspicuously from any other *Platanus* leaves found in the Latah and is referred to this species on account of the agreement in venation and the markedly decurrent perfoliate base.

Occurrence: Republic, Wash.

Order RANALES

Family MENISPERMACEAE

Genus MENISPERMITES Lesquereux

Menispermites latahensis Berry, n. sp.

Plate 52, Figure 4

Leaves of relatively small size, about as long as their maximum width, trilobate, with a wide central lobe and a pair of basal lateral lobes. Sinuses rounded, extending inward about halfway to the midvein. Margin with shallow, irregularly spaced dentate teeth, most prominent toward the tip of the central lobe and on the proximal side of the lateral lobes. Apex rounded. Tips of lateral lobes rounded, asymmetric. Base perfoliate. Texture thin. Length about 4.8 centimeters, maximum width, across lateral lobes, 5.25 centimeters. Primaries stout, diverging from the base at angles of about 45°, the laterals curving outward to the tips of the lateral lobes. Secondaries numerous, ascending, indifferently camptodrome or craspedodrome according as the margin at their extremities is entire or toothed. Areolation large, polygonal.

This characteristic species is clearly a member of the Menispermaceae and is not unlike some of the modern forms which American botanists refer to the genus *Cebatha* Forskal but which the Europeans generally include in the large genus *Cocculus* De Candolle. It is also similar to some of the forms referred to *Menispermum* Linné, which, as now restricted, includes an existing species in eastern North America and another in eastern Asia. In view of the uncertainty of the generic affinity I prefer to refer the fossil to the form genus *Menispermites*, proposed by Lesquereux to fit just such cases.

Leaves of this family are common in the Upper Cretaceous of western North America but are extremely rare in the Tertiary of that region. The present species is not only a link with the past but also a link between eastern Asia and eastern North America, where its descendants still survive.

Occurrence: Vera, Wash.; brickyard at Spokane, Wash.

Family MAGNOLIACEAE

Genus LIRIODENDRON Linné

Liriodendron hesperia Berry, n. sp.

Plate 51, Figures 2, 3

Carpels dry, ligneous, indehiscent; with a proximal laterally compressed pericarp and a distal ligneoscarious wing; broadly lanceolate, abruptly pointed distad. The wing has a conspicuous midvein, which is a continuation of the vertical angles of the pericarp, and two or three subparallel longitudinal veins from the base; these fork distad, as shown in the illustrations; the surface is transversely roughened between the veins, more prominently centrally. The roughened surface of an existing fruit does not show this clearly, but if comparison is made with a partly decayed modern fruit it is seen to have the same transverse knots of sclerotic tissue, exactly like that seen in the fossils. This species is based upon the two specimens figured, neither of which is entirely complete. The larger, which has a length of not quite 3 centimeters, of which one-third is pericarp, and a width of 7 millimeters, shows the inner side of a carpel in which the pericarp is somewhat distorted and flattened; the midvein is wider than on the opposite surface, and the specimen shows distinctly the more coriaceous tip. The smaller specimen, which lacks the apex, is an impression of the outer surface of a carpel; it has an estimated length of 2.5 centimeters and a maximum width of 5.5 millimeters; the impression of the pericarp is fusiform, 5.5 millimeters long and 2.5 millimeters in maximum width, deeply impressed in the clay matrix.

Of the two living species, *Liriodendron tulipifera* and *L. chinensis*, the fossil is most like the former, American form—in fact, the two can not be distinguished. The carpels of the Chinese species are readily differentiated from both.

These specimens are unique in the Cenozoic history of western North America. The genus *Liriodendron*, as is well known, attained a holarctic distribution during Upper Cretaceous time and is represented by

[23] Knowlton, F. H., in Turner, H. W., Auriferous gravels of the Sierra Nevada: Am. Geologist, vol. 15, p. 378, 1895.

numerous species in both eastern and western North America, the Arctic region, and Europe. No North American occurrences of Tertiary age have heretofore been recorded,[24] although fossil species of this age have been found in the Arctic region and as late as the Pliocene of Holland and France in Europe and the Altai region in Asia. The Holland occurrence is represented by carpels which have been referred to *Liriodendron tulipifera*. As the two existing and closely related living species are found in China and in southeastern North America, and as the genus was so abundantly represented all over North America during the Upper Cretaceous period, its apparent absence in the Tertiary deposits has been incomprehensible and its presence has been freely predicted. Its discovery in the Latah formation adds a most important mesophytic element to the Latah flora, and we may confidently expect the discovery of the foliage, for the carpels are absolutely characteristic.

The only other possible comparison is with the samaras of *Fraxinus*, and they are obviously so differently organized that I have not deemed it necessary to enumerate the contrasts.

Occurrence: Brickyard at Spokane, Wash.

Genus MAGNOLIA Linné

Magnolia californica Lesquereux

Magnolia californica Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 25, pl. 6, figs. 6, 7 (not fig. 5), 1878.

There are four more or less complete specimens in the Latah collections characteristic of this species, which has been recorded previously from the Miocene of California and Yellowstone Park and from the supposed Eocene of southwestern Oregon.

Occurrence: Vera, Wash.; brickyard, Deep Creek Canyon, and Spokane, Portland & Seattle Railway cut No. 1 at Spokane, Wash.

Magnolia dayana Cockerell

Magnolia lanceolata Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 24, pl. 6, fig. 4, 1878.
Knowlton, U. S. Geol. Survey Bull. 204, p. 58, 1900.
Magnolia dayana Cockerell, Am. Naturalist, vol. 44, p. 35, 1910.
Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 24, fig. 3, 1926.

There are in the Latah collections four specimens of this large *Magnolia* which are typical of this species. None are entirely complete, but some show the tip and others the base and indicate leaves about 24 centimeters long and 7 to 8 centimeters in maximum width.

The species has been recorded previously from the Miocene of California, the upper part of the Clarno formation of Oregon, the Ellensburg formation of Washington, and the supposed Eocene of southwestern Oregon.

Occurrence: Deep Creek Canyon and Spokane, Portland & Seattle Railway cut No. 1 at Spokane, Wash.

Order ROSALES

Family HAMAMELIDACEAE

Genus LIQUIDAMBAR Linné

Liquidambar californicum Lesquereux, emended

Liquidambar californicum Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 14, pl. 6, fig. 7c; pl. 7, figs. 3, 6, 1878.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 174, 1920.
Liquidambar europaeum Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 159, pl. 32, fig. 1, 1883.
Newberry, U. S. Geol. Survey Mon. 35, p. 100, pl. 47, figs. 1–3, 1898.
Knowlton, U. S. Geol. Survey Bull. 204, p. 62, 1902; U. S. Nat. Mus. Proc., vol. 17, p. 226, 1894; Geol. Soc. America Bull., vol. 5, p. 585, 1893.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 174, 1920.
Liquidambar protensum Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 13, pl. 8, fig. 3, 1888.
Knowlton, U. S. Geol. Survey Bull. 204, p. 62, 1902.
Liquidambar sp. Knowlton, in Lindgren, Jour. Geology, vol. 4, p. 890, 1896.
Liquidambar europaeum patulum Knowlton, U. S. Geol. Survey Bull. 204, p. 62, pl. 10, fig. 5, 1902.
Liquidambar europaeum Al. Braun. Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 14, 1888.
Liquidambar sp.? Knowlton, U. S. Geol. Survey Bull. 204, p. 63, pl. 12, fig. 4, 1902.
Liquidambar pachyphyllum Knowlton, U. S. Geol. Survey Bull. 204, p. 63, pl. 9, fig. 1, 1902; U. S. Geol. Survey Prof. Paper 140, p. 42, pl. 22, fig. 7; pl. 29, fig. 1, 1926.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 174, pl. 15, figs. 2, 3, 1920.
Liquidambar convexum Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 94, pl. 7, fig. 16, 1908.
Liquidambar acutilobum Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 175, pl. 15, fig. 4, 1920.

Knowlton recorded five different forms from the Mascall formation and Chaney four forms from the Eagle Creek formation. To anyone who has collected the leaves of our existing *Liquidambar styraciflua* Linné or who contemplates Heer's excellent figures of *Liquidambar europaeum* Al. Braun, from the Swiss Miocene, it must be obvious that there is the widest variation in size, degree of lobation, and relative proportions in the same species; somewhat less, but still considerable variation in texture; and less but still some variation in the marginal teeth and details of venation. When a variety of species, based on foliar features, are described from a single outcrop such a differentiation does violence to the facts. All the western American Miocene leaves of *Liquidambar* could readily be matched among the material of *Liquidambar europaeum* from the type locality at Oeningen, Baden, or they could equally well be matched among the leaves of our existing sweet gum, *Liquid-*

[24] A doubtful leaf fragment from the upper Eocene of British Columbia has been referred tentatively to *Liriodendron* (Berry, E. W., Canada Geol. Survey Bull. 42, p. 110, 1926); and Chaney (Walker Mus. Contr., vol. 2, No. 5, p. 173, pl. 14, fig. 4, 1920) has recorded a very doubtful fragment from the Eagle Creek formation.

ambar styraciflua. If it is reasonable to conclude that the existing American species has not come down unchanged since Tertiary time it is unreasonable to suppose that an identical Miocene species inhabited Europe and western North America.

If Braun's name is discarded for American forms the oldest available is *Liquidambar californicum* Lesquereux, which I consider includes all the nominal species that have been referred to this genus from the western American Miocene.

The material in the Latah formation, although not abundant, admirably illustrates the usual situation. Knowlton figured both three-lobed and five-lobed forms from the Latah formation as *Liquidambar pachyphyllum*. The present collection contains narrow acuminately lobed three-lobed leaves with a cuneate base and larger five-lobed leaves with broad lobes and a cordate base. The venation and the very characteristic margin are identical in both, and I have not the slightest doubt that all the Latah leaves represent a single species.

The species, as conceived by me, is found in California, Oregon, Washington, and Colorado. Undoubtedly the fine fruit from the Latah formation described by Knowlton [25] belongs to it. This, too, is not at all different from the fruits of our existing eastern American species.

Occurrence: Well near Mica, Wash.; cut No. 2 on Oregon-Washington Railroad & Navigation Co.'s line, Deep Creek Canyon, and brickyard, Spokane, Wash.

Family GROSSULARIACEAE

Genus RIBES Linné

Ribes fernquisti Berry, n. sp.

Plate 63, Figure 21

Leaves relatively small, trilobate. Margin, except at base and in the sinuses, with course dentate teeth. Texture subcoriaceous. Length about 5 centimeters, as is also the maximum width. Apical lobe about as broad as it is long, bluntly pointed at apex. Base of the leaf truncate. Sinuses narrow and not deep. Primaries three from the top of the petiole, stout and prominent. Secondaries stout, prominent, diverging from the primaries at acute angles. There are three or four subopposite to alternate secondaries in the central lobe, curved proximad and more straight distad, and craspedodrome. In the lateral lobes the basal secondary on the outside diverges close to the base and is relatively straighter and more prominent than its fellows and might be termed a subprimary. There is a secondary on the outside below the basal secondary on the inside, and the latter is much curved, ascending inside the sinus margin and ending camptodromely if the margin is entire and craspedodromely if it has ascended to a point where there is a tooth on the margin. The primaries, particularly the lateral ones, are slightly flexuous with respect to the alternate divergence of the secondaries. The Tertiary branches from the distal parts of the secondaries are well marked, and the ultimate ones are usually craspedodrome. Internal tertiaries are transverse and percurrent or inosculating in the middle region. The areolation is an open mesh that agrees precisely with that in leaves of existing members of the genus.

The species is named for the collector.

With the exception that some modern leaves of *Ribes* tend to have a cordate base, this Latah species shows all the foliar features of the genus, especially in the form of the teeth and in the position and disposition of the veins.

Ribes has not often been recognized in the fossil state. Two species have, however, been recorded from Florissant, Colo., but both of these are unlike the Latah form. There are over 60 existing species of *Ribes*, all shrubby, and widely distributed in the North Temperate Zone and in the Andes of South America. Fully 50 species are known from North America. There are 18 in the Recent flora of Washington—5 in the arid transition zone and a sixth in the Sonoran zone.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Family SAXIFRAGACEAE

Genus HYDRANGEA Linné

Hydrangea bendirei (Ward) Knowlton

Plate 52, Figure 7

Hydrangea bendirei Knowlton, in Merriam, California Univ. Dept. Geology Bull., vol. 2, p. 309, 1901.
Knowlton, U. S. Geol. Survey Bull. 204, p. 60, pl. 9, figs. 6, 7, 1902; U. S. Geol. Survey Prof. Paper 140, p. 42, pl. 24, fig. 6, 1926.
Marsilea bendirei Ward, U. S. Geol. Survey Fifth Ann. Rept., p. 446, 1885.
Porana bendirei (Ward) Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 16, pl. 8, fig. 4, 1888.

There are two specimens of this species in the recent collections. The one figured is complete and of special interest, because it has five fully developed sepals instead of the normal four, a feature not uncommon in existing species. There is considerable variability in this feature in the sterile flowers of existing hydrangeas, and the fossil is otherwise identical not only with the type but with the single specimen from the Latah formation described by Knowlton in 1926.

Occurrence: Spokane, Portland & Seattle Railway cut, Spokane, Wash.; Republic, Wash.

[25] Knowlton, F. H., Flora of the Latah formation of Spokane, Wash., and Coeur d'Alene, Idaho: U. S. Geol. Survey Prof. Paper 140, p. 42, pl. 10, fig. 10, 1926.

Family DRUPACEAE

Genus PRUNUS Linné

Prunus rustii Knowlton

Plate 55, Figure 1

Prunus rustii Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 43, pl. 24, figs. 4, 5, 1926.

This characteristic species, sparingly represented in the collections studied by Knowlton, is not uncommon in the later collections. A complete leaf is figured herewith.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Republic, Wash.; Deep Creek Canyon, brickyard, and Chicago, Milwaukee & St. Paul Railway cut, Spokane, Wash

Family ROSACEAE

Genus AMELANCHIER Medicus

Amelanchier scudderi Cockerell

Plate 55, Figure 4

Amelanchier scudderi Cockerell, Torrey Bot. Club Bull., vol. 33, p. 310, text fig. 4, 1906.

This species was based upon a single incomplete specimen from Florissant, so that whatever variation was present can not be determined. The complete leaves in the Latah formation are not exactly like the type but are so similar that I have no doubt that they represent the same botanic species. They are relatively slightly longer and narrower and consequently have more secondaries; the base is rounded like the tip instead of being broadly cuneate, and the teeth are more numerous. The Latah leaves may be described as follows:

Leaves almost orbicular, widest in the middle and about equally rounded at the apex and base. Midvein straight and fairly stout. Secondaries thin, seven or eight pairs, mostly simple, regularly curved and subparallel, rarely forked, camptodrome. Areolation typical of the genus. Lower margins entire, upper two-thirds with regular teeth. Teeth with a broad crenate-like base and an ultimate apiculate serration. Each tooth receives a short tertiary veinlet.

This is distinctly an *Amelanchier* and not a *Malus*. It is close to the leaves of the existing *Amelanchier alnifolia* Nuttall, from some of the leaves of which it is scarcely distinguishable. *Amelanchier alnifolia* is a tall shrub or small tree ranging from Alaska through the Coast Ranges to northern California and eastward to northern Michigan. It is found alike in moist valleys, meadows, and dry slopes but makes its best growth in the rich bottom lands of the lower Columbia River and the similar meadow lands around Puget Sound.

The genus is widely distributed throughout the north temperate zone. It is abundant at Florissant, with three species, but is otherwise unknown in the Pacific slope Miocene.

Occurrence: Brickyard at Spokane, Wash.

Genus CERCOCARPUS Humboldt, Bonpland, and Kunth

Cercocarpus praeledifolius Berry, n. sp.

Plate 64, Figure 7

Leaves small, lanceloate, petiolate, widest medianly and about equally tapering to the pointed apex and slightly decurrent base. Texture coriaceous. Margins slightly irregular, involute. Length about 1 centimeter or slightly more; maximum width 3 to 4 millimeters. Petiole stout, about 1.5 millimeters long. Midvein stout, prominent. Secondaries stout, ascending, closely spaced, craspedodrome.

This characteristic little leaf is especially like those of the existing *Cercocarpus ledifolius* Nuttall, which is prevailingly a shrubby form of poor soils ranging from western Wyoming to Montana, Idaho (Coeur d'Alene Mountains), and Oregon (eastern Blue Mountains) and southward through the Great Basin and Wasatch Ranges to the eastern slopes of the Sierra Nevada and northern slopes of the San Bernardino Mountains, northern New Mexico and Arizona. Although commonly an arid type in chaparral, it reaches its largest size in moist richer soils, as on the hills of central Nevada.

The genus contains about six species confined to western North America and Mexico. Several fossil species have been described, including one, *Cercocarpus antiquus* Lesquereux,[26] from the supposed Miocene of California. This is much larger than the Latah species and more like the existing *Cercocarpus parvifolius* Nuttall.

Occurrence: Brickyard at Spokane, Wash.

Family CAESALPINIACEAE

Genus CASSIA Linné

Cassia idahoensis Knowlton

Plate 55, Figures 2, 3

Cassia obtusa Knowlton, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 731, pl. 100, figs. 4, 5, 1898 [not Clos, 1845].

Cassia idahoensis Knowlton, U. S. Geol. Survey Bull. 696, p. 146, 1919.

This species was described in 1898 from the Payette formation at Marsh, Idaho, to which it has hitherto been confined. There are three specimens from the Latah formation which are identical with the type in all their features except that they are larger.

Occurrence: Vera, Wash.; brickyard and Spokane, Portland & Seattle Railway cut, Spokane, Wash.

[26] Lesquereux, Leo, Report on the fossil plants of the auriferous gravel deposits of the Sierra Nevada: Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 37, pl. 10, figs. 6-11, 1878.

Cassia sophoroides (Knowlton) Berry

Plate 56, Figure 1

Phyllites sophoroides Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 48, pl. 26, fig. 8, 1926.

The single imperfect specimen of this species from the Edwards ranch, Stanley Hill, Coeur d'Alene, Idaho, was referred by Knowlton to the form genus *Phyllites*, although its leguminous character was recognized. These leaflets are inequilateral throughout; the petiolule is stout and about 3 millimeters long; the tip is usually slightly more extended than in Knowlton's type.

Although the features of these leaflets are shared by a large number of genera of the leguminous alliance, they conform to that found in many species of *Cassia*, both recent and fossil, and as this genus is one more likely to occur in this strictly temperate flora than tropical genera with similar leaflets, I have transferred them to *Cassia*.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; Spokane, Portland & Seattle Railway cut No. 4 and brickyard at Spokane, Wash.

Cassia spokanensis Berry, n. sp.

Plate 63, Figure 18

This is superficially like *Carpites paulownia* Knowlton,[27] of the Latah flora, but is clearly an altogether different object. The leguminous genera whose foliage has been recognized are *Cassia*, *Cercis*, *Sophora*, and *Leguminosites*. The last is a form genus, and both *Cercis* and *Sophora* have radically different pods, leaving only *Cassia*, and it is to *Cassia* that I have referred numerous similar pods from the Eocene of southeastern North America and various localities in South America.

Pod compressed, nearly equilateral in its oval profile, rapidly narrowed to the rounded tip and similarly narrowed to the stout stipitate portion above the calyx. Texture coriaceous and apparently indehiscent. Obviously single or few seeded. Length 4.3 centimeters; maximum width 2.4 centimeters. The stout stipitate basal portion included in the length as given above is 7 millimeters long and 2 millimeters wide. Placental margin conspicuously thickened.

Occurrence: Brickyard at Spokane, Wash.

Family PAPILIONACEAE

Genus SOPHORA Linné

Sophora spokanensis Knowlton

Plate 56, Figures 5, 6

Sophora spokanensis Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 44, pl. 28, fig. 6, 1926.

This species was described from a single fragment of a leaflet. It is not uncommon in the recent collections from the Latah formation and may be more completely characterized as follows:

Leaflets showing considerable variation in size and outline, even on a single leaf; varying from elongate-elliptical to ovate-lanceolate; generally widest medially but sometimes in the lower half. Apex narrowly to broadly rounded and nearly equilateral. Base broadly rounded, inequilateral. Petiolule short and stout, 2 millimeters or less in length. Midvein stout, prominent. Secondaries thin, somewhat irregularly spaced, diverging from the midvein at angles of 45° or less, camptodrome. Length from 2.5 to 4.5 centimeters; a single terminal leaflet, obviously undeveloped, is 1.5 centimeters long and about 4 millimeters in maximum width.

One specimen shows part of a leaf with eight leaflets in position; these increase in size and relative width as well as spacing from the tip toward the base. The leaf is odd-pinnate, thus conforming to the arrangement in *Sophora*. I much doubt its reference to *Sophora*, however, and it appears to me to be more probably referable to *Robinia*, which has similar, odd-pinnate leaves. It is not greatly different, except for its larger size, from *Robinia brittoni* Cockerell,[28] from Florissant, Colo. I have not, however, changed the generic reference, preferring to wait for certainty before making the change.

Occurrence: Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash.

Sophora alexanderi Knowlton

Plate 56, Figures 2, 3

Sophora alexanderi Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 43, pl. 28, figs. 3–5, 1926.

This fine species is not uncommon in the Latah formation but thus far has been found only as detached leaflets. The numerous specimens in the recent collections are all confined to one locality.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; brickyard, Spokane, Wash.

Genus MEIBOMITES Knowlton

Meibomites knowltoni Berry, n. sp.

Plate 56, Figure 7

Leaflet rhomboidal, somewhat inequilateral, with a broadly cuneate pointed tip and a rounded base. Margins strictly entire. Texture of considerable consistency. Length about 6 centimeters; maximum width, midway between the apex and the base, about 4 centimeters. Petiolule short and stout, barely a millimeter in length. Midvein stout and prominent. Secondaries thin, three camptodrome pairs; the base pair are from the extreme base of the midvein, opposite, thickened, diverging at acute angles, ascending in such a way as to appear like lateral primaries, camptodrome.

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[27] Knowlton, F. H., Flora of the Latah formation of Spokane, Wash., and Coeur d'Alene, Idaho: U. S. Geol. Survey Prof. Paper 140, p. 50, pl. 29, fig. 12, 1926.

[28] Cockerell, T. D. A., Descriptions of Tertiary plants: Am. Jour. Sci., 4th ser., vol. 26, p. 543, fig. 8, 1908.

This species is unfortunately represented only by the single specimen figured. The venation is typically leguminous, and the species may be a variant of *Meibomites lucens* Knowlton of the Latah formation or a terminal leaflet of which Knowlton's specimen was a lateral leaflet, as certain similar existing species of *Meibomia* have the terminal leaflet apparently triveined and the laterals pinnately veined, as in the species *M. nudiflora* (Linné) Kuntze, *M. grandiflora* (Walter) Kuntze, and others.

The present fossil shows considerable resemblance to what Cockerell described from Florissant as *Philadelphus palaeophilus*,[29] but that species is smaller and toothed distad.

The genus *Meibomia* Adanson (*Desmodium* Desvaux) contains more than 200 existing species of perennial herbs, some of them woody at the base, widely distributed in North and South America, Africa, and Australia.

Occurrence: Brickyard at Spokane, Wash.

Genus LEGUMINOSITES Bowerbank

Leguminosites bonseri Berry, n. sp.

Plate 56, Figure 4

Leaflets small, sessile, ovate-lanceolate and somewhat falcate, inequilateral, widest below the middle. Tip pointed, apiculate. Base markedly unsymmetrical, full and rounded on one side, pointed on the other. Margins entire. Texture relatively coriaceous. Midvein stout and prominent, curved. Secondaries relatively stout, about five pairs, diverging from the midvein at wide angles, camptodrome.

I am quite uncertain regarding the botanic affinity of these small leaflets. The four specimens in the collection are all from one locality, and all suggest that they might be small abnormal leaflets of some plant whose normal foliage was somewhat different.

Occurrence: Brickyard at Spokane, Wash.

Leguminosites alexanderi Berry, n. sp.

Plate 63, Figure 16

Pod (or follicle) of small size, unsymmetrically ovate, compressed, upper margin full, lower margin straighter. Apex missing. Stipe stout, about 3 millimeters long. Pod 1.2 centimeters long by 6 millimeters in maximum diameter. Substance of considerable consistency, with an open polygonal areolation. Evidently few or single seeded. Named for the collector.

This small pod is unlike any previously known from the Miocene. It seems obviously referable to the leguminous alliance, but its generic reference is uncertain.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander.

[29] Cockerell, T. D. A., The fossil flora of Florissant, Colo.: Am. Mus. Nat. Hist. Bull., vol. 24, p. 92, pl. 10, fig. 37, 1908.

Order SAPINDALES

Family SAPINDACEAE

Genus SAPINDUS Linné

Sapindus spokanensis Berry, n. name

Sapindus angustifolius Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 415, 1874; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 265, pl. 49, figs. 2–7, 1878.

Knowlton, U. S. Geol. Survey Bull. 204, p. 79, 1902 [not Blume].

The name *Sapindus angustifolius* was proposed by Lesquereux for the leaflets of *Sapindus* from Florissant, Colo. The species was subsequently recorded from the Fort Union formation of Montana and from the Mascall formation of Oregon. As conceived by Lesquereux it had wide limits, and at least two of its variants have been referred to new species by Cockerell.[30] The leaflets of *Sapindus* show a great variability and much convergence, and it may well be that fossil species have been unduly multiplied. Leaflets agreeing with Lesquereux's type material are sparingly represented in the Latah formation. *Phyllites crustacea* Knowlton,[31] from the Latah formation at Mica, may represent a leaflet of this species.

Occurrence: Brickyard at Spokane, Wash.

Sapindus armstrongi Berry, n. sp.

Plate 63, Figure 14

Leaflets relatively small, ovate, inequilateral. Tip acute. Base prolonged downward from the narrower side of the lamina about 2 millimeters below the base on the wider side of the lamina. Petiolule stout, curved, about 2 millimeters long. Margins entire, evenly rounded. Texture subcoriaceous. Length about 5.5 centimeters; maximum width about 2 centimeters. Midvein stout, prominent. Secondaries stout, about nine pairs, diverging from the midvein at wide angles and camptodrome in the marginal region. Tertiaries well marked, variably subpercurrent. Areolation of very fine subquadrangular meshes.

This apparently represents a new species, one that is uncommon in the present collections. It is named for L. K. Armstrong, president of the Northwest Science Association.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander.

[30] Cockerell, T. D. A., The fossil flora of Florissant, Colo.: Am. Mus. Nat. Hist. Bull., vol. 24, p. 101, 1908.

[31] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 140, p. 47, pl. 29, fig. 6, 1926.

Family CELASTRACEAE

Genus CELASTRUS Linné

Celastrus lacoei Lesquereux

Celastrus lacoei Lesquereux, Cretaceous and Tertiary floras, p. 184, 1883.
Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 281, pl. 24, fig. 6, 1916.

This species, which was described from Florissant, Colo., is represented by a single complete specimen in the recent collections from the Latah formation. The spatulate form, toothed margin, size, and venation are absolutely characteristic.

Occurrence: Brickyard at Spokane, Wash.

Celastrus spokanensis Berry, n. sp.

Plate 64, Figure 5

Leaves relatively small, obovate or broadly spatulate with a widely rounded tip and a decurrent base, about 3.5 centimeters long and 2 centimeters in maximum width. Leaf substance thin but apparently stiff. Margins with extremely fine, closely spaced serrate teeth. Petiole broad, with several parallel vascular strands. Midvein relatively broad but not especially prominent. Secondaries thin, numerous, diverging from the midvein at acute angles in a somewhat flabellate manner, ascending, sometimes forked and inosculating, not craspedodrome but sending branches to the marginal teeth. Tertiaries not made out.

In general appearance this leaf suggests, at first sight, the family Rosaceae, especially the crus-galli section of *Crataegus*. It is also not dissimilar from *Crataegus teutonica* described by Unger from the Miocene of Parschlug in Styria. The details of the venation, however, appear to me to be more like that characteristic of the family Celastraceae, as exemplified in the genus *Maytenus* or in numerous exotic existing species of *Celastrus* such as *trigynus*, *senegalensis*, *nutans*, and *nemorosus*.

There are species of *Celastrus* in the Miocene of the Mascall formation of Oregon, the Payette formation of Idaho, and two at Florissant, Colo., but these are all markedly distinct from the Latah species.

Occurrence: Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash., collected by C. O. Fernquist.

Genus EUONYMUS Linné

Euonymus knowltoni Berry, n. sp.

Plate 56, Figure 9

Leaves of medium size, ovate-lanceolate. Tip acuminate, not greatly produced. Base broadly cuneate. Texture subcoriaceous. Margin with fine, closely spaced, inconspicuous serrate teeth. Length about 11 centimeters; maximum width, near the middle of the leaf, about 3.5 centimeters. Petiole not preserved. Midvein stout and prominent. Secondaries thin, five or six irregularly spaced pairs; diverging from the midvein at angles of about 45°; more in the tip; sweeping upward in long ascending curves and arching along the margins. Tertiaries thin, typical of the Celastraceae, and exactly matched in the genus *Euonymus*.

This characteristic form is not common in the collections, but this is probably without significance. The genus makes its appearance in the basal Eocene but has heretofore been unknown in American post-Eocene deposits, although common in European deposits of later Tertiary age and present in the existing flora of North America, in which there are about five temperate species and five or six additional in Central America.

The existing species number about 65 and are widely distributed throughout the Northern Hemisphere but massed in the southeastern Asiatic region. Two survive as shrubs in the moister parts of the Pacific coastal region.

Occurrence: Brickyard at Spokane, Wash.

Family ACERACEAE

Genus ACER Linné

Acer oregonianum Knowlton

Plate 57, Figure 2; Plate 63, Figure 11

Acer oregonianum Knowlton, U. S. Geol. Survey Bull. 204, p 75, pl. 13, figs. 5–8, 1902.

In addition to leaves of maple there are seven fruits contained in the recent collections from the Latah formation representing four localities. These are all of a single species and are indistinguishable from *Acer oregonianum*, of the Mascall formation of Oregon, and quite unlike the other three nominal species of *Acer* fruits which Knowlton described from the Mascall.

Knowlton compared *Acer oregonianum* with the fruits of the existing *Acer macrophyllum* Pursh, which they much resemble. They are somewhat smaller than these and about equally like the existing *Acer circinatum* Pursh. Both these modern species are abundant stream-bank and rich-bottom species of British Columbia, Washington, Oregon, and California—regions of deep moist soil and abundant precipitation. Over 15 species of *Acer* have been described from the Miocene of the Pacific slope of North America, but there is a certain duplication in the unavoidable practice of giving different names to the leaves and fruits. The genus is common at Florissant, Colo., and in the California, Mascall, and Eagle Creek Miocene. It has recently been reported by Chaney from Trout Creek, Oregon, and 49 camp, Nevada.[31a]

[31a] In an account of the flora of the Crooked River Basin of Oregon published since this paper was written (Chaney, R. W., Carnegie Inst. Washington Pub. 346, p. 126, 1927), Chaney refers fruits identical with those from the John Day Basin described by Knowlton as *Acer oregonianum* to *Acer osmonti*, without, however, mentioning Knowlton's specimens. Although it is probable that the fruits and leaves described as *Acer osmonti* belong to the same species, such practices are to be deprecated in the absence of direct proof of relationship.

Occurrence: Republic, Wash.; Deep Creek Canyon, brickyard, and Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash.

Acer chaneyi Knowlton

Plate 63, Figure 13

Acer chaneyi Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 27, fig. 2, 1926.

This species was described from the single specimen figured, which was fairly complete but lacked the terminal lobe. This deficiency I am able to supply from a recent specimen collected by E. E. Alexander.

The species is a handsome one with long, slender, much cut lobes and appears to be very similar to if not identical with *Acer osmonti* Knowlton,[31b] described from the beds at Bridge Creek, in the John Day Basin, and recently recorded by Chaney [31c] from the Crooked River Basin in Oregon.

Occurrence: Brickyard at Spokane, Wash.

Acer merriami Knowlton

Acer merriami Knowlton, U. S. Geol. Survey Bull. 204, p. 76, pl. 14, figs. 2, 3, 1902; U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 28, fig. 1, 1926.

A fragmentary specimen and its counterpart are contained in the present collection from the locality south of Vera. Knowlton's Latah material came from a well at Mica.

Occurrence: Well at Mica, Wash.; south of Vera, Wash.

Acer bendirei Lesquereux

Acer bendirei Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 14, pl. 5, 1888.

Knowlton, U. S. Geol. Survey Bull. 204, p. 73, 1902; U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 27, fig. 3, 1926.

There are two specimens of this species in the recent collections. It occurs also in the Miocene of Oregon (Mascall formation) and California. Knowlton's Latah specimen was obtained from a well at Mica.

Occurrence: Well at Mica, Wash.; brickyard and Spokane, Portland & Seattle Railway cut No. 1, Spokane, Wash.

Acer minor Knowlton

Plate 64, Figure 2

Acer minor Knowlton, U. S. Geol. Survey Bull. 204, p. 76, pl. 14, figs. 2, 3, 1902; U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 27, fig. 4, 1926.

This species was described originally by Knowlton from the Mascall formation of the John Day Basin, Oregon, and was one of three species of fruits founded largely on differences of size. A very imperfect specimen from the Latah formation at Deep Creek, northwest of Spokane, was referred to this species in 1926 by Knowlton, who remarks that maples seem to be rare in the Spokane area. Subsequent collections in this area show this not to have been the case, as both leaves and fruits are not at all uncommon. Presumably the present fruit represents one of the leaf species. One other type of maple fruit has been described from the Latah formation in the present work and identified as *Acer oregonianum* Knowlton. The latter is three to four times the size of *Acer minor*, with more spreading wings and has less oval seed cavities. I have no doubt that the two represent different species and not merely differences in size and form of a single species.

The present specimen was collected recently by C. O. Fernquist and shows the complete fruit but lacks the peduncle. The seed cavities are relatively wide, and the base of the wings is incurved so that the wing axes are parallel. The whole is but 11 millimeters long and 7 millimeters wide. It adds another common element to the floras of the Mascall and Latah formations.

Occurrence: Deep Creek Canyon and brickyard, Spokane, Wash.

[31b] Knowlton, F. H., U. S. Geol. Survey Bull. 204, p. 72, pl. 13, fig. 3, 1902.
[31c] Chaney, R. W., op. cit., p. 126, pl. 17, fig. 6; pl. 18, figs. 1, 3, 5, 1927.

Family ANACARDIACEAE

Genus RHUS Linné

Rhus merrilli Chaney

Plate 51, Figure 8

Rhus merrilli Chaney, Carnegie Inst. Washington Pub. 346, p. 125, pl. 16, figs. 1, 2, 1927.

This new species, described since the major portion of this paper was written, is represented in the Latah flora by several specimens which I had supposed were variants of *Quercus simulata* Knowlton. The type came from the Bridge Creek formation of the Crooked River basin in eastern Oregon, and is said to bear a close resemblance to *Rhus sylvestris* Siebold and Zuccarini of central and southern China and Chosen; it is thus another link in the community of relationship between the present Chinese flora and the Miocene flora of western North America.

Occurrence: Brickyard at Spokane, Wash.

Family HIPPOCASTANACEAE

Genus AESCULUS Linné

Aesculus hesperia Berry, n. sp.

Plate 56, Figure 8

Leaflets large, obovate in general outline. Apex abruptly pointed. Base narrowly cuneate. Margins throughout with closely spaced serrate teeth, which become more prominent and aquiline or couchant-serrate distad. Length 18 centimeters; maximum width 8 centimeters. Midvein stout, prominent on the under side of the leaflet, slightly flexuous. Secondaries stout, prominent; about ten opposite to alternate, irregularly spaced pairs; the lower four or five pairs diverged from the midvein at angles of 45° or less, are straight or flexuous ascending, eventually camptodrome but sending off on the outside numerous regular tertiaries, the distal craspedodrome, the proximal camptodrome and sending off regular craspedodrome veinlets to the marginal teeth; the distal secondaries diverge at wider angles, 45° or more, are more curved than the proximal ones, and likewise send branches of the second or third order to the marginal teeth. The internal tertiaries are prominent, regularly spaced, generally simple percurrent but occasionally forked.

This striking species is unfortunately represented only by the single specimen figured. It has the characters of this genus well marked and is quite unlike the other American Miocene species, which comprise a smaller form from the Mascall formation of Oregon and an undescribed species from the auriferous gravel of California.

Aesculus has about a dozen existing species and is represented in the warmer temperate parts of all the holarctic continents. Among these a single form, usually a small tree, survives on the Pacific slope, where it has become restricted to the wetter valleys and stream borders in California.

Occurrence: Spokane, Portland & Seattle Railway cut, Spokane, Wash.

Order RHAMNALES

Family RHAMNACEAE

Genus PALIURUS Jussieu

Paliurus hesperius Berry

Plate 57, Figure 1

Paliurus hesperius Berry, Am. Jour. Sci., 5th ser., vol. 16, p. 40, figs. 1–3, 1928.

Leaves of medium size, broadly ovate, widest below the middle; the apex pointed but not extended; base broadly rounded or slightly cordate. Texture subcoriaceous. Margins with closely spaced, prevailingly small, crenate teeth. Length about 7 centimeters; maximum width about 4.5 centimeters. Petiole not preserved. Midvein stout, prominent. Lateral primaries diverge from the base at acute angles; these are as stout as the midvein and curve upward and barely escape being acrodrome by uniting with short secondaries from the distal part of the midvein. The lateral primaries give off on the outside several camptodrome secondaries. The areolation is a fine mesh indistinctly preserved.

Leaves of this type have been referred to *Zizyphus*, *Grewiopsis*, and *Populus*, but their features are more distinctly those of *Paliurus*.

The genus is represented in existing floras by only two or three species of southern Europe and Asia and is no longer a native of the Western Hemisphere. About 30 fossil species have been described, based for the most part upon leaves. The oldest of these occur in the North American Upper Cretaceous. The fruits are perfectly characteristic, and the oldest known instance of their occurrence is *Paliurus mississippiensis* Berry,[32] of the lower Eocene in southwestern North America. Lesquereux [33] identified a leaf of somewhat dubious characteristics as a species of *Paliurus* from the Miocene of Florissant, Colo.

My reasons for referring the present form to *Paliurus* rather than to *Rhamnus* or *Ceanothus* is its perfect agreement with the existing Asiatic *Paliurus orientalis* and the presence of characteristic *Paliurus* fruits in beds of approximately the same age as the Latah formation at Grand Coulee, Douglas County, Wash.

Occurrence: Spokane, Wash.

Genus RHAMNUS Linné

Rhamnus spokanensis Berry, n. sp.

Plate 57, Figures 4, 5

Robinia? sp., Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 44, pl. 28, figs. 7, 7a, 1926.

Additional material enables me to assign the correct botanic position to the small leaf which Knowlton tentatively referred to the genus *Robinia*. This was not a leaflet of a pinnate leaf but a complete leaf, the venation of which is entirely unlike that of *Robinia* and, on the other hand, characteristic of the genus *Rhamnus*. It may be described as follows:

Leaves of variable but small size, inequilaterally elliptical, with a rounded or subcordate decurrent base and a slightly narrowed rounded or bluntly pointed apex. Margins entire, sometimes slightly undulate. Texture subcoriaceous. Length ranging from 1.5 to 3.75 centimeters; maximum width, in median region, from 9 millimeters to 1.6 centimeters. Petiole stout, enlarging proximad, curved, about 5 millimeters long in the largest leaf seen. Midvein relatively very stout, somewhat flexuous curved proximad. Secondaries five or six pairs, relatively stout, at least two pairs diverging at acute angles from the top of the petiole, occasionally forking, eventually ascending subparallel with the lateral margins, along which they arch. The more distal secondaries are less straight than the basals, irregularly spaced, and ascending. The tertiaries are well marked, simple or inosculating, percurrent.

The genus *Rhamnus*, with about 60 existing species, is found in all temperate regions except Australia and

[32] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 279, pl. 71, fig. 4, 1916.

[33] Lesquereux, Leo, The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 188, pl. 38, fig. 12, 1883.

the islands of the Pacific. There are two species and as many varieties living on the Pacific slope, but these are quite different from the present fossil, which is also markedly distinct from previously described Miocene forms, of which there are four at Florissant and in Yellowstone Park.

The present species, except for its more rounded tip, is very much like the late Miocene *Rhamnus oeningensis* Heer, of Europe.

Occurrence: Spokane, Portland & Seattle Railway cut and brickyard at Spokane, Wash.

Order MALVALES

Family TILIACEAE

Genus TILIA Linné

Tilia hesperia Berry, n. sp.

Plate 57, Figure 3

Leaves large, broadly ovate and inequilateral, of thin texture, about 15 or 16 centimeters in length and 9 centimeters in maximum width below the middle. Apex acuminate. Base missing. Midvein stout and relatively straight. Secondaries stout, about six alternate pairs, diverging about 45°, curving upward, craspedodrome, giving off one or more craspedodrome branches on the outside toward their tips. The basal pair are not differentiated from their fellows except for the series of craspedodrome tertiaries which they give off on the outside. The inner tertiaries are regularly spaced subpercurrent, frequently inosculating veins of considerable caliber. The margin is regularly serrate, with relatively small teeth.

This leaf is about the size of the larger leaves of the existing Tilias of southeastern North America, from which it differs primarily in its somewhat less relative width and more produced tip. The only western Tertiary species known to me, *Tilia populifolia* Lesquereux, from Florissant, is similar except that the basal secondaries are differentiated as lateral primaries. A second Miocene species, *Tilia pedunculata* Chaney,[34] is based upon a fruit bract of a linden from the Eagle Creek formation of Oregon. As no foliage was discovered in the Eagle Creek formation, it is possible that this fruit bract may represent the botanic species of which *Tilia hesperia* is the foliage.

The genus *Tilia* is found at the present time widely distributed in the humid north temperate zone except in western America, central Asia, and the Himalayan region.

Occurrence: Spokane, Portland & Seattle Railway cut at Spokane, Wash.

[34] Chaney, R. W., The flora of the Eagle Creek formation: Walker Mus. Contr., vol. 2, No. 5, p. 179, pl. 19, figs. 3, 4, 1920.

Family MALVACEAE

Genus HIBISCUS? Linné

Hibiscus? occidentalis Berry, n. sp.

Plate 64, Figures 13–15

Carpels small, compressed, ovate, broadly rounded distad, asymmetrically contracted proximad. Embryo nearly straight. Carpel wall finely netted, veined, with scarious margin about 1 millimeter wide, radially veined. Length about 6 millimeters; maximum width about 3 millimeters.

These objects are not uncommon in the Latah formation and appear to be definitely referable to the Malvaceae and probably to the genus *Hibiscus*.

That genus, heretofore unknown in the fossil state, so far as I am aware, comprises nearly 200 recent species, widely distributed in warm and temperate regions.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist and E. E. Alexander.

Order PARIETALES

Family TERNSTROEMIACEAE

Genus TERNSTROEMITES Berry

Ternstroemites idahoensis (Knowlton) Berry

Plate 58, Figure 1

Myrica? idahoensis Knowlton, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 724, pl. 99, fig. 7, 1898; U. S. Geol. Survey Bull. 696, p. 395, 1919.

This species was described from the Payette formation of Idaho and doubtfully referred to the genus *Myrica* by Knowlton. If the type had shown the venation it would have been obvious that this form was not related to *Myrica*. Characteristic leaves are present in the Latah formation. These vary in length from 6 to 10 centimeters and in maximum width from 1.7 to 2.6 centimeters. The midvein becomes characteristically thickened and prominent in the lower half of the leaf. The marginal teeth show some variation in size and are obsolete below. The secondaries are largely immersed, about eight camptodrome pairs.

This leaf is clearly referable to the Ternstroemiaceae (Theaceae), which are so common in the early Tertiary of southeastern North America and in the existing floras of southern and eastern Asia and tropical America. It seems probable that the present fossil species represents either *Stuartia* Linné or *Gordonia* Linné, the only two surviving genera in temperate North America, both of which are represented in eastern North America and eastern Asia, but I prefer to refer it to the form genus *Ternstroemites*, although it is exceedingly like the leaves of *Gordonia*.

Occurrence: Brickyard at Spokane, Wash.

Order LAURALES

Family LAURACEAE

Genus LAURUS of authors

Laurus princeps Heer

Plate 58, Figure 5

Laurus princeps Heer, Flora tertiaria Helvetiae, Band 2, p. 77, pl. 89, figs. 16, 17; pl. 90, figs. 17, 20, 1856.
Lesquereux, Cretaceous and Tertiary floras, p. 250, pl. 58, fig. 2, 1883.
Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 725, pl. 95, fig. 3, 1899.
Laurus grandis Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 23, figs. 1-3, 1926.

The type came from the European Miocene, and the propriety of considering a western American form as identical with it is highly questionable.

The species occurs in the auriferous gravel of California and probably in the Miocene of Yellowstone Park.

Occurrence: Bigelow Gulch, near Hillyard, Wash.; brickyard and Spokane, Portland & Seattle Railway cut, Spokane, Wash.; cut 1 mile west of Shelley Lake, 10 miles east of Spokane, Wash.

Laurus grandis Lesquereux

Plate 58, Figure 3

Laurus grandis Lesquereux, Cretaceous and Tertiary floras, p. 251, pl. 58, figs. 1, 3, 1883.
Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 725, pl. 93, fig. 3; pl. 95, fig. 1, 1899.

This species, which is recorded from California and Yellowstone Park, is represented by several specimens from the Latah formation, of which one of the more complete is figured.

Occurrence: Brickyard and Spokane, Portland & Seattle Railway cut, Spokane, Wash.

Laurus similis Knowlton

Plate 58, Figure 2

Laurus similis Knowlton, U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 48, pl. 5, figs. 1–4, 1900.
Chaney, Walker Mus. Contr., vol. 2, No. 5, p. 173, 1920.
Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 23, figs. 4–6; pl. 24, fig. 2, 1926.

As may be gathered from the previously figured material, this species, as conceived by its describer, exhibits considerable variability. It was originally described from the west side of the Cascade Range in Oregon and subsequently recorded by Chaney from the Eagle Creek formation. It proves to be abundant in the Latah formation, Knowlton having recorded it from several localities, and several additional are represented in the recent collections. One medium-sized specimen shows the complete petiole, which is stout, expanding proximad to the stout base, and 3.5 centimeters long.

Occurrence: Deep Creek, Bigelow Gulch near Hillyard, Vera, Chicago, Milwaukee & St. Paul Railway cut, brickyard, and Spokane, Portland & Seattle Railway cut, all near Spokane, Wash.

Genus SASSAFRAS Nees

Sassafras hesperia Berry, n. sp.

Plate 59, Figure 2

This species is based upon the single leaf figured, which can not be expected to portray the foliage accurately. However, the leaf variations of the recent and fossil species have been so exhaustively studied that it is not difficult to surmise the limits of variation in the leaves of this Miocene species. The type may be described as follows:

Leaf of medium size and texture, oval in general outline, divided by a relatively narrow but rounded sinus, which extends about one-third of the distance to the base, into a broad, round-margined, bluntly pointed terminal lobe and a more pointed, subconical, lateral lobe. The base is broadly cuneate. The margins are entire but slightly undulate, and there is a slight emargination midway up on the right, where the leaf is deformed by lateral pressure after its inclusion in the clay. Length about 9 centimeters; maximum width about 5.25 centimeters. The petiole is stout but broken away just below the base of the leaf. The midvein is stout. Lateral primaries, nearly as stout as the midrib, diverge from the midvein at acute angles; the left-hand one runs to the tip of the lateral lobe; the right-hand one becomes thinner distad, where it is deformed and its ultimate course obscured, although it probably inosculates with a branch from the basal secondary on the right side. The secondaries diverge at angles of 45° or slightly more; those from the midvein comprise three pairs, which ascend in sweeping curves except for the lowermost on the left, which is straighter and continuously stouter and which runs directly to the sinus, where it joins the vein forming the marginal hem of the sinus. The secondaries from the lateral primaries form full curves except in the tip of the lateral lobe, where their initial course is straighter and they are more abruptly camptodrome. The tertiaries are well marked and are typical of the genus. In the base of the leaf a well-developed vein on each side ascends parallel and close to the margin to join a branch from the basal secondary on each side, giving an inverted triangle effect, which is characteristic of *Sassafras*.

As I have mentioned, the bilobate, mitten-like leaf of the type can hardly be considered to be characteristic of *Sassafras hesperia*, which must have had also entire and trilobate leaves as in our existing American species of *Sassafras*. It adds a striking element to the Latah flora and one that is unique in the Tertiary floras of North America, illustrating the danger of relying on negative evidence.

A second leaf of what is presumably this same species has been collected by C. O. Fernquist since the foregoing description was written and verifies the prediction there made. This second specimen is smaller and is symmetrically trilobate with three primaries. The lobes are broader, less elongate, and more abruptly conical than in the specimen figured.

Sassafras appears in the geologic record toward the end of the Lower Cretaceous in both western Europe (Albian) and eastern North America (Patapsco formation). It is exceedingly common in the Upper Cretaceous of North America, Europe, and the Arctic. The Eocene has several species in Greenland and Europe but only a single one in North America, and this in British Columbia, *Sassafras selwyni* Dawson.[35] *Sassafras hesperia* is sufficiently like *S. selwyni* to be considered its Miocene survivor in the West. The later Tertiary records are all from Europe, where the genus survived well into Pleistocene time. Among the abundant later Tertiary floras of North America not a trace of *Sassafras* has been discovered, although it must have been a member of our eastern mesophytic and Pacific humid floras during all of that long time. Our existing American species, long considered the sole survivor of the genus, ranges from Massachusetts to Iowa and Kansas and from Ontario and Michigan to Florida and Texas. *Sassafras* is one of the few genera of the large and prevailingly tropical family Lauraceae that are confined to the temperate zone. Recently two living species have been discovered in China, adding another example to the many previously known of closely related plants occurring in southeastern North America, western North America, and eastern Asia and no longer native in Europe, although present there in late Tertiary and even in Pleistocene time.[35a]

Occurrence: Brickyard at Spokane, Wash.

Genus UMBELLULARIA Nuttall

Umbellularia dayana (Knowlton) Berry

Plate 58, Figure 4

Salix dayana Knowlton, U. S. Geol. Survey Bull. 204, p. 31, pl. 2, figs. 9, 10, 1902; U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, figs, 1, 2, 1926.

This species, described as a willow from the Mascall formation of Oregon, was recorded by Knowlton from the Latah formation at the Edwards ranch, Stanley Hill, Coeur d'Alene, Idaho. The venation is not that of *Salix* but is typically lauraceous, and I have therefore transferred it to the genus *Umbellularia*.

This genus, represented in the living flora by a single species which is associated with the redwood and which ranges from the Rogue River Valley in Oregon southward through the Coast Ranges and along the western slopes of the Sierra Nevada to the San Bernardino Mountains, is represented in the upper part of the Clarno formation of the John Day Basin in Oregon by *Umbellularia oregonensis* (Knowlton and Cockerell) Chaney.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; brickyard at Spokane, Wash.

Umbellularia lanceolata Berry, n. sp.

Plate 59, Figure 1

Leaves mostly small, lanceolate; widest medially and usually slightly more tapering distad than proximad, although occasionally the reverse is true. Margins entire, sometimes faintly undulate. Texture coriaceous. Length 6.5 to 8.5 centimeters; maximum width 1.5 to 1.85 centimeters. Tip acuminate. Base narrowly cuneate. Petiole stout, its length unknown. Midvein stout, prominent. Secondaries four to six stout, subopposite to alternate pairs, hence widely but fairly regularly spaced, curved, ascending, ultimately camptodrome. Areolation finely meshed, lauraceous.

This characteristic form differs from the associated *Umbellularia dayana* in its generally smaller size, lanceolate outline, narrower base, and much more ascending secondaries.

Occurrence: Deep Creek Canyon and brickyard at Spokane, Wash.

Order UMBELLALES

Family ARALIACEAE

Genus ARALIA of authors

Aralia whitneyi Lesquereux

Aralia whitneyi Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, No. 2, p. 20, pl. 5, fig. 1, 1878.
Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 748, pl. 99, fig. 3, 1899.
Chaney, Am. Jour. Sci., 5th ser., vol. 2, p. 90, 1921.

This characteristic species is represented by a specimen and its counterpart from Republic. It occurs in the Miocene of California and Yellowstone Park and doubtfully in the Mascall formation of Oregon. It has recently been recorded from the Puente formation of California.

Occurrence: Republic, Wash.

Family CORNACEAE

Genus CORNUS Linné

Cornus acuminata Berry, n. sp.

Plate 59, Figure 3

Leaves ovate-lanceolate, widest below the middle, with an extended acuminate tip, of somewhat delicate texture. Margins entire. Base missing, presumably cuneate. Midvein slender, curved. Sec-

[35] Berry, E. W., Tertiary floras of British Columbia: Canada Geol. Survey Bull. 42, p. 114, pl. 14, figs. 1-4, 1926.

[35a] Since this report was written R. W. Chaney (op. cit., p. 58) has recorded the presence of a *Sassafras* leaf in the Clarno formation of the Crooked River Basin in Oregon.

ondaries two opposite, subacrodrome pairs, originating in the basal third of the leaf.

This species is based upon the single incomplete specimen figured, and its botanic relationship is somewhat questionable. It is referred to *Cornus* because of its resemblance to the leaves of the existing *Cornus canadensis* Linné, from which its sole difference is the produced tip of the fossil leaf.

Cornus canadensis is a widely ranging herbaceous form of low woods found from Newfoundland to Alaska and southward to Colorado and California. The genus *Cornus* contains about 25 existing species in the North Temperate Zone and in South America. The fossil species are numerous and extend back to Upper Cretaceous time. There are three other Miocene species on the Pacific slope—one in Yellowstone Park and two in California.

Occurrence: Republic, Wash.

Genus NYSSA Linné

Nyssa knowltoni Berry, n. sp.

Plate 59, Figure 7

Leaves elliptical, bluntly pointed at the apex, rounded at the base, of thin texture. Margins entire except for a few scattered blunt points distad. Length about 10 centimeters; maximum width, near the middle of the leaf, 6.5 centimeters. Petiole not preserved. Midvein stout, prominent, curved. Secondaries stout, ten or eleven pairs, irregularly spaced and more crowded toward the base; they diverge from the midvein at wide angles and are camptodrome. Tertiaries mostly percurrent, thin. The single specimen is somewhat inequilateral.

This may represent the foliage of the same botanic species which furnished the *Nyssa* fruits in the Latah formation.

Occurrence: Brickyard at Spokane, Wash.

Nyssa magnifica (Knowlton) Berry

Carpites magnifica Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 50, pl. 29, fig. 10, 1926.

Additional material from a new locality is contained in the recent collections. The ribs are more clearly defined than in the type and are six in number on the impression and hence must have been more numerous around the whole periphery. In life the cross section must have been round or but slightly compressed. This is clearly indicated by the present material. I see no reason for doubting that this represents a stone of a large-fruited *Nyssa*. I have handled a great many of these from the early Tertiary and Pleistocene, and the Latah species resembles some of the former very closely.

The genus is an old one, present in the early Tertiary of the western United States but not certainly known from the Miocene except in the eastern part of the continent. The existing species of *Nyssa* are all arborescent and are confined to southeastern Asia and southeastern North America, although they are not uncommon in the European Tertiary. The genus is apparently represented by a single leaf in the present collections. A somewhat dubious leaf form from the Eagle Creek formation of Oregon is referred to *Nyssa* by Chaney.[36]

Occurrence: Spokane, Portland & Seattle Railway cut and brickyard, Spokane, Wash.

Family UMBELLIFERAE

Genus UMBELLIFEROSPERMUM Berry, n. gen.

Umbelliferospermum latahense Berry, n. sp.

Plate 64, Figures 10–12

The type and only species of this new genus is based upon four specimens, well shown in the accompanying figures. Fruit relatively large, dry, flattened, about 1 centimeter long and from 0.75 to 1 centimeter in maximum width; the carpellary part 10 millimeters long by 5 to 7 millimeters in maximum width; bordered by wings which are about 1 millimeter wide at the base and increase in width upward and extend beyond the top of the carpels as auriculate lobes. Carpel with one or two longitudinal ribs on the face, emarginate at the base, crowned with two styles about 4 millimeters long, their bases surrounded by a rosette of processes about half the length of the styles, presumably representing calyx teeth or stylopodium processes.

I have not been able to match these fruits exactly among the recent genera in this extensive family and have therefore coined for them the form genus *Umbelliferospermum*. Among similar recent Umbelliferae the fossils appear to most resemble the genus *Rhodosciadum* S. Watson or *Deania* Coulter and Rose, which comprises five or six existing Mexican species.

Occurrence: Brickyard at Spokane, Wash., collected by E. E. Alexander and C. O. Fernquist.

Series GAMOPETALAE

Order ERICALES

Family ERICACEAE

Genus ARCTOSTAPHYLOS Adanson

Arctostaphylos knowltoni Berry, n. sp.

Plate 59, Figure 4

Leaves sessile, obovate, subcoriaceous, entire margined. Length about 4 centimeters; maximum width 12 or 13 millimeters. Midvein stout, prominent. Secondaries largely immersed, diverging from midvein at varying acute angles, ascending, camptodrome. Tertiaries largely immersed.

These leaves appear to be clearly allied to those of the modern species of this genus, which number about a score, some holarctic in their distribution. The genus is especially abundant in western North America.

Occurrence: Brickyard at Spokane, Wash.

[36] Chaney, R. W., The flora of the Eagle Creek formation: Walker Mus. Contr., vol. 2, No. 5, p. 180, pl. 20, figs. 1–3, 1920.

Arctostaphylos spatulata Berry, n. sp.

Plate 64, Figure 6

Leaves small, narrow and elongated, spatulate, mucronate tipped, widest above the middle, the entire margins gradually and straightly narrowed to the narrowly cuneate and practically sessile base. Texture coriaceous. Length about 2.6 centimeters; maximum width 6 millimeters. Midvein stout and prominent, thickening proximad. Secondaries thin, about five ascending camptodrome pairs.

This is quite distinct from the associated *Arctostaphylos knowltoni* and apparently represents a second and hitherto undescribed late Tertiary species.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Genus MENZIESIA J. E. Smith

Menziesia knowltoni Berry, n. sp.

Plate 63, Figure 12

Leaves small, slightly obovate, widest medially and the base slightly more narrowed than the tip. Thin in texture and with entire margins. Length 3 to 3.5 centimeters; maximum width 1.2 to 1.6 centimeters. Petiole stout and short, about 2 millimeters in length. Midvein stout and prominent. Secondaries thin, regularly spaced, five or six camptodrome pairs.

These leaves present the features of the genus *Menziesia*, which has not, so far as I know, been found fossil heretofore. The existing species number seven or eight, one in the eastern mesophytic region of North America, three in western North America, and the rest in eastern Asia. The present fossil species is much like *Menziesia glabella* Gray, a shrub found from Lake Superior to Oregon and British Columbia.

Occurrence: Brickyard at Spokane, Wash.

Family VACCINIACEAE

Genus VACCINIUM Linné

Vaccinium americanum (Lesquereux) Berry

Vaccinium salicoides Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 46, pl. 28, figs. 9, 9a, 1926.

Salix pseudoargentea Knowlton, U. S. Geol. Survey Bull. 204, pl. 2, figs. 2–4, 1902; in Smith, U. S. Geol. Survey Geol. Atlas, Folio 86 (Ellensburg, Wash.), p. 3, 1902.

Santalum americanum Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 164, pl. 32, fig. 7, 1883.

This species, described from the Mascall formation of Oregon and also recorded from the Ellensburg formation of Washington, is sparingly represented in the Latah formation and at Florissant, Colo. It is obviously not a *Salix*, its somewhat coriaceous texture and areolation stamping it as a member of the Vacciniaceae, and it appears identical with what Knowlton called *Vaccinium salicoides* from the Latah formation of the Coeur d'Alene district, Idaho.

The genus *Vaccinium*, with over 100 existing species, is widely distributed in temperate and cooler parts of the world, with nine species in the present flora of Washington.

Occurrence: Stanley Hill, Coeur d'Alene, Idaho; brickyard at Spokane, Wash.

Vaccinium bonseri Berry, n. sp.

Plate 59, Figure 5

Leaves small, sessile, spatulate, coriaceous, with entire margins. Length 1.1 to 1.4 centimeters; maximum width 5.5 to 7 millimeters. Apex rounded, apiculate. Base cuneate. Midvein stout and prominent, expanding sixfold near the base. Secondaries four or five stout, largely immersed pairs, camptodrome.

These characteristic little leaves are very similar to those of *Vaccinium uliginosum* Linné and *V. vitis-idaea* Linné and perhaps are most like *Vaccinium lucidum* of gardens.

Occurrence: Spokane, Portland & Seattle Railway cut No. 1 and brickyard at Spokane, Wash.

Vaccinium bonseri serrulatum Berry, n. var.

Plate 63, Figures 19, 20

Leaves sessile, small, elongate-elliptical, relatively coriaceous. Margins with tiny, remotely and irregularly spaced, serrate teeth. Apex bluntly pointed. Base entire, slightly decurrent to the greatly expanded base of the midvein. Length about 11 millimeters; maximum width, midway between the apex and the base, about 6 millimeters. Midvein stout and curved, its proximal fourth much expanded, and prominent on the under side of the leaf. Secondaries three or four pairs, stout, irregularly camptodrome. Tertiaries well marked, inosculating and becoming attenuated to form an oblique mesh which becomes finer in the base of the leaf.

At first sight this leaf suggests some of the smaller leaflets of various Rosaceae, as, for example, *Rosa nitida* Willdenow, but the venation is ericaceous and not rosaceous, the Rosaceae differing in areolation and being characterized by more numerous and more clearly defined secondaries. It is also similar to leaves from the European Tertiary which Heer and Saporta have referred to the genus *Myrsine*.

The genus *Vaccinium* seems to be clearly indicated by the size, texture, venation, and marginal characters, and as the size and form are so similar to the associated *Vaccinium bonseri* it is described as a variety of that species, from which its chief difference is the toothed margin. As in the living species of *Vaccinium* there are a considerable number in which the margins range from entire to serrulate, it is not only possible but probable that the present form and *Vaccinium bonseri* represent a single Miocene species. This can not be demonstrated, however, except by the rather unlikely contingency of finding material which would show both forms on a single twig.

Similarities between the present fossil forms and the leaves of several existing species of *Vaccinium* might be pointed out. There is considerable resemblance to the existing holarctic *Vaccinium vitis-idaea* Linné and to *Vaccinium caespitosum* Michaux, which ranges from Labrador and Maine to Colorado and Alaska, and also to several of more temperate habitat—for example, *Vaccinium vacillans* Kalm—and others might be mentioned.

Occurrence: Brickyard at Spokane, Wash.

Vaccinium spokanense Berry, n. sp.

Plate 64, Figure 8

Leaf small, ovate, with a bluntly pointed tip and a broad sessile base. Margins entire. Length about 1.9 centimeters; maximum width, midway between the apex and the base, 8 millimeters. Midvein stout and prominent, expanding at the truncate base to the full width, which is 2.5 millimeters. Secondaries relatively stout, five or six ascending pairs, diverging from the midvein at acute angles, especially the lower three pairs, which diverge from the expanded proximal part of the midvein, camptodrome.

This characteristic small leaf is thus far represented by only the specimen figured.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

Order EBENALES

Family EBENACEAE

Genus DIOSPYROS Linné

Diospyros princetoniana Cockerell

Plate 59, Figure 6; Plate 60, Figures 1–3

Diospyros princetoniana Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 105, pl. 10, fig. 36, 1908.

This species, as described by Cockerell, was based upon a meager amount of material. According to Knowlton,[37] the material which he studied in the Hambach collection from Florissant, as well as Cockerell's species, is not to be distinguished from the American material which Lesquereux and others have referred to the European *Diospyros brachysepala* Al. Braun. The status of *D. brachysepala* is most uncertain. The type material came from the late Miocene (Sarmatian) of Baden, but various workers have recorded the species from every conceivable Tertiary horizon in Europe, and American students have recorded it from a large number of early Tertiary localities in North America. Obviously as the name stands in the literature it represents a composite species. Despite the similarity in the leaves from North America and Europe it is highly improbable that a single botanic species ranged over two continents.

Leaves of this type are not uncommon in the Latah formation, and I have taken up Cockerell's name for them, despite their practical identity with the European late Miocene leaves. The Latah leaves in my opinion are clearly referable to *Diospyros*, the venation and general facies being uniform despite the considerable variability in size and outline. The species may be more fully described as follows:

Leaves broadly lanceolate, usually widest medially but occasionally above the middle. Generally about equally pointed at both ends but showing a tendency for the tip to be less acute than the base. The base is normally decurrent, but the tip is frequently apiculate. Texture subcoriaceous. Petiole stout, 5 to 10 millimeters in length. Midvein stout, prominent on the under side of the leaf, frequently curved. Secondaries thin, not prominent, ascending, camptodrome. Length 3.5 to 8 centimeters; maximum width 1.1 to 3 centimeters.

The specimens from the Latah formation may be compared with the Miocene forms figured by Heer.[38]

I am not prepared to say whether the forms from Oklahoma and Yellowstone Park which have been referred to *Diospyros brachysepala* represent *Diospyros princetoniana* or not.

Occurrence: Brickyard, Spokane, Wasn., where it is common and to which it is confined.

Order GENTIANALES

Family APOCYNACEAE

Genus APOCYNOPHYLLUM Unger

Apocynophyllum latahense Berry, n. sp.

Plate 60, Figures 4, 7

Leaves of variable size, oblong lanceolate, the top missing in all the specimens, presumably pointed, the base abruptly incurved and decurrent. Margins entire. Length (estimated) 10 to 15 centimeters; maximum width 2.25 to 4.25 centimeters. Petiole long and very stout, preserved for 2.5 centimeters in a small specimen. Midvein very stout. Secondaries relatively thin, numerous, diverging from the midvein at wide angles, camptodrome.

These leaves, all of which are unfortunately incomplete, have all the features of the Apocynaceae. Their exact generic affinity is uncertain.

Occurrence: Deep Creek Canyon, Spokane, Portland & Seattle Railway cut No. 4, and brickyard at Spokane, Wash.

Order POLEMONIALES

Family CONVOLVULACEAE

Genus PORANA Burmann

Porana microcalyx (Knowlton) Berry

Diospyros? microcalyx Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 46, pl. 22, figs. 5, 6, 1926.

An additional complete specimen of this form from a new locality enables me to correct Knowlton's tentative reference of it to the genus *Diospyros*. It

[37] Knowlton, F. H., U. S. Nat. Mus. Proc., vol. 51, p. 285, 1916.

[38] Heer, Oswald, Flora tertiaria Helvetiae, pl. 102, figs. 1-14, 1859.

does not belong to that genus, nor is Knowlton's description fully complete. The persistent sepals are five in number divided to the base, and narrow to blunt pointed when completely worked out of the matrix. The venation is not longitudnal but reticulate, with several veins from the base, much as in *Porana oeningensis* Heer, which it greatly resembles. The capsule is preserved as a spheroidal cavity about 2 millimeters in diameter.

The genus *Porana*, which is confined to the Old World in the recent flora, is not uncommon in the later Tertiary of Europe. It has not been previously recognized in North America except at Florissant, Colo., where it is not uncommon and represented by three species, all of which differ from the one under consideration.

Occurrence: Spokane, Portland & Seattle Railway cut and brickyard at Spokane, Wash.

Order RUBIALES

Family CAPRIFOLIACEAE

Genus VIBURNUM Linné

Viburnum lantanafolium Berry, n. sp.

Plate 60, Figure 6

Leaves entire, ovate, subcoriaceous. Margins with regular, closely spaced dentate teeth. Length about 11 centimeters; maximum width about 7 centimeters. Midvein stout, prominent. Secondaries stout, seven or eight mostly alternate pairs; diverging from the midvein at angles of 45° or less, ascending, craspedodrome; the two or three basal pairs curve upward and then outward distad, giving off several craspedodrome tertiaries; these craspedodrome branches from the secondaries become progressively less numerous toward the tip of the leaf. Internal tertiaries well marked, closely spaced, mostly percurrent.

This striking species is unfortunately represented by only the single incomplete specimen figured, but the generic character of the venation is so typical that there can be no doubt of its affinity. It adds a new type to the flora of the Pacific slope Miocene.

The genus has about 100 existing species, mostly in eastern Asia and North America but represented in Europe, Africa, Australia, and South America. There are about 20 species in the United States, but none of the western ones are arborescent. The genus is an old one with many fossil species and is well represented in the Eocene of the Western States but is not certainly known from the Miocene, although doubtfully recorded from California and Saskatchewan.

The present fossil species is extremely like the leaves of *Viburnum lantana* Linné, of middle Europe, the type of the section *Lantana* of the subgenus *Euviburnum*. It is also similar to *Viburnum palaeolantana* Unger, of the Pliocene of Styria.

Occurrence: Spokane, Portland & Seattle Railway cut No. 4 at Spokane, Wash.

Viburnum fernquisti Berry, n. sp.

Plate 63, Figure 10

Stone compressed, oval and slightly unsymmetrical in outline, widest medially, rounded proximad and bluntly pointed distad, coriaceous, with two or three low rounded unequally developed longitudinal ridges on each surface. Length 6.5 millimeters: maximum width 3.5 millimeters.

A species based upon foliage is associated with these stones, and it is quite probable that stones and leaves represent the same botanical species, but this can not be demonstrated.

Occurrence: Brickyard at Spokane, Wash., collected by C. O. Fernquist.

POSITION UNCERTAIN

Carpolithus pteraformis Berry, n. sp.

Plate 60, Figure 5

Winged fruits or seeds of considerable size, irregularly elliptical. Base rounded, expanding on one side of the seed or the seed cavity about one-fourth of the distance above the base to about twice its basal width, arching to the rounded sligthly inequilateral tip—the margin straighter on the opposite side. Seed or seed cavity but slightly thicker than the wing, rounded distad, pointed proximad, situated in the narrowed base of the wing, about 1.25 centimeters long and 5 millimeters wide. Whole fruit 3 centimeters long and 1.1 centimeters in maximum width. Wing substance coriaceous, without venation, obliquely wrinkled, with a conspicuously beveled distal margin. This and other features suggest that it represents a winged seed of a capsular fruit and that these seeds were closely packed in the fruit.

Superficially these fossils suggest the seeds of the winged-seeded conifers and also the samaras of *Acer*. They are clearly not related to either of these and are readily discriminated from the seeds of *Pinus* and the samaras of *Acer* occurring in the Latah formation. They are thicker and lack the venation of both of these types. They may represent the genus *Gordonia*.

Occurrence: Vera, Deep Creek Canyon, and brickyard at Spokane, Wash.

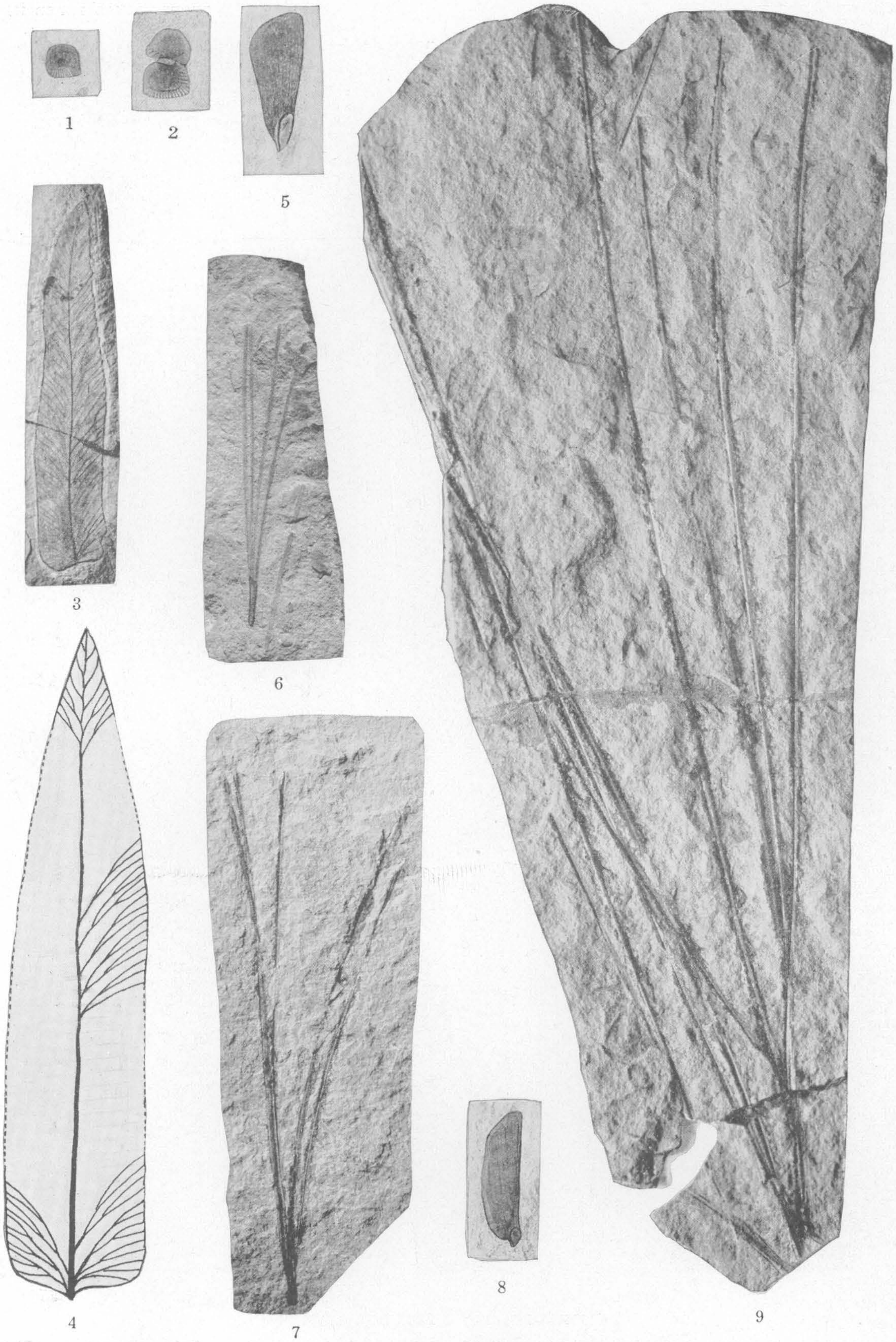
Carpites menthoides Knowlton

Carpites menthoides Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 49, pl. 26, fig. 4, 1926.

Specimens ranging from 1 to 2 centimeters in diameter are contained in the recent collections. I regard their implied relationship with the Labiateae as entirely problematic.

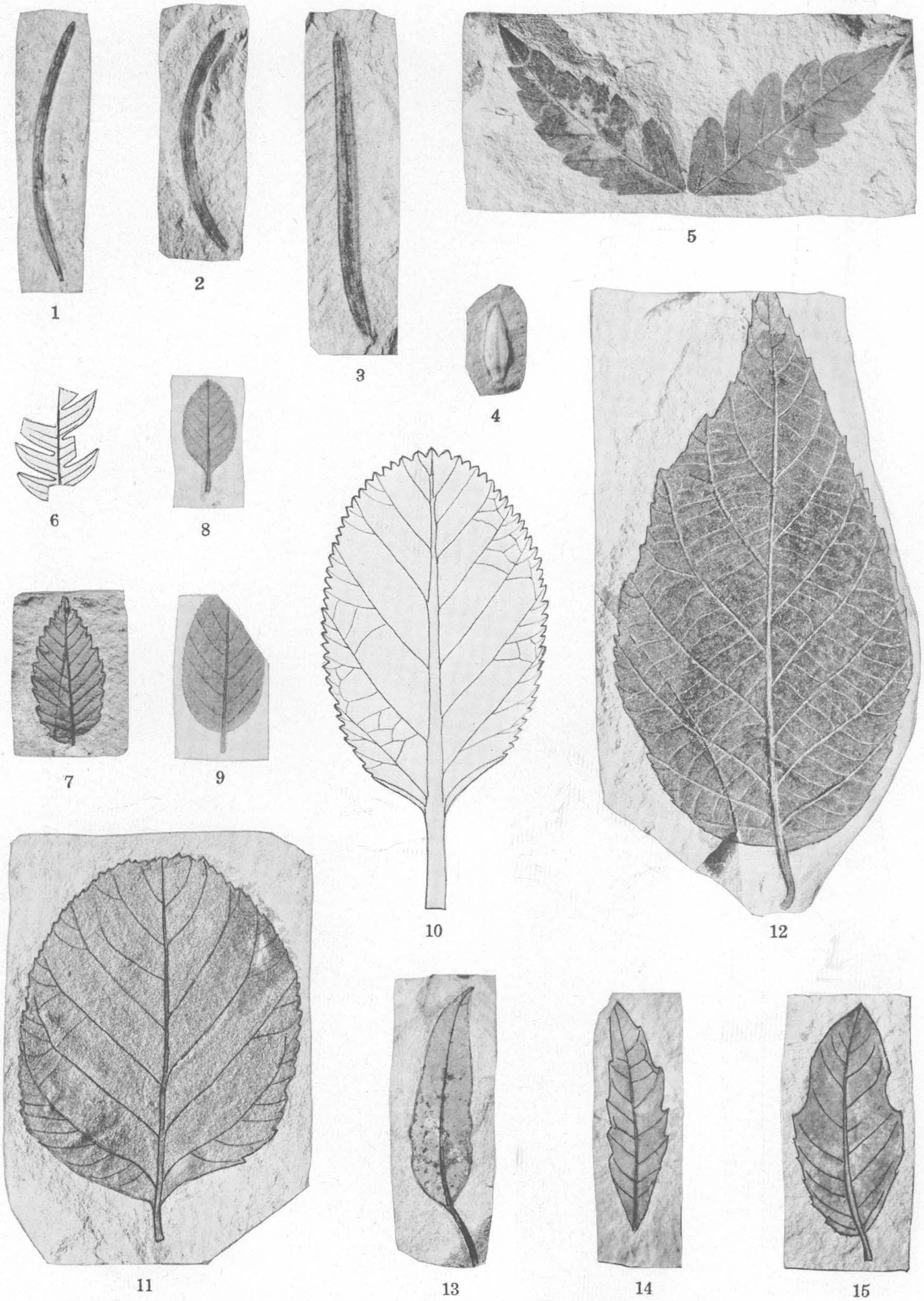
Occurrence: Deep Creek Canyon, Spokane, Portland & Seattle Railway cut No. 1, and brickyard at Spokane, Wash.

PLATES 49–64



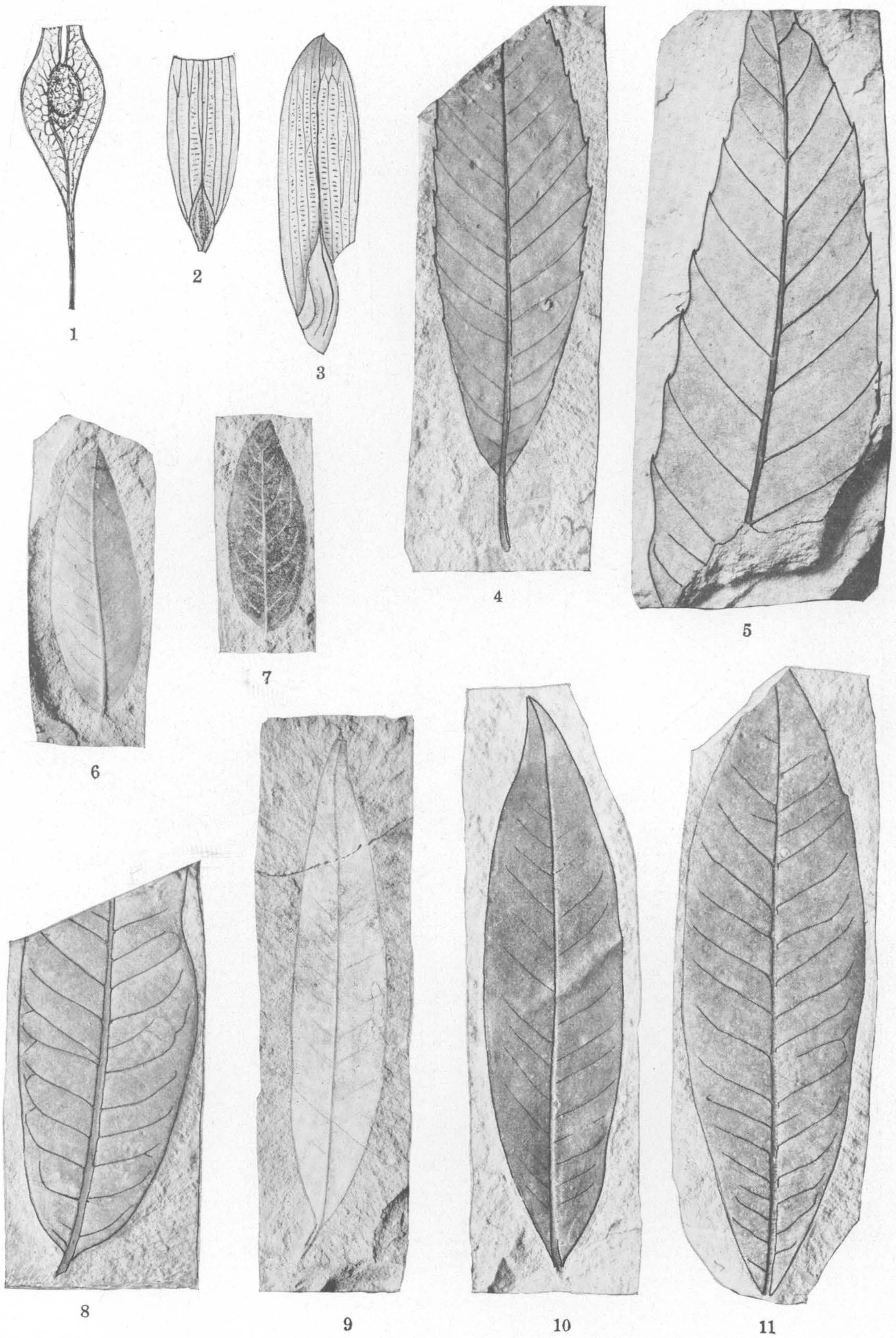
FOSSILS FROM THE LATAH FORMATION

1, 2. Fish scales, probably of *Leuciscus* (p. 226).
3, 4. *Asplenium occidentale* Berry, n. sp. (p. 236). Figure 4 shows the venation in the distal, medial, and proximal parts of a pinnule, × 2.
5, 8. *Pinus monticolensis* Berry, n. sp., winged seeds (p. 238).
6. *Pinus tetrafolia* Berry, n. sp. (p. 238).
7. *Pinus latahensis* Berry, n. sp. (p. 238).
9. *Pinus macrophylla* Berry, n. sp. (p. 238).



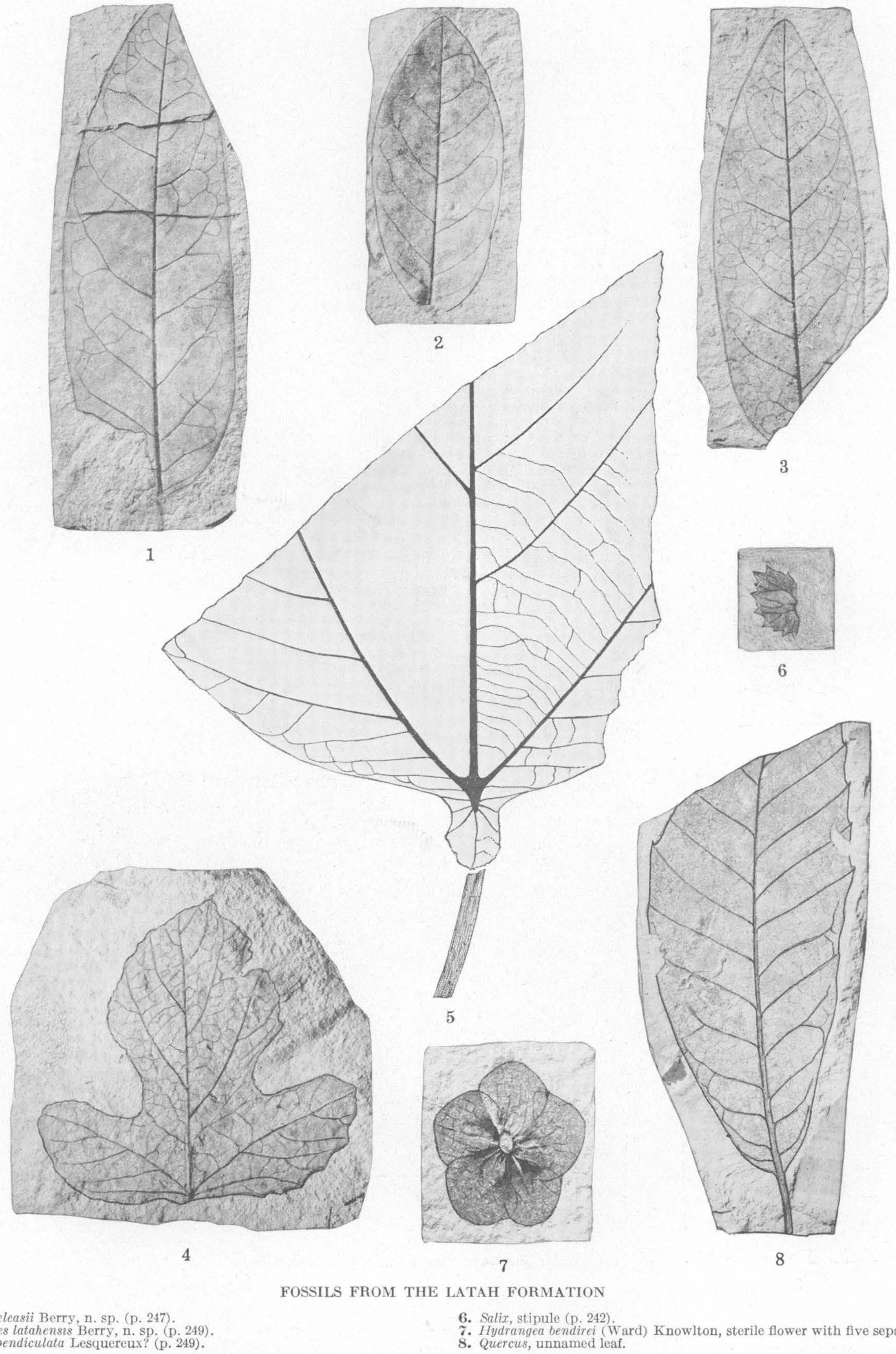
FOSSILS FROM THE LATAH FORMATION

1-3. *Potamogeton heterophylloides* Berry, n. sp., showing variation among the submerged leaves (p. 240).
4. *Populus,* bud scale (p. 243).
5. *Comptonia insignis* (Lesquereux) Cockerell (p. 241).
6. *Comptonia hesperia* Berry, n. sp., fragment of a leaf (p. 241).
7. *Fagopsis longifolia* (Lesquereux) Hollick, a small leaf (p. 245).
8-10. *Alnus elliptica* Berry, n. sp. (p. 244). Figure 10 shows Figure 8 × 4 to show details of marginal teeth and venation.
11. *Alnus prerhombifolia* Berry, n. sp. (p. 244).
12. *Betula largei* Knowlton (p. 244).
13-15. Unnamed anomalous or juvenile leaves of *Quercus.*



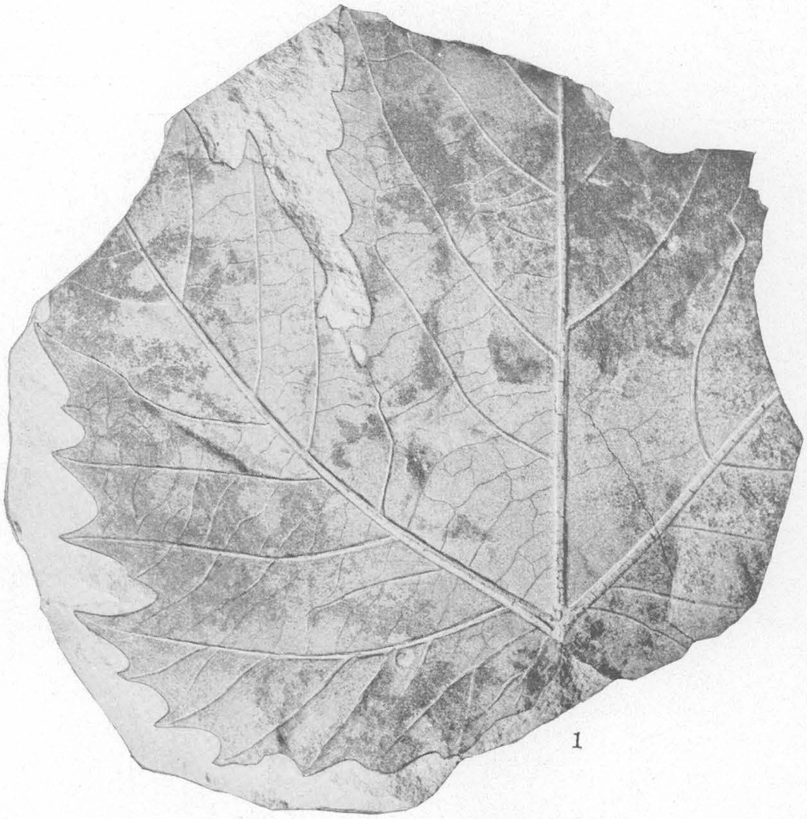
FOSSILS FROM THE LATAH FORMATION

1. *Ulmus*, characteristic winged fruit, × 2 (p. 247).
2, 3. *Liriodendron hesperia* Berry, n. sp., winged fruits, × 2 (p. 249).
4, 5. *Castanea orientalis* Chaney (p. 245).
6, 7, 9–11. *Quercus simulata* Knowlton, illustrating variation in size and appearance of the leaves of this species (p. 246).
8. *Rhus merrilli* Chaney (p. 256).

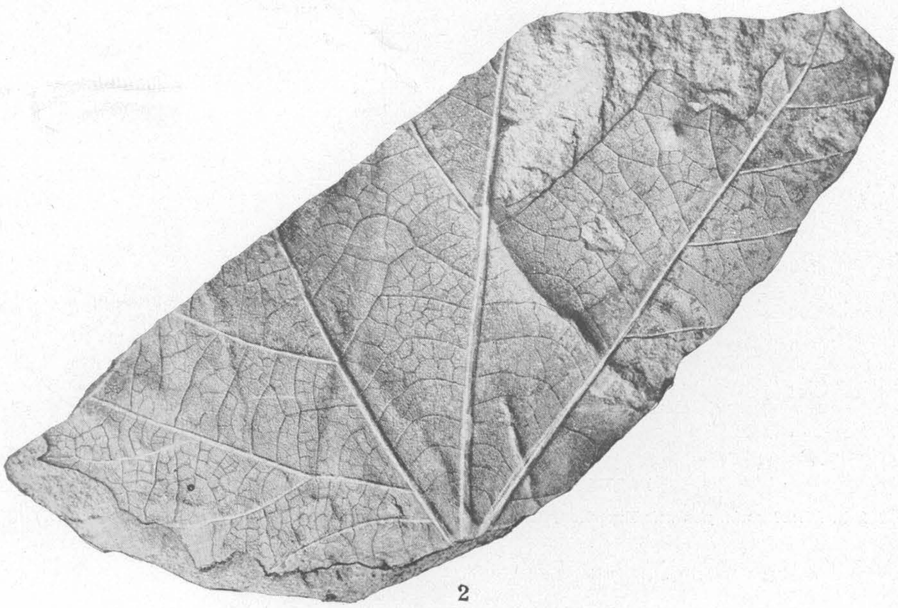


FOSSILS FROM THE LATAH FORMATION

1–3. *Quercus treleasii* Berry, n. sp. (p. 247).
4. *Menispermites latahensis* Berry, n. sp. (p. 249).
5. *Platanus appendiculata* Lesquereux? (p. 249).
6. *Salix*, stipule (p. 242).
7. *Hydrangea bendirei* (Ward) Knowlton, sterile flower with five sepals (p. 251).
8. *Quercus*, unnamed leaf.



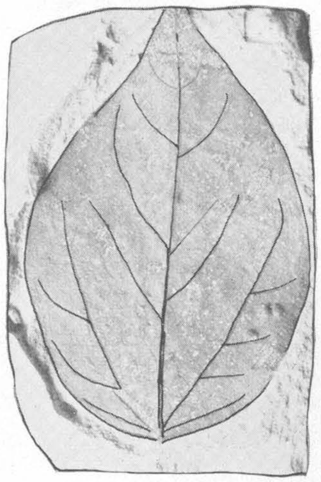
1



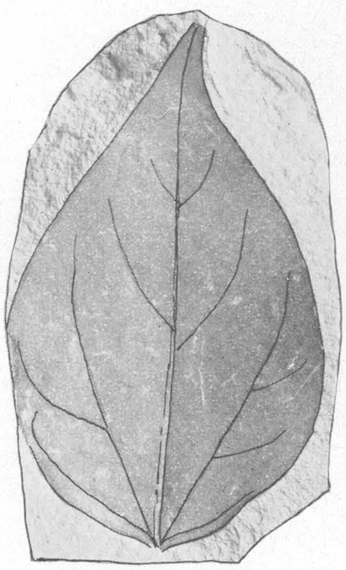
2

FOSSILS FROM THE LATAH FORMATION

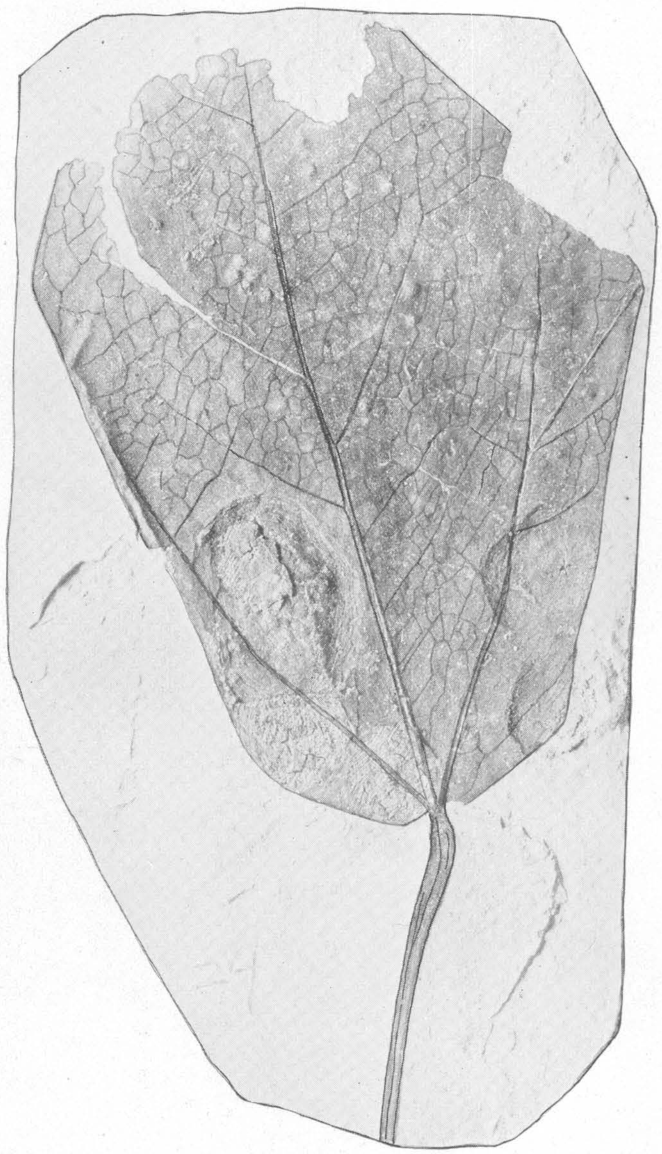
1, 2. *Platanus dissecta* Lesquereux (p. 248). The fragment shown in Figure 2 gives the details of venation



1



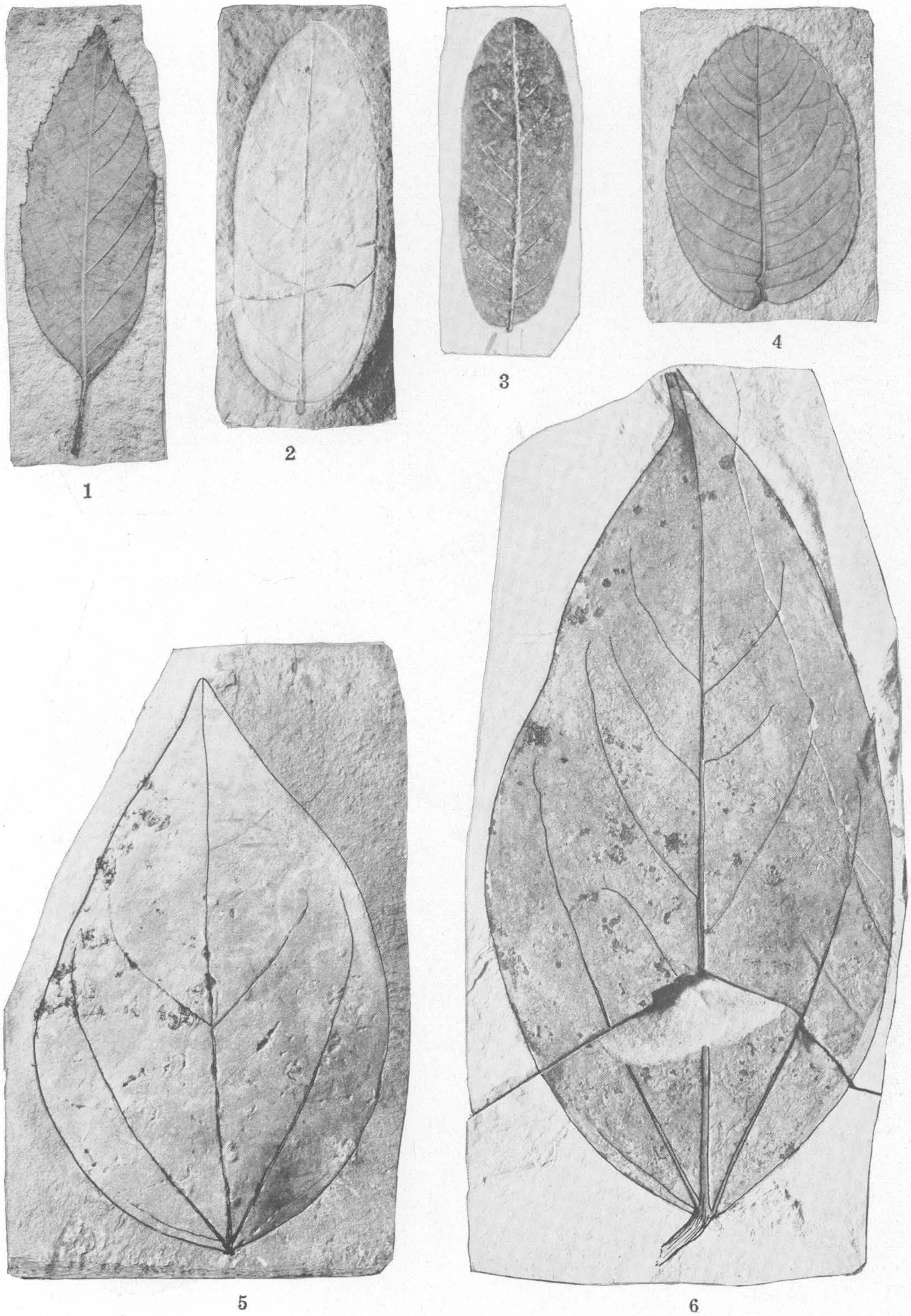
2



3

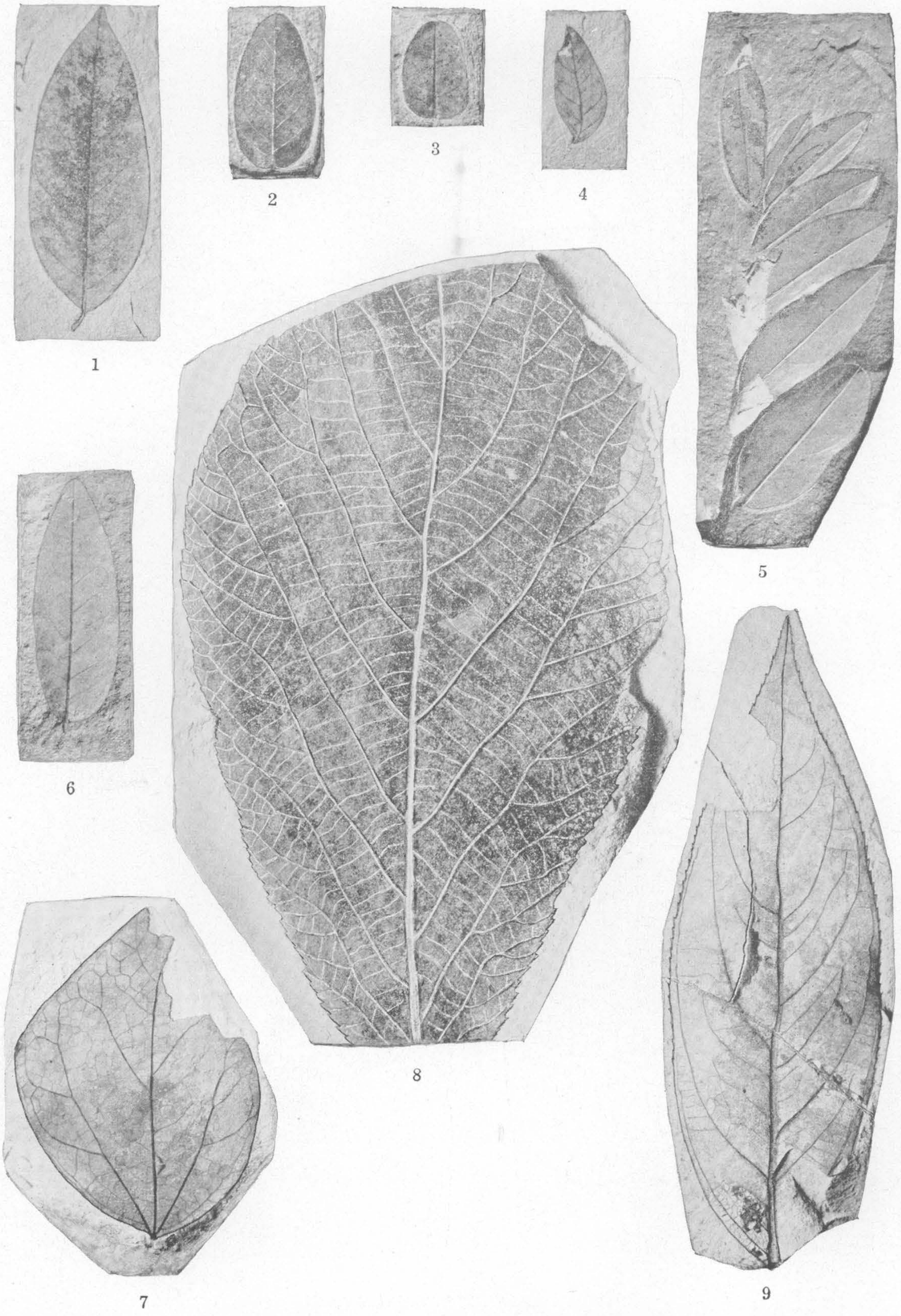
FOSSILS FROM THE LATAH FORMATION

1–3. *Ficus*? *washingtonensis* Knowlton, illustrating the variations of size and form in this species (p. 248)



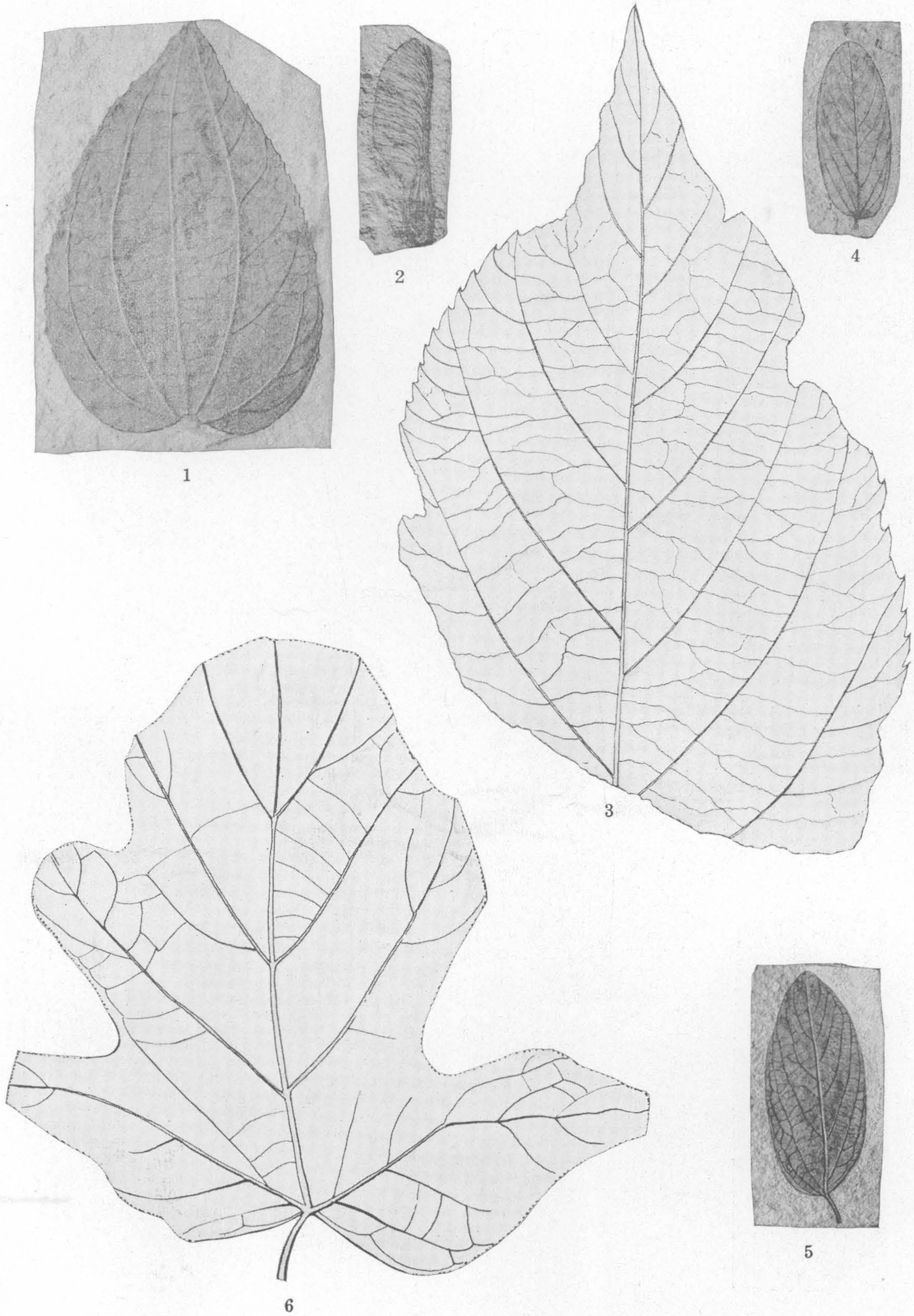
FOSSILS FROM THE LATAH FORMATION

1. *Prunus rustii* Knowlton (p. 252).
2, 3. *Cassia idahoensis* Knowlton (p. 252)
4. *Amelanchier scudderi* Cockerell (p. 252).
5, 6. *Ficus? washingtonensis* Knowlton (p. 248).



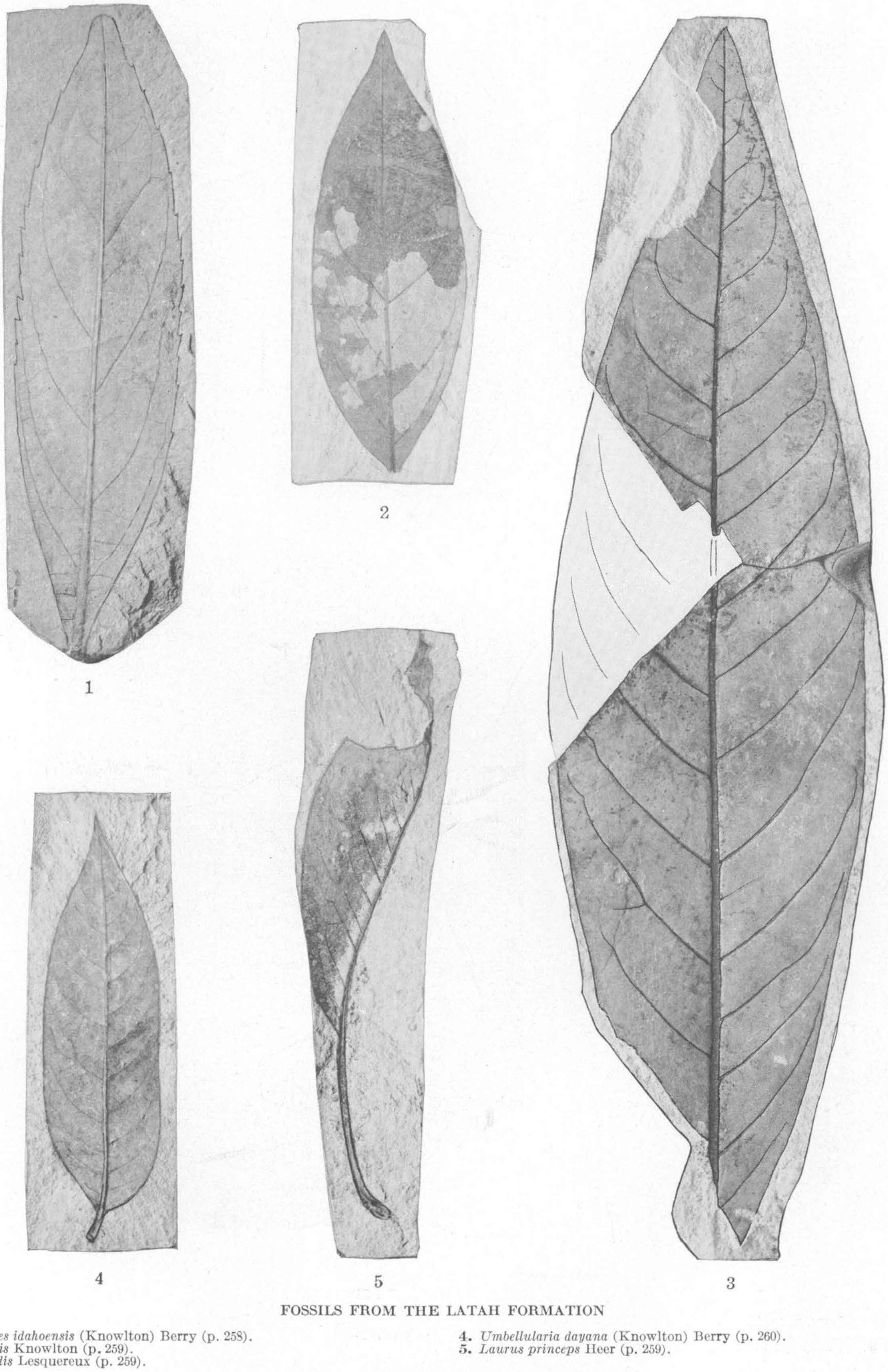
FOSSILS FROM THE LATAH FORMATION

1. *Cassia sophoroides* (Knowlton) Berry (p. 253).
2, 3. *Sophora alexanderi* Knowlton (p. 253).
4. *Leguminosites bonseri* Berry, n. sp. (p. 254).
5, 6. *Sophora spokanensis* Knowlton (p. 253). Much of the pinnate leaf is shown in Figure 5.
7. *Meibomites knowltoni* Berry, n. sp. (p. 253).
8. *Aesculus hesperia* Berry, n. sp. (p. 256).
9. *Euonymus knowltoni* Berry, n. sp. (p. 255).



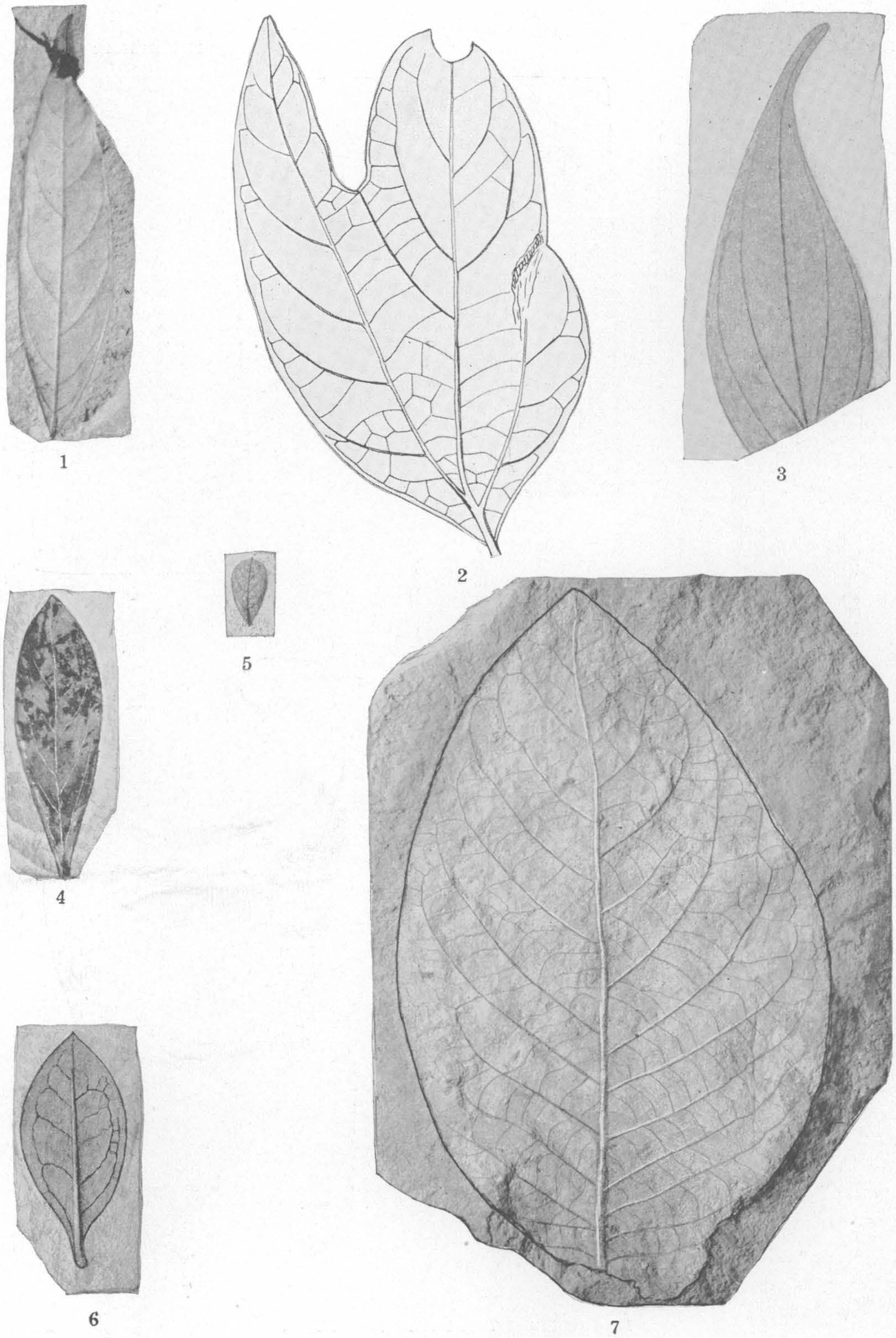
FOSSILS FROM THE LATAH FORMATION

1. *Paliurus hesperius* Berry, n. sp. (p. 257).
2. *Acer oregonianum* Knowlton, winged fruit (p. 255).
3. *Tilia hesperia* Berry, n. sp., part of a large leaf (p. 258).
4, 5. *Rhamnus spokanensis* Berry, n. sp. (p. 257).
6. *Acer*, sp.



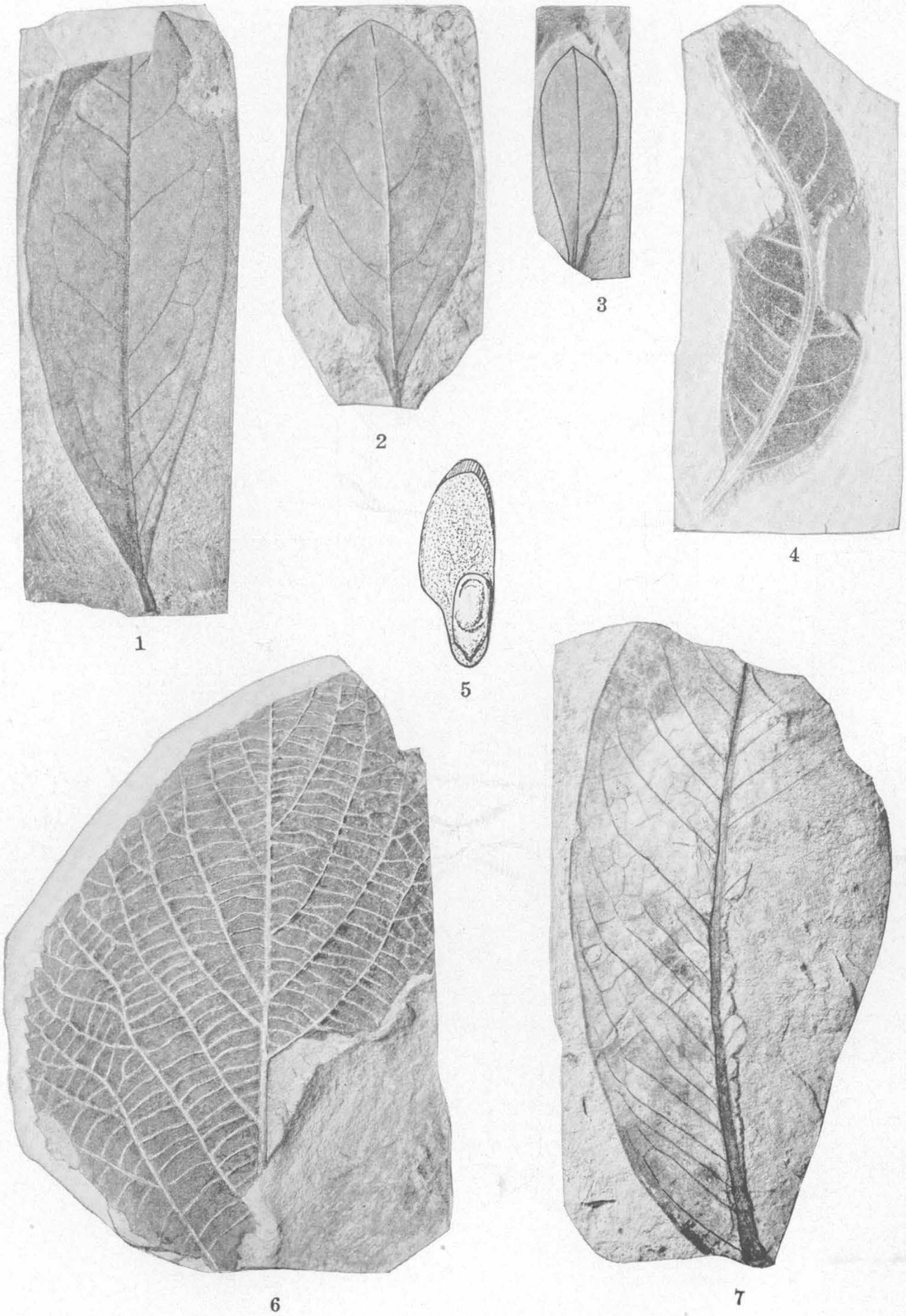
FOSSILS FROM THE LATAH FORMATION

1. *Ternstroemites idahoensis* (Knowlton) Berry (p. 258).
2. *Laurus similis* Knowlton (p. 259).
3. *Laurus grandis* Lesquereux (p. 259).
4. *Umbellularia dayana* (Knowlton) Berry (p. 260).
5. *Laurus princeps* Heer (p. 259).



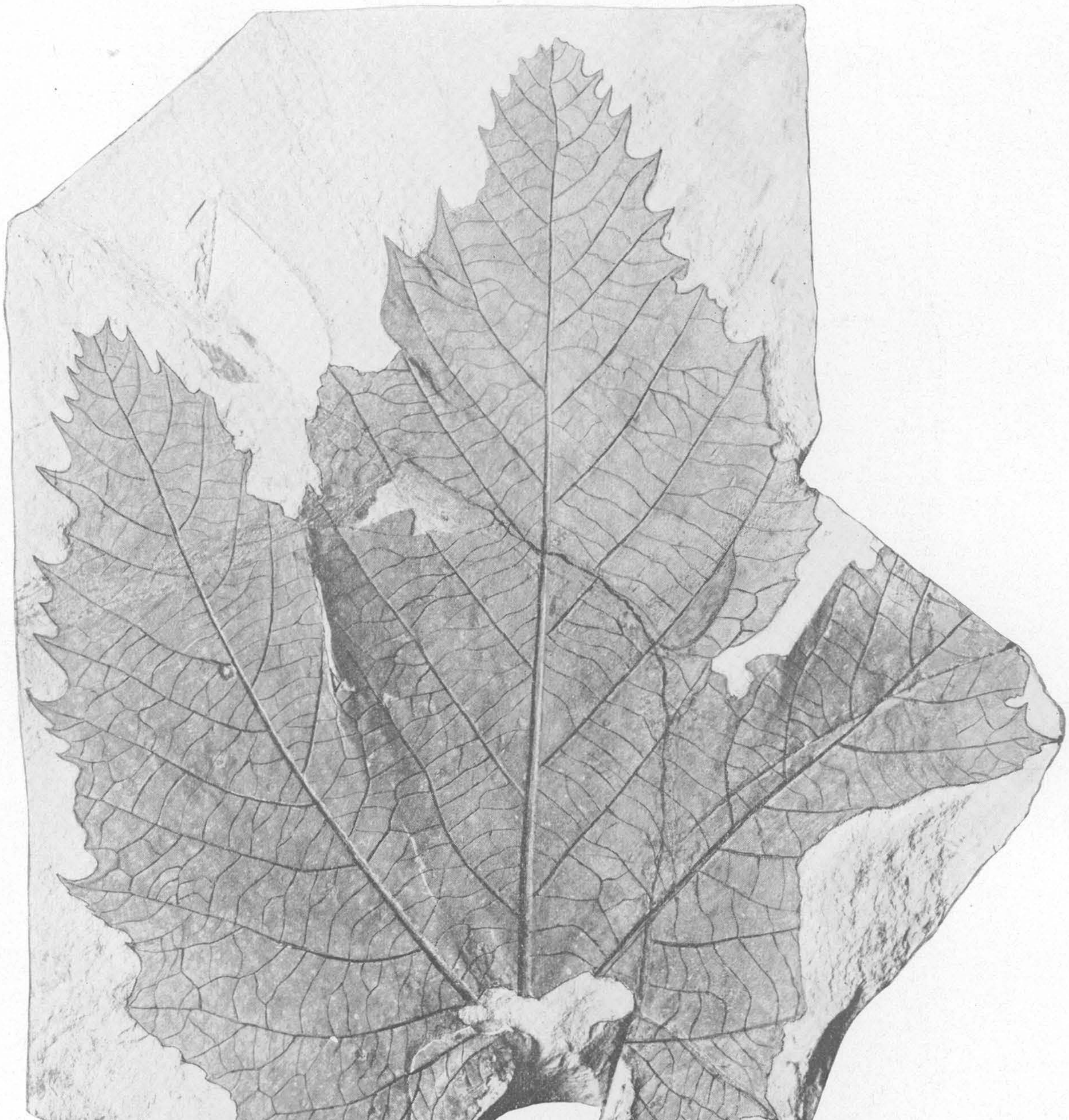
FOSSILS FROM THE LATAH FORMATION

1. *Umbellularia lanceolata* Berry, n. sp. (p. 260).
2. *Sassafras hesperia* Berry, n. sp. (p 259).
3. *Cornus acuminata* Berry, n. sp. (p. 260).
4. *Arctostaphylos knowltoni* Berry, n. sp. (p. 261).
5. *Vaccinium bonseri* Berry, n. sp. (p. 262).
6. *Diospyros princetoniana* Cockerell (p. 263).
7. *Nyssa knowltoni* Berry, n. sp. (p. 261).



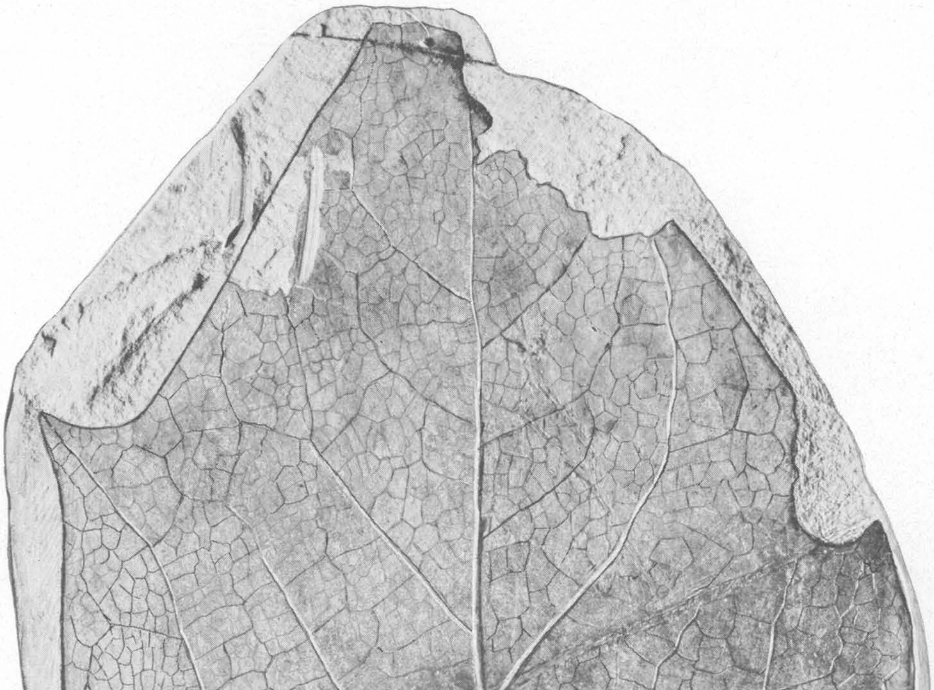
FOSSILS FROM THE LATAH FORMATION

1-3. *Diospyros princetoniana* Cockerell, showing the limits of variation of this species (p. 263).
4, 7. *Apocynophyllum latahense* Berry, n. sp., showing the limits of variation of this species (p. 263).
5. *Carpolithus pteraformis* Berry, n. sp., a characteristic winged fruit (p. 264).
6. *Viburnum lantanafolium* Berry, n. sp. (p. 264).



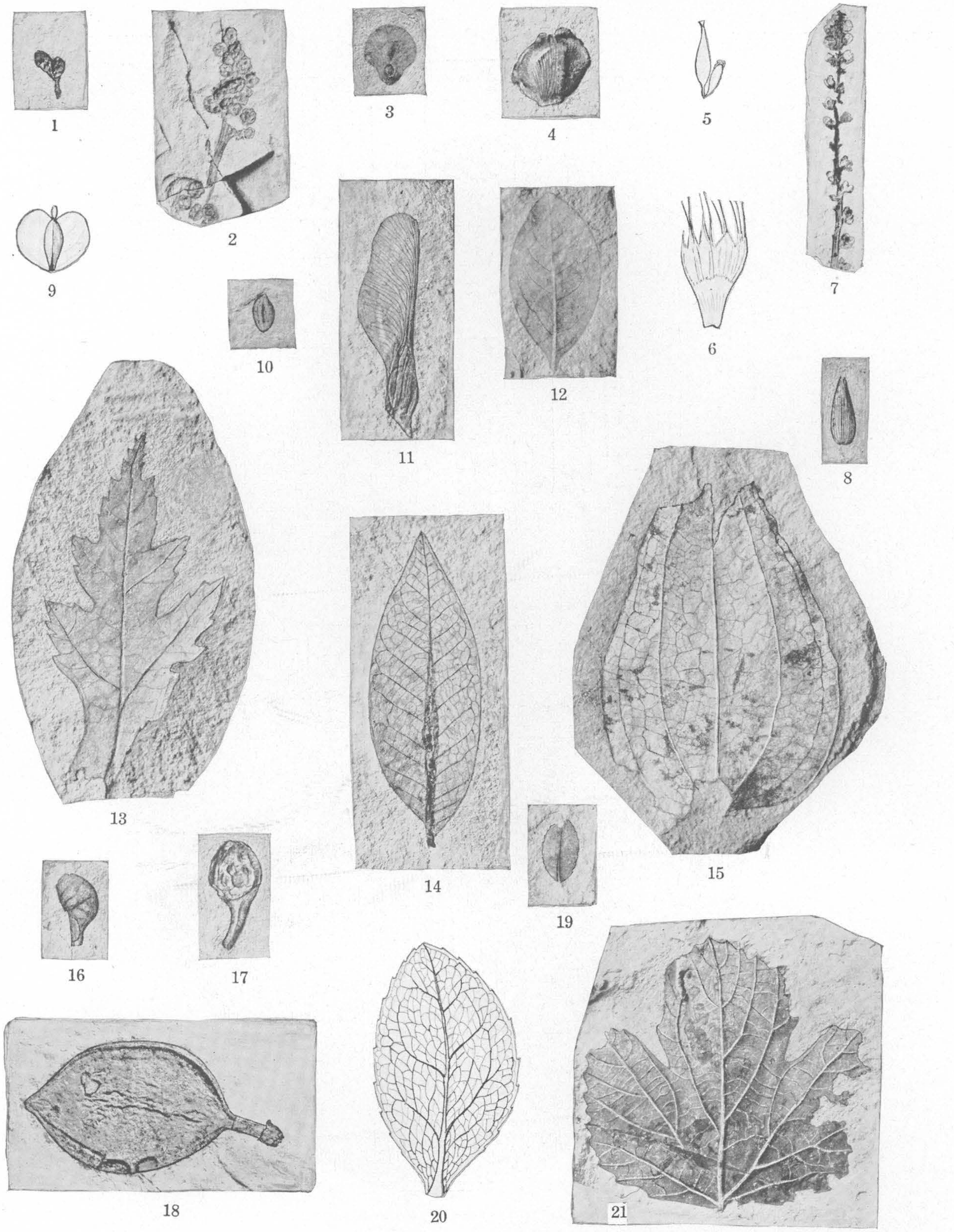
FOSSILS FROM THE LATAH FORMATION

Platanus dissecta Lesquereux (p. 248). A nearly complete leaf from the brickyard at Spokane, Wash.



FOSSILS FROM THE LATAH FORMATION

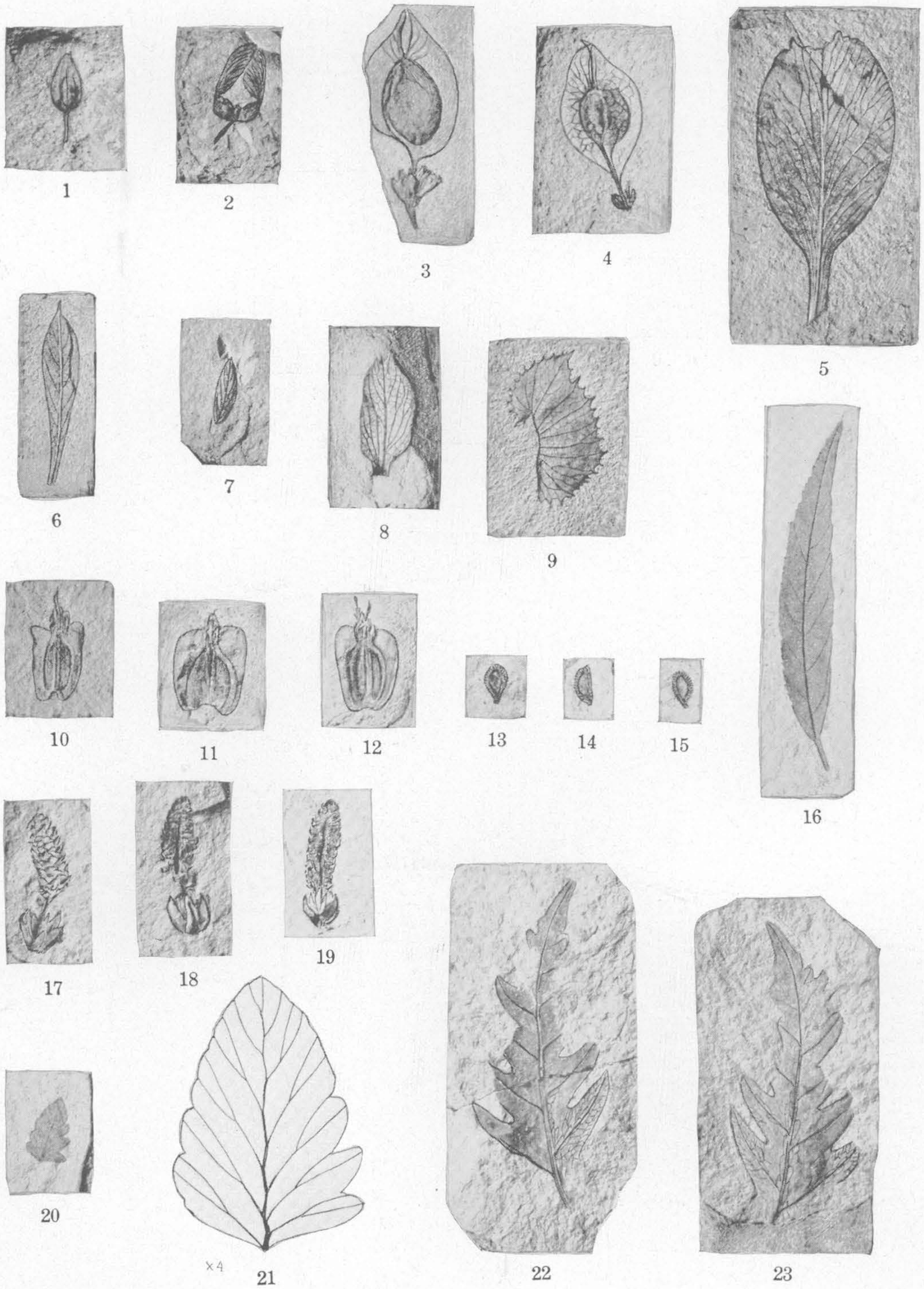
Ficus? washingtonensis Knowlton (p. 248). An unusually large leaf from the brickyard at Spokane, Wash., showing a conical marginal lobe on one side, and the wings on the upper part of the petiole.



FOSSILS FROM THE LATAH FORMATION

1. *Glyptostrobus*?, staminate aments (p. 239).
2. *Taxodium*, staminate aments (p. 237).
3, 4. *Tsuga latahensis* Berry, n. sp., cone scales (p. 239).
5. *Salix*, pistillate flower, × 2 (p. 242).
6. *Populus*, bract of a pistillate flower, × 4 (p. 243).
7. *Populus*, pistillate ament (p. 243).
8. *Populus*, bud scale (p. 243).
9. *Betula*, winged fruit, × 2 (p. 244).
10. *Viburnum fernquisti* Berry, n. sp., stone (p. 264).
11. *Acer oregonianum* Knowlton (p. 255).
12. *Menziesia knowltoni* Berry, n. sp. (p. 262).
13. *Acer chaneyi* Knowlton, apical lobe (p. 256).
14. *Sapindus armstrongi* Berry, n. sp. (p. 254).
15. *Smilax lamarensis* Knowlton (p. 240).
16. *Leguminosites alexanderi* Berry, n. sp., pod (p. 254).
17. *Carpites ginkgoides* Knowlton.
18. *Cassia spokanensis* Berry, n. sp., pod (p. 253).
19, 20. *Vaccinium bonseri serrulatum* Berry, n. var., Figure 20 × 4 (p. 262).
21. *Ribes fernquisti* Berry, n. sp. (p. 251).

All from the brickyard at Spokane, Wash.



FOSSILS FROM THE LATAH FORMATION

1. Unnamed fruit, × 4.
2. *Acer minor* Knowlton (p. 256).
3, 4. *Ulmus*, fruits × 2 (p. 247).
5. *Celastrus spokanensis* Berry, n. sp. (p. 255).
6. *Arctostaphylos spatulata* Berry, n. sp. (p. 262).
7. *Cercocarpus praeledifolius* Berry, n. sp. (p. 252).
8. *Vaccinium spokanense* Berry, n. sp. (p. 263).
9. *Salix*, stipule (p. 242).
10-12. *Umbelliferospermum latahense* Berry, n. sp. (p. 261).
13-15. *Hibiscus? occidentalis* Berry, n. sp., seed (p. 258).
16. *Salix florissanti* Knowlton and Cockerell (p. 242).
17-19. *Pinus*, staminate aments (p. 239).
20, 21. *Woodsia bonseri* Berry, n. sp. (p. 236). Figure 21 × 4.
22, 23. *Woodwardia praeradicans* Berry, n. sp. (p. 236).

All from brickyard at Spokane, Wash.

EXOGYRA OLISIPONENSIS SHARPE AND EXOGYRA COSTATA SAY IN THE CRETACEOUS OF THE WESTERN INTERIOR

By John B. Reeside, Jr.

INTRODUCTION

This paper records the occurrence in the Upper Cretaceous of the Western Interior of *Exogyra olisiponensis* Sharpe, not hitherto noted in the United States, and of *Exogyra costata* Say, not previously known outside of the Atlantic and Gulf coastal region. Notes on the genus and both species are included, and representative specimens are figures.

GENUS EXOGYRA

The genus *Exogyra* has been discussed at length by many writers since its establishment in 1820 by Say.[1] Among the later descriptions that of Pervinquière [2] is particularly useful for Cretaceous species. The extensive treatise of Jourdy [3] is the most comprehensive general discussion and affords a compact history of the vicissitudes the genus has undergone since its establishment, a statement of its present scope, range, and other details of highest interest to the student of *Exogyra*. No better characterization is available than that given by Jourdy,[4] which may be translated as follows:

General form.—Arcuate, in a sort of crescent in the narrow, elongated species. The oldest species are unornamented, small, even dwarfed; the later species are often large and ornamented to various degrees.

Upper (right) valve.—Generally flat, thin, operculiform, marked by concentric growth lines disposed in spirals whose center is at the beak, placed at the posterior summit of the shell. Sometimes radial ribs, rarely tubercles.

Lower (left) valve.—Deep, carinate, and with helicoid beak in proportion as the area of attachment is less extended; absolutely flat in the case of maximum area of attachment. Sometimes winglike expansions beneath the hinge. The ornamentation consists of concentric striae, more or less lamellose, or of radial ribs, more or less fine, rarely tuberculated or spinose.

Hinge.—The hinge of the lower valve, in youth and in small species, reduced to a ligamental groove, twisted and without thickened lateral ridges; that of heavier species is at first anodont but becomes monodont in the most differentiated species, the latter arrangement characterized by a blunt tooth in the upper valve corresponding to a shallow groove or dimple in the lower valve.

As understood by the above characterization, *Exogyra* ranges from the upper Liassic (Toarcian) to the end of the Cretaceous and possibly into the Tertiary, changing, in general, from small, rather flattened, unsculptured species to large, deep-shelled, sculptured species.

Pervinquière,[5] dealing chiefly with Cretaceous forms, divided *Exogyra* into groups whose limits, he says, "are often difficult to define" and which are possibly to be viewed as subgenera. These groups are:

1. Group of *E. costata* Say.
2. Group of *E. latissima* Lamarck (*couloni-aquila*) (=*Aetostreon* Bayle).
3. Group of *E. columba* Lamarck (=*Rhynchostreon* Bayle).
4. Group of *E. africana* Coquand.
5. Group of *E. haliotidea* Sowerby.
6. Group of *E. flabellata* Goldfuss (=*Ceratostreon* Bayle).

Jourdy [6] considered Pervinquière's grouping not sufficiently comprehensive and lacking the phylogenetic viewpoint and proposed another, as follows:

A. Gibbous and smooth line derived from *E. monoptera* Deslongchamps; several species show a suggestion of excrescences, *E. arduennensis* D'Orbigny, *E. larteti* Coquand.

B. Shallow, smooth line derived from *E. lingulata* (Walton) Lycett, continued by *E. rauliniana* D'Orbigny, *E. haliotidea* Sowerby, *E. bourgeoisi* Coquand, *E. auricularis* Goldfuss.

C. Smooth line carried to the end of the Jurassic by *E. nana* Sowerby and branching in the Cretaceous into two lines:

C_1. An entirely unsculptured line including *E. tombeckiana* D'Orbigny; large forms like *E. aquila* Goldfuss; *E. conica* Sowerby; *E. langloisi* Coquand; a few forms inclined to become spinose, *E. couloni* Defrance, *E. plicifera* Dujardin.

C_2. A lamellose line apparently beginning with *E. polygona* Von Buch, continued by *E. africana* Lamarck, *E. deletrei* Coquand, *E. subfimbriata* Coquand, etc. Through *E. ponderosa* Roemer it produced *E. costata* Say, and through other lamellose forms, *E. overwegi* Von Buch, *E. texana* Roemer,[7] *E. fourneti* Coquand.

D. Sculptured Jurassic line, derived from the line of *E. nana* through *E. praevirgula* Douvillé and Jourdy, the source of the ornate species which are the most numerous and most beautiful of the genus. There are two lines:

D_1. Line of *E. virgula* Defrance, with very fine, regular costation, including *E. larteti* Coquand, *E. suborbiculata* Lamarck, *E. decussata* Goldfuss, *E. columba* Lamarck.

D_2. Line of *E. catalonica* Loriol with strong ribs, derived from *E. virgula* through *E. welschi* Jourdy. It reaches the Cretaceous through *E. minos* Coquand and continues by *E. callimorphe* Coquand, *E. boussingaulti* D'Orbigny, *E. harpa* Forbes, *E. olisiponensis* Sharpe, *E. flabellata* Goldfuss, *E. matheroniana* D'Orbigny, *E. laciniata* Nilsson, *E. lemeslei* Jourdy.

[1] Say, Thomas, Observations on some species of zoophytes, shells, etc., principally fossil: Am. Jour. Sci., vol. 2, p. 43, 1820.

[2] Pervinquière, Léon, Études de paléontologie tunisienne, pt. 2, Gastropodes et lamellibranches des terrains crétacés, pp. 172-193, Paris, 1912.

[3] Jourdy, Edmond, Histoire naturelle des Exogyres: Annales de paléontologie, vol. 13, pts. 1, 2, 1924.

[4] Idem, p. 97.

[5] Pervinquière, Léon, op. cit., p. 172.

[6] Jourdy, Edmond, op. cit., p. 91.

[7] *E. texana* has been placed by many authors under *E. flabellata* and surely belongs to the same group. Jourdy must have placed the species here by error instead of in the group D_2.

Jourdy notes the lack of important variations in the sculpture of the upper (right) valve. It shows from the earliest species the well-defined spiral trace of the beak and only in a few species any but concentric sculpture. The helix of the beak of the lower (left) valve also enters but little into the evolution of either genus or species. The very earliest forms are so strongly attached that they do not show a helix, though it is present in the oldest forms of *E. nana* (Callovian). Slender beaks are the more numerous and persist almost to the end of the Cretaceous, though the best-developed helices appear in the Upper Cretaceous. In a general way the forms that end the several genetic lines have the best development of dentate hinge, ornamented surface, and helicoid beaks, and there is a progression from simpler early types to more complex later types.

Exogyra olisiponensis Sharpe

Plates 65–68; Plate 69, Figures 1–4.

1850. *Exogyra olisiponensis* Sharpe, Geol. Soc. London Quart. Jour., vol. 6, p. 185, pl. 19, figs, 1, 2.

1862. *Ostrea overwegi* Coquand (not Von Buch), Soc. émulation Provence Mém., vol. 2, p. 226, pl. 19, figs. 1–6.

1862. *Ostrea coquandi* Julien. Coquand, op. cit., p. 324, pl. 33, figs. 10–12.

1864. *Ostrea (Exogyra) cornuarietis* Meneghini (not Goldfuss), Soc. ital. sci. nat. Atti, vol. 6, p. 412, pl. 4, figs. 1 a–c.

1869. *Ostrea olisiponensis* Sharpe. Coquand, Monographie du genre *Ostrea*, terrain crétacé, p. 125, pl. 45, figs. 1–7.

1869. *Ostrea overwegi* Coquand (not Von Buch), op. cit., p. 140, pl. 44, figs, 1–7 (8–9?); pl. 46, figs. 14–15.

1872. *Ostrea olisiponensis* Sharpe. Lartet, Annales sci. géol., vol. 3, p. 59, pl. 11, figs. 1–2.

1875. *Exogyra ponderosa* White (not Roemer), U. S. Geog. Surveys W. 100th Mer. Rept., vol. 4, pt. 1, p. 172, pl. 14, figs. 1 a–c.

1877. *Ostrea olisiponensis* Sharpe. Lartet, Exploration géologique de la Mer Morte, p. 138, pl. 9, figs. 1–3.

1880. *Ostrea oxyntas* Coquand, Acad. Hippone Bull. 15, p. 170.

1882. *Exogyra oxyntas* Coquand. Seguenza, R. accad. Lincei Atti, ser. 13, vol. 12, p. 178, pl. 18, figs. 1 a–c.

1882. *Exogyra olisoponensis* Sharpe. Seguenza, op. cit., p. 180. pl. 17, figs. 2 a–b.

1886. *Exogyra pseudoafricana* (part) Choffat, Faune crétacique du Portugal, vol. 1, ser. 1, p. 38 (not Ostreidae, pl. 4, figs. 1–4); ser. 4, Ostreidae, pl. 6, fig. 14 [1902].

1891. *Ostrea olisiponensis* Sharpe. Peron, Exploration scientifique de la Tunisie, pt. 4, Invertébrés fossiles des terrains crétacés, p. 114, pl. 23, figs. 14–18.

1902. *Ostrea (Exogyra) olisiponensis* Sharpe. Choffat, Faune crétacique du Portugal, vol. 1, ser. 4, p. 166, Ostreidae, pl. 6, figs. 17–19.

1903. *Exogyra olisiponensis* Sharpe. Fourtau, Inst. égyptien Bull., ser. 4, vol. 4, p. 283, text figs. 3–5.

1903. *Exogyra olisiponensis* Sharpe var. *duplex*, Paulcke, Neues Jahrb., Beilage-Band 17, p. 269, pl. 15, figs. 7, 8.

1905. *Ostrea (Exogyra) olisiponensis* Sharpe. Choffat, Contributions à la connaissance géologique des colonies portugaises d'Afrique, pt. 2, Nouvelles données sur la zone littorale d'Angola, p. 44, pl. 1, figs. 4, 5.

1911. *Ostrea (Exogyra) olisiponensis* Sharpe. Woods, in Falconer, The geology and geography of northern Nigeria, app. 2, p. 277, pl. 20, figs. 1–3.

1912. *Exogyra olisiponensis* Sharpe. Pervinquière, Études de paléontologie tunisienne, pt. 2, Gastropodes et lamellibranches des terrains crétacés, p. 174, pl. 13, figs. 4, 5, 9.

1918. *Exogyra olisiponensis* Sharpe? Böse, Texas Univ. Bull. 1856, p. 230, pl. 20, fig. 4.

1927. *Exogyra olisiponensis* Sharpe. Reeside, in Wasson and Sinclair, Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 1268, pl. 11, figs. 1–3.

Sharpe's original description of the species, based on material from the "Hippurite limestone" at Lisbon, Portugal, is as follows:

> Shell nearly hemispherical; upper valve thick, slightly gibbose, covered with regularly concentric scales, the beak incurved in the plane of the valve; lower valve very thick and very gibbose, regularly rounded on the anterior margin and somewhat produced posteriorly; the surface squamose, with the edges of the scales raised up into short ribs, of which there are 10 or 12 near the margin of an old shell; in some specimens the ribs are nearly continuous; in others they only occur near the margin of the scales, while in others they are hardly visible; the surface of the valve between the ribs is nearly smooth; beak of the lower valve laterally involute; the surface of attachment usually small.

Coquand in his earlier work [8] assigned to *E. olisiponensis* only distantly ribbed, somewhat spinose, keeled shells, assigning to *E. overwegi* Von Buch the finer-ribbed, rather evenly sculptured, well-rounded forms. Under *E. overwegi* he distinguished five varieties—*costulata*, *scabra*, *rugosa*, *reticulata*, and *laevigata*. Coquand later [9] noted that the real *E. overwegi* was a different and much later type and renamed his material *E. oxyntas*. Coquand cited *E. olisiponensis* from southern France, Spain, Portugal, Algeria, and Palestine. He cited his *E. overwegi* (=*oxyntas*) from Sicily, Tripoli, Tunisia, Palestine, southern France, and Spain.

Meneghini [10] assigned to *E. cornuarietis* Goldfuss nearly smooth forms of *E. olisiponensis* from Sicily.

Lartet [11] followed Coquand in his use of the names *E. overwegi* and *E. olisiponensis* as applied to specimens from Palestine, putting the relatively fine-ribbed forms into the first and the more coarsely ribbed forms into the second species.

Seguenza [12] also followed Coquand in distinguishing *E. olisiponensis* from *E. oxyntas*. Under *E. olisiponensis* he named three varieties—the typical form, var. *ecostata*, and var. *prominens*. Under *E. oxyntas* he accepted Coquand's five varieties and added four more—*ecostata*, *italica*, *asperrima*, and *brancaleonensis*.

[8] Coquand, Henri, Géologie et paléontologie de la région sud de la province de Constantine: Soc. émulation Provence Mém., vol. 2, p. 226, pl. 19, figs. 1–6, 1862; Monographie du genre *Ostrea*, terrain crétacé, pp. 125, 140, pl. 44, figs. 1–7; pl. 45, figs. 1–7, Marseille, 1869.

[9] Coquand, Henri, Études supplémentaires sur la paléontologie algérienne: Acad. Hippone Bull. 15, p. 170, 1880.

[10] Meneghini, Giuseppe, Studii paleontologici sulle ostriche cretacee di Sicilia: Soc. ital. sci. nat. Atti, vol. 6, p. 412, pl. 4, figs. 1 a–c, 1864.

[11] Lartet, Louis, Essai sur la géologie de la Palestine: Annales sci. géol., vol. 3, p. 59, pl. 11, figs. 1–2, 1872.

[12] Seguenza, Giuseppe, Studi geologici e paleontologici sul cretaceo medio dell, Italia meridionale: R. accad. Lincei Atti, ser. 3, vol. 12, pp. 178–180, pl. 17, figs. 2–2b; pl. 18, figs. 1–1c, 1882.

The variety *brancaleonensis*, so far as one may judge from figures, has the broad rounded ribs of the *costata* group rather than the narrow ribs of the earlier group to which *E. olisiponensis* belongs. Seguenza's specimens came from Sicily.

Choffat [13] seems to have included in his *E. pseudoafricana* feebly costate shells that belong to *E. olisiponensis*, believing that the second species were derived from the first. Choffat also called attention to the radial ribs on the upper valves of many individuals of *E. olisiponensis*, a feature that had escaped record by the previous students of the species.

Peron [14] united *E. oxyntas* and parts of certain other species, as conceived by Coquand, with *E. olisiponensis*. He showed that the presence of a keel on the shell is a very variable feature: in Sharpe's type its prominence is accidental and due to the large size of the area of attachment, and it is not the important character which Coquand thought it to be. Peron noted the great range of variability in size, form, and both concentric and radial sculpture that may be met in a large collection and was inclined to consider *E. pseudoafricana* Choffat as belonging to *E. olisiponensis* and also part of *E. trigeri* Coquand. Peron dealt with material from Tunisia and assigned it to the Cenomanian.

Choffat [15] in a later paper did not accept Peron's assimilation of *E. oxyntas* and *E. olisiponensis*. He also recanted his earlier opinion of relationship between *E. pseudoafricana* and *E. olisiponensis* and gave the range of *E. olisiponensis* as from upper Cenomanian to upper Turonian, assigning the type locality to the upper Turonian. On the basis of about 100 specimens from the type locality (Alcantara, near Lisbon, Portugal), he gave an emended diagnosis of the species which may be translated as follows:

> Shell inequivalve, higher than wide in youth; in adult age the dimensions are equal, or the width is greater than the height. Outline oval or subcircular, anterior border rectilinear, forming generally a rounded angle with the pallial border.
>
> Upper valve oval, thick, lightly and irregularly convex, with beak recurved in the plane of the shell, smooth or nearly smooth in the earliest stages, then acquiring growth lamellae that are vertical, sharp, crowded closely together, bifurcating and uniting again in a short distance. Besides the concentric lamellae there are radial swellings irregular, generally narrow, raised (as much as 3 millimeters), hardly any wider at base than at summit; they are irregularly spaced and seem sometimes to bifurcate. They rarely appear at a diameter of 10 millimeters, but generally at that of 20 millimeters, but I know only two specimens in which they appear as late as in the specimen figured by Sharpe. Their number ranges from 7 to 12.
>
> Lower valve very thick, very gibbous, the anterior third more or less flattened and the rest of the shell regularly rounded with beak generally more or less flattened, as in Sharpe's figure and in my Figure 19; very rarely free, as in my Figure 17. Scar of attachment generally small. The exterior surface is ornamented by growth lamellae, often raised along radial lines, forming sometimes continuous ribs, lamellose, spinose when well preserved, more or less widely spaced, reaching to the beak when attachment does not prevent. Some disappear before reaching the pallial border; others appear on the middle of the shell. Their distance apart and consequently their number is variable; the original of Sharpe and that of my Figure 17 may be considered to have distant ribs, but others have them much nearer. Ligamental groove deep in young individuals and shallow in the older ones. Muscular impression of medium size, near the anterior border.

Paulcke [16] described from Peru *E. olisiponensis* var. *duplex*, founding it on shells with a broad furrow extending from the beak on the posterior side of the lower valve and especially strong radial ribs on the upper valve extending almost from the beak instead of leaving a central area smooth or with only concentric sculpture. With this variety he said he found the typical form of the species.

Fourtau [17] included under *E. olisiponensis* *E. oxyntas* and *E. pseudoafricana*, believing that he had them all together in the Cenomanian of Egypt.

Choffat [18] described from Angola typical *E. olisiponensis* and reiterated his stand of 1902 that *E. pseudoafricana* is distinct.

Schlagintweit [19] recorded *E. olisiponensis* from Peru, suggesting that possibly *E. polygona* Von Buch as figured by Von Buch and Gabb is to be considered identical with *E. olisiponensis*, though he allowed the question to remain open until the originals could be compared.

Woods [20] described from Nigeria specimens of *E. olisiponensis* marked by only a few radial ribs. Woods considered the two Nigerian localities as Turonian, though only one furnished associated species.

Pervinquière [21] described from the middle and upper Cenomanian of Tunisia both typical and varietal forms of *E. olisiponensis*. He united with it *E. oxyntas* Coquand and part of *E. pseudoafricana* Choffat. Pervinquière mentioned six variants (see p. 270), though he saw no advantage in naming them. He believed *E. olisiponensis* to be exclusively Cenomanian.

Böse [22] reported from Coahuila, Mexico, a single specimen which he referred with doubt to *E. olisiponensis* and to the Cenomanian. It is not well preserved but seems to the writer, so far as the figure may indicate, to belong to the species.

[13] Choffat, Paul, Faune crétacique du Portugal, vol. 1, ser. 1, p. 38, 1886; vol. 1, ser. 4, Ostreidae, pl. 6, fig. 14, 1902.

[14] Peron, Alphonse, Exploration scientifique de la Tunisie, pt. 4, Invertébrés fossiles des terrains crétacés de la région sud des hauts plateaux de la Tunisie, pp. 114–119, pl. 23, figs. 14–18, Paris, 1891.

[15] Choffat, Paul, Faune crétacique du Portugal, vol. 1, ser. 4, p. 166, Ostreidae, pl. 6, figs. 17–19, 1902.

[16] Paulcke, Wilhelm, Ueber die Kreideformation in Südamerika und ihre Beziehungen zu anderen Gebieten: Neues Jahrb., Beilage-Band 17, p. 269, pl. 15, figs. 7, 8, 1903.

[17] Fourtau, R., Contribution à l'étude de la faune crétacique d'Égypte: Inst. Égyptien Bull., ser. 4, vol. 4, p. 283, text figs. 3–5, 1903.

[18] Choffat, Paul, Contributions à la connaissance géologique des colonies portugaises d'Afrique, pt. 2, Nouvelles données sur la zone littorale d'Angola, p. 44, pl. 1, figs. 4, 5, Lisbon, 1905.

[19] Schlagintweit, Otto, Die fauna des Vracon und Cenoman in Peru: Neues Jahrb., Beilage-Band 33, p. 109, 1911.

[20] Woods, Henry, The paleontology of the Upper Cretaceous despoits of northern Nigeria, in Falconer, J. D., The geology and geography of northern Nigeria, appendix 2, p. 277, pl. 20, figs. 1–3, London, 1911.

[21] Pervinquière, Léon, Études de paléontologie tunisienne, pt. 2, Gastropodes et lamellibranches des terrains crétacés, p. 174, pl. 13, figs. 4, 5, 9, Paris, 1912.

[22] Böse, Emil, On a new ammonite fauna of the lower Turonian of Mexico: Texas Univ. Bull. 1856, p. 230, pl. 20, fig. 4, 1918.

It appears to the writer, after examination of the many published figures and of the specimens noted below, that there is no really essential difference between *E. oxyntas* and *E. olisiponensis* and that they may be considered one species with variable sculpture. *E. olisiponensis* may then be thought of as including a series of forms ranging in radial sculpture of the left valve from nearly smooth forms through forms with discontinuous irregular ribs to forms with strong widely spaced ribs and forms with closer-set weaker ribs. The ribs are always narrow and the interspaces relatively wide, concave. In concentric sculpture it ranges from nearly smooth forms to forms with conspicuous lamellae raised into high spinose flutings. In size it is usually 50 to 80 millimeters in maximum dimension, though it may reach 165 millimeters. In form it varies less than in sculpture: The outline is usually oval to subcircular; the upper valve is nearly flat; the lower valve is gibbous, regularly rounded. The degree of coiling varies, being dependent on the size of the area of attachment. In large collections all the extreme variants are connected by series of intermediate forms, and no chronologic value appears to attach to individual variants.

Pervinquière's grouping of the variants is perhaps as good as any:

1. Typical form. Upper valve with central part ribless; lower valve with ribs distant, discontinuous, rising into spines.
2. Var. *oxyntas* Coquand. Lower valve with ribs relatively fine, numerous, continuous, not spinose.
3. Var. *duplex* Paulcke. Upper valve with strong radial ribs reaching almost to the nucleus of the shell; lower valve with strong, distant, spinose ribs and with a deep sulcus on posterior side bordered by high ribs.
4. Var. unnamed (=*cornuarietis* Meneghini, not Goldfuss). Lower valve ribbed on only third or half of shell nearest the beak, remainder nearly smooth.
5. Var. unnamed (=*pseudoafricana* Coquand, part). Lower valve nearly smooth or lamellose; ribs very few or weak.
6. Var. unnamed (=*trigeri* Coquand of Peron). Lower valve with lamellae only, raised here and there in flutings; no ribs.

From southern Utah the writer has some 19 specimens assignable to *E. olisiponensis*. To these may be added that figured by C. A. White [23] as *E. ponderosa* Roemer. Sixteen of the specimens came from a locality 2 miles northeast of Notom, Wayne County, Utah, on the road from Notom to Caineville, collected in part by E. M. Spieker and the writer, in part by the late Robert Forrester, of Salt Lake City (U. S. Geol. Survey localities 6942 and 12248). Eight of these specimens are right valves and eight are left valves. A single large specimen was collected by H. B. Waters at a locality 2 miles west of Escalante, Garfield County (U. S. Geol. Survey locality 10401). Two other large specimens were collected years ago in southern Utah by members of the Powell Survey of Colorado River. One of these is marked "Black Bluff," but the second is unlabeled. White's figured specimen came from Impracticable Ridge.

[23] White, C. A., Report upon the invertebrate fossils collected in portions of Nevada, Utah, Colorado, New Mexico, and Arizona: U. S. Geog. Surveys W. 100th Mer. Rept., vol. 4, pt. 1, p. 172, pl. 14, figs. 1 a–c, 1875.

For comparison the writer has three specimens from Colombia collected by Dr. M. A. Rollot; half a dozen specimens from eastern Ecuador collected by J. H. Sinclair and Theron Wasson; and three specimens from Angola collected by C. W. Washburne. Chief dependence was necessarily placed on published figures.

The stratigraphic position of the collection from the locality 2 miles northeast of Notom is at the base of the Mancos shale. The only fossil directly associated with *E. olisiponensis* here is *Gryphaea newberryi* Stanton, which occurs in great abundance, though one of the valves of *E. olisiponensis* was attached to a shell of *Plicatula hydrotheca* White and bears a fairly clear mold of it. Over a large area in Utah, Colorado, and New Mexico *Gryphaea newberryi* marks a zone in which occur lower Turonian species such as *Metoicoceras whitei* Hyatt, and there is every reason to believe that the age at the locality near Notom is the same. The locality 2 miles west of Escalante is near the base of the beds of Colorado age, a horizon definitely lower Turonian. The specimen from Black Bluff grew upon a shell of *Anchura? forresteri* Reeside [24] closely akin to *A. olisiponensis* Choffat, assigned to the lower Turonian.

The following notes on the specimens from Utah will be of service:

Right valves unassigned to varieties (pl. 65, figs. 1–7; pl. 66, fig. 3).—These are very close to various figured right valves. They do not show the ribs extending as close to the nucleus as in Paulcke's specimen,[25] but are much like those figured by Choffat [26] and Peron.[27]

Typical variety (pl. 65, figs. 8–11; pl. 66, figs. 1–2).—Some of the specimens from Utah fit very well Sharpe's figure.[28] They also resemble closely the specimens figured by Choffat [29] and by Peron,[30] though the ribs on the latter are nearly continuous. The forms figured by Woods [31] and Fourtau [32] are closest perhaps to the forms here considered typical though having fewer and weaker ribs and inclining toward the ribless variants. Böse's specimen [33] seems to be closest to those placed here.

Variety duplex Paulcke (pl. 66, figs. 4–11).—One specimen from Utah (pl. 66, figs. 6–8) is very close to Paulcke's type.[34] A second (pl. 66, figs. 4, 5) has

[24] Reeside, J. B., jr., Five new species of Cretaceous mollusks from Colorado and Utah: Washington Acad. Sci. Jour., vol. 18, pp. 1928.
[25] Paulcke, Wilhelm, op. cit., pl. 15, fig. 8.
[26] Choffat, Paul, Faune crétacique du Portugal, vol. 1, ser. 4, Ostreidae, pl. 6, fig. 17 b, 1902; Contributions à la connaissance géologique des colonies portugaises d'Afrique, pt. 2, Nouvelles données sur la zone littorale d'Angola, pt. 1, fig. 5, 1903.
[27] Peron, Alphonse, op. cit., pl. 23, fig. 15.
[28] Sharpe, Daniel, op. cit., pl. 19, fig. 1.
[29] Choffat, Paul, Faune crétacique du Portugal, vol. 1, ser. 4, Ostreidae, pl. 6, fig. 17 a, 1902.
[30] Peron, Alphonse, op. cit., pl. 23, fig. 16.
[31] Woods, Henry, op. cit., pl. 20, figs. 1–3.
[32] Fourtau, R., op. cit., fig. 5.
[33] Böse, Emil, op. cit., pl. 20, fig. 4.
[34] Paulcke, Wilhelm, op. cit., pl. 15, figs. 7–8.

weaker ribs. Choffat's specimen from Angola[35] is very like those from Utah. A fine specimen of the variety *duplex* from Colombia, collected by Dr. M. A. Rollot, of Bogotá, is figured for comparison (pl. 66, figs. 9–11). It is a little stronger in sculpture than those from Utah but otherwise is much like them.

Variety oxyntas Coquand (pl. 67; pl. 68, figs. 1–2).—The specimens from Utah referred to the variety *oxyntas* are not as finely and as evenly ribbed as those figured by Coquand[36] and have more inclination toward a spinose ornamentation but are nevertheless close enough to be placed with them. A specimen figured by Lartet[37] as *E. overwegi* var. *scabra* is much like those from Utah, as is also one figured by Peron.[38] Two specimens from Angola are figured for comparison (pl. 68, figs. 1–2).

Variety forresteri Reeside, n. var. (pl. 68, figs. 3–5; pl. 69, figs. 1–4).—Several large shells from southern Utah, one preserving both valves, seem to differ enough to deserve a new varietal name. The right valve shows an umbonal smooth area bordered by a zone of fine radial striations; the remainder of the surface shows concentric lamellae interrupted by areas of indistinct fine radial striation. The left valve has close-set regular ribs, like those of the variety *oxyntas*, in the umbonal region, but these pass into irregular flutings on the middle of the shell and the latest stages of growth show chiefly the concentric lamellae.

E. ponderosa White (not Roemer)[39] belongs here (pl. 69, figs. 1–2). One of Coquand's figures of *E. overwegi* (= *oxyntas*)[40] suggests the form also. Other comparisons with published figures might be made but seem of rather doubtful value.

Exogyra costata Say

Plate 69, Figures 5–8

1820. *Exogyra costata* Say, Am. Jour. Sci., vol. 2, p. 43.
1828. *Exogyra costata* Say. Morton, Acad. Nat. Sci. Philadelphia Jour., ser. 1, vol. 6, p. 85, pl. 6, figs. 1–4.
[For complete synonymy for years 1828–1926 see Wade, U. S. Geol. Survey Prof. Paper 137, p. 56, 1926.]
? 1927. *Exogyra* cf. *E. overwegi* Von Buch. Trechmann, Geol. Mag., vol. 64, p. 53..
Not 1871. *Exogyra costata* Say. Stoliczka, Palaeontologia indica, Cretaceous fauna of southern India, vol. 3, p. 461, pl. 40, figs. 1–3; pl. 41, fig. 1.

Exogyra costata Say has recently been described in great detail by Stephenson,[41] and there is no need of repeating the discussion here. The species is characterized by attaining a large size; by the well-rounded form of the lower valve; by the sculpture of the lower valve—regularly arranged, simple or bifurcating, broad, flattened ribs separated by very narrow interspaces; by the sculpture of the upper valve—prominent concentric lamellae with rarely radial costae on the posterior portion.

To judge from scattered citations and figures in the literature *E. overwegi* Von Buch is of nearly the same age and very much like *E. costata* in form and sculpture. Whether it is identical can be decided only by comparison of authentic material of *E. overwegi* with *E. costata*. The identity of *E. overwegi* was for long obscured by confusion with *E. olisiponensis* Sharpe (see pp. 268–270), and only in later works has it been correctly interpreted.

The writer has in hand two mutually attached shells of *E. costata* collected by W. T. Lee in the SE. ¼ sec. 11, T. 6. N., R. 69 W., about 5 miles south of Fort Collins, Colo., and just south of Fossil Creek. The horizon is in the sandstone constituting the exposures long known as Fossil Ridge, which has yielded a large fauna listed by Henderson.[42] Stratigraphically the sandstone of Fossil Ridge is near the top of a series of five sandstones which in early work were interpreted as one and named the Hygiene sandstone. Later work by several geologists, especially those examining the region for oil companies, has shown the series to include an interval of some 1,500 feet. The five sandstones are now called, in ascending order, the Hygiene, Terry, Rocky Ridge, Larimer, and Richard sandstone members of the Pierre shale.[43] The Rocky Ridge and Larimer sandstones make Fossil Ridge. The Milliken sandstone member of the Fox Hills sandstone, containing *Sphenodiscus lenticularis* Owen, lies 5,000 to 6,000 feet higher in the section than the sandstones of Fossil Ridge, and the Niobrara formation about 3,000 feet below them. The fossils reported from the sandstones of Fossil Ridge show that they are of upper Campanian age; these include such species as *Baculites ovatus* Say, *Baculites compressus* Say, *Acanthoscaphites? nodosus* Owen, *Placenticeras intercalare* Meek, and *Ptychoceras* sp. An element in the fauna of Fossil Ridge of great interest as joining with *Exogyra costata* in indicating a connection with that of the Gulf series consists of the species *Capulus spangleri* Henderson, *Gyrodes abyssina* (Morton), *Gyrodes crenata* (Conrad), *Anchura haydeni* White, and *Volutoderma clatworthyi* Henderson. In the Gulf series *Exogyra costata* is not usually associated with fauna containing the genus *Placenticeras*, its normal range being higher, but it does at some places so occur.

[35] Choffat, Paul, Contributions à la connaissance géologique des colonies portugaises d'Afrique, pt. 2, Nouvelles données sur la zone littorale d'Angola, pl. 1, figs. 4–5, 1903.

[36] Coquand, Henri, Monographie du genre *Ostrea*, terrain crétacé, pl. 44, figs. 1–7, 1869.

[37] Lartet, Louis, op. cit., pl. 11, fig. 2.

[38] Peron, Alphonse, op. cit., pl. 23, fig. 14.

[39] White, C. A., op. cit., pl. 14, figs. 1 a–c.

[40] Coquand, Henri, Monographie du genre *Ostrea*, terrain crétacé, pl. 44, fig. 5, 1869.

[41] Stephenson, L. W., Species of *Exogyra* from the eastern Gulf region and the Carolinas: U. S. Geol. Survey Prof. Paper 81, pp. 50–53, pl. 16, figs. 3–4; pl. 17, figs. 1–2; pl. 18; pl. 19, figs. 1–4; pl. 20, fig. 1, 1916; The Cretaceous formations of North Carolina: North Carolina Geol. and Econ. Survey, vol. 5, pt. 1, pp. 173–179, pl. 47, figs. 2–5; pl. 48, 1923.

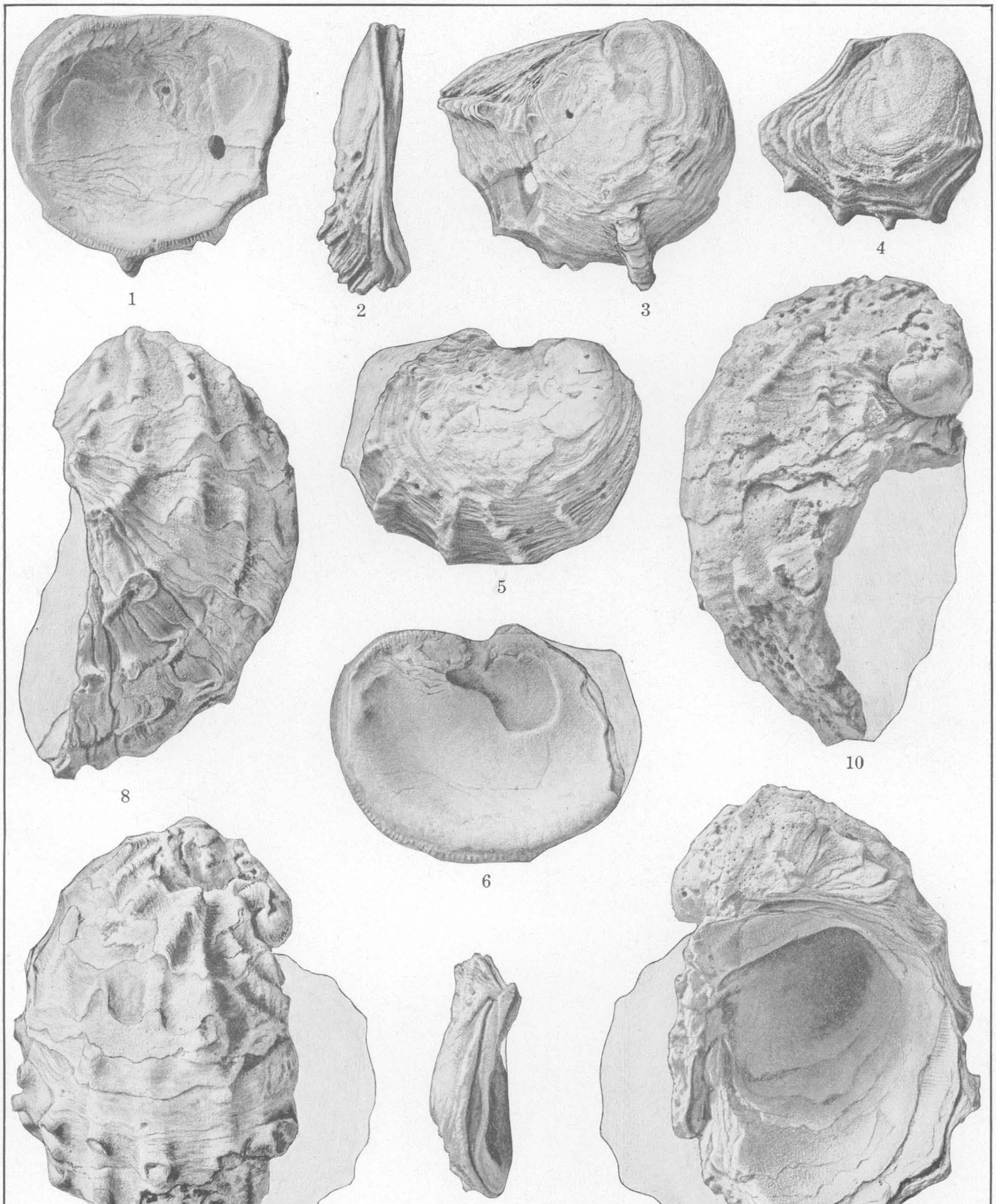
[42] Henderson, Junius, The Cretaceous formations of northeastern Colorado: Colorado Geol. Survey Bull. 19, pp. 31–32, 1920.

[43] Mather, K. F., Gilluly, James, and Lusk, R. D., Geology and oil and gas prospects of northeastern Colorado: U. S. Geol. Survey Bull. 796, pp. 65–124, 1928.

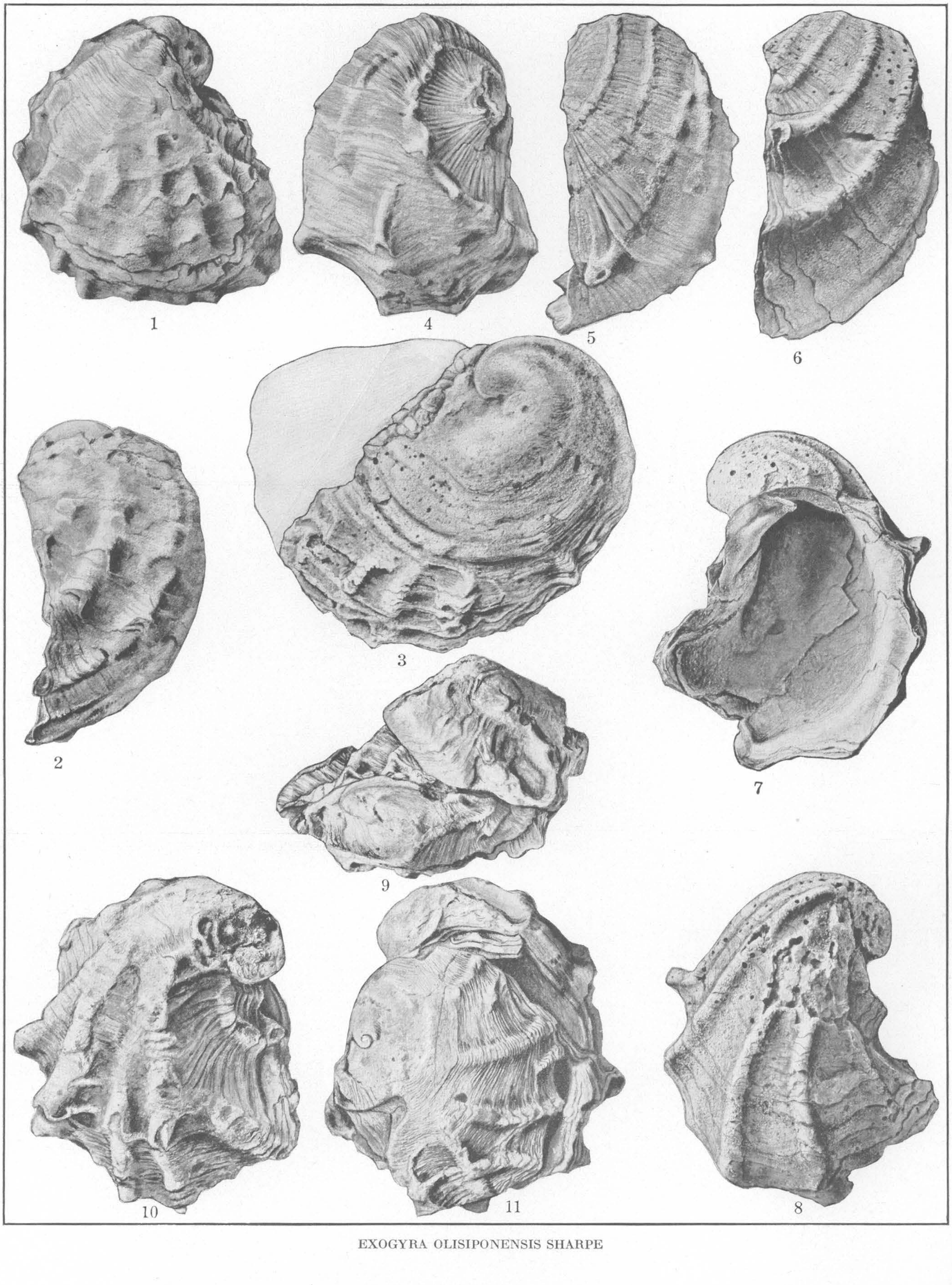
PLATES 65–69

PLATE 65

		Page
FIGURES 1–7.	*Exogyra olisiponensis* Sharpe. Three right valves from the base of the Mancos shale on the road from Notom to Caineville, 2 miles northeast of Notom, Wayne County, Utah. U. S. Nat. Mus. catalogue No. 73613	270
8–11.	*Exogyra olisiponensis* Sharpe, typical variety. Left valve from same locality. U. S. Nat. Mus. catalogue No. 73612	270



EXOGYRA OLISIPONENSIS SHARPE

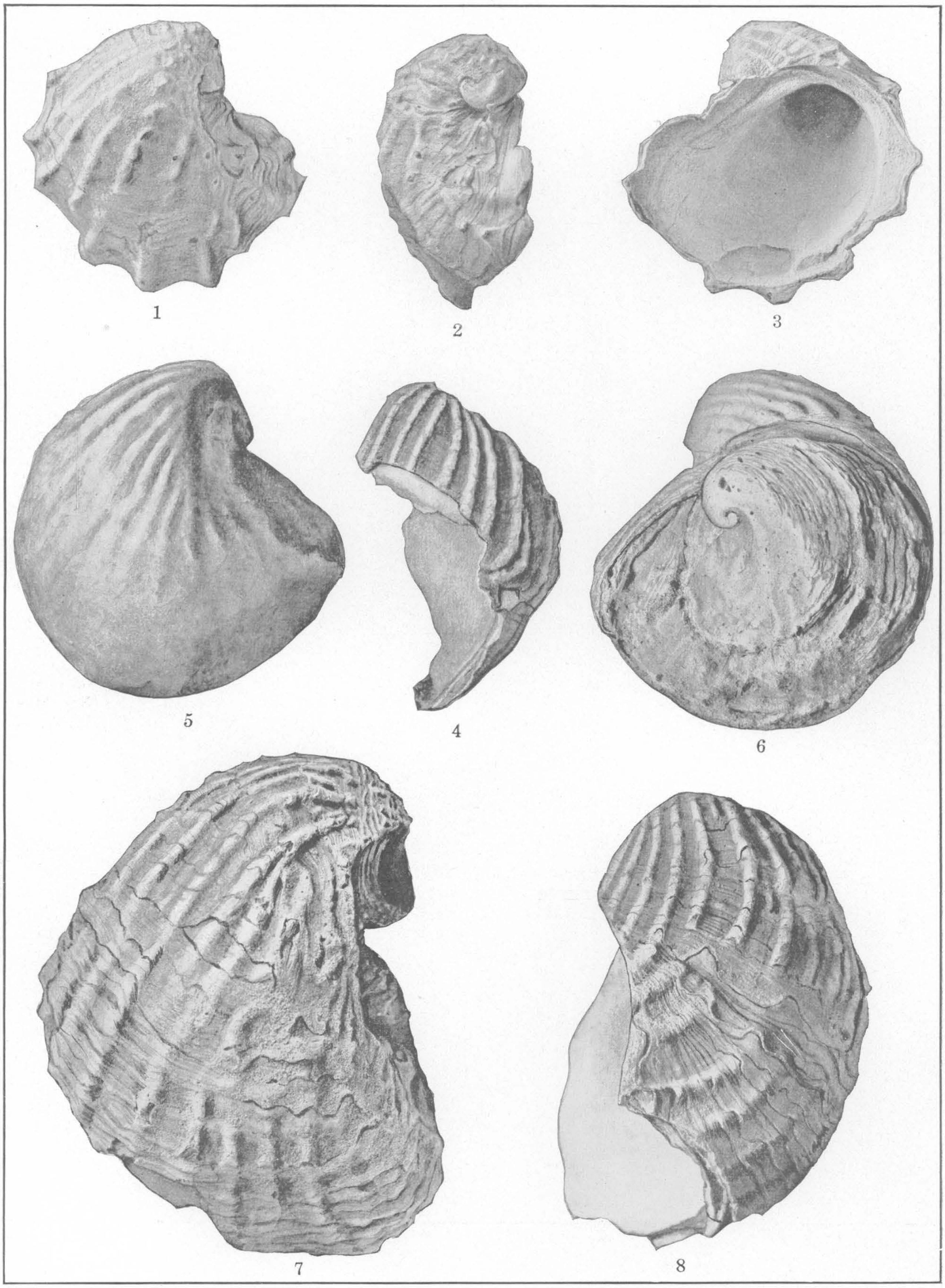


EXOGYRA OLISIPONENSIS SHARPE

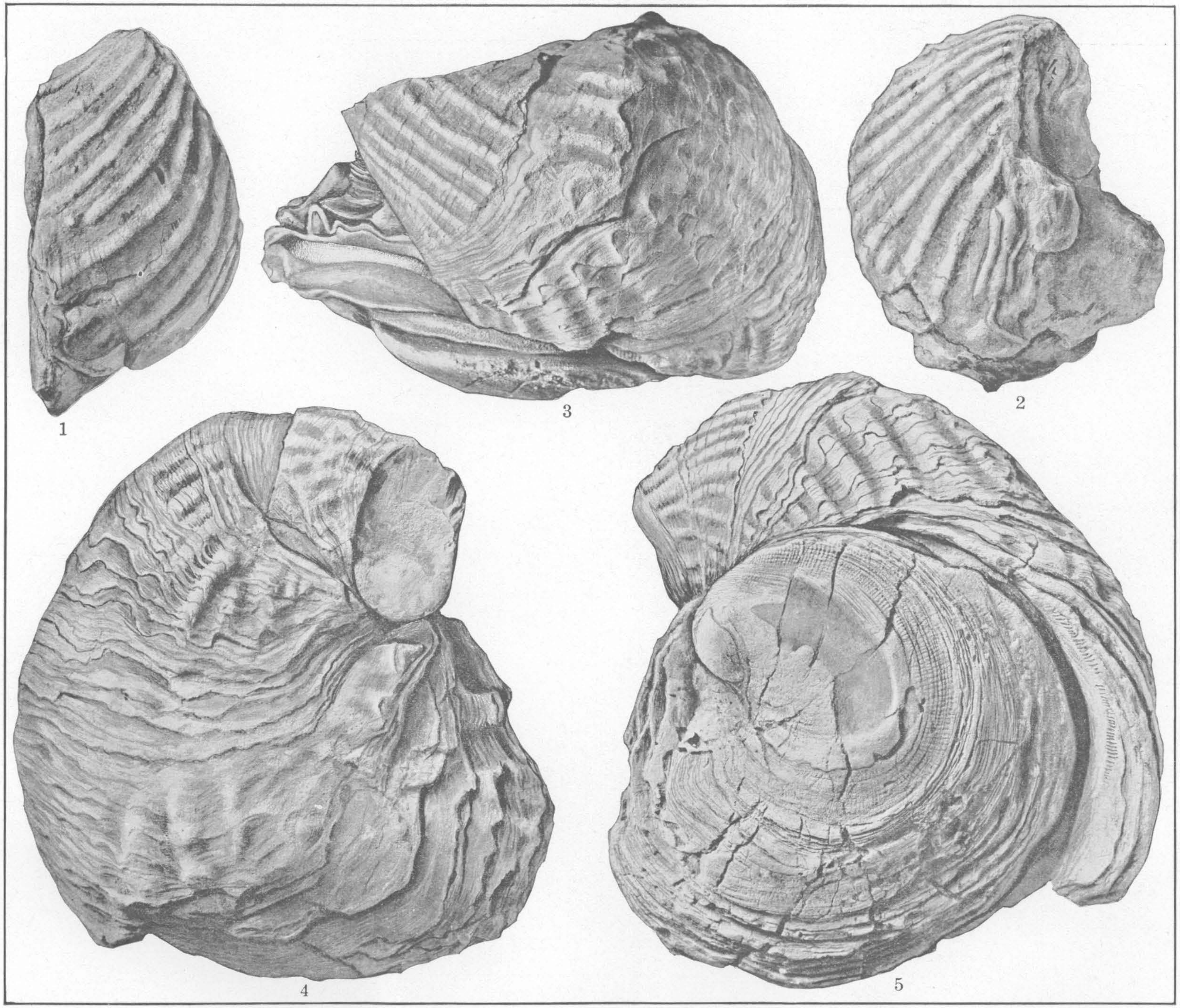
PLATE 66

PLATE 67

		Page
FIGURES 1–3.	*Exogyra olisiponensis* Sharpe var. *oxyntas* Coquand. Left valve from base of Mancos shale on road from Notom to Caineville, 2 miles northeast of Notom, Wayne County, Utah. U. S. Nat. Mus. catalogue No. 73610	271
4.	*Exogyra olisiponensis* Sharpe var. *oxyntas* Coquand. Left valve from same locality. U. S. Nat. Mus. catalogue No. 73610	271
5–6.	*Exogyra olisiponensis* Sharpe var. *oxyntas* Coquand. Complete shell, somewhat weathered, from locality 4 kilometers east of Novo Redondo, Angola, shown for comparison. U. S. Nat. Mus. catalogue No. 73604	271
7–8.	*Exogyra olisiponensis* Sharpe var. *oxyntas* Coquand. Left valve from Black Bluff, Utah. U. S. Nat. Mus. catalogue No. 73611	271



EXOGYRA OLISIPONENSIS SHARPE



EXOGYRA OLISIPONENSIS SHARPE

PLATE 68

PLATE 69

		Page
FIGURES 1–2.	*Exogyra olisiponensis* Sharpe var. *forresteri* Reeside, n. var. Left valve figured by C. A. White as *E. ponderosa* Roemer. Impracticable Ridge, Utah. U. S. Nat. Mus. catalogue No. 13417	271
3–4.	*Exogyra olisiponensis* Sharpe var. *forresteri* Reeside, n. var. Left valve from southern Utah, exact locality unknown. U. S. Nat. Mus. catalogue No. 73608	271
5–7.	*Exogyra costata* Say. Two mutually attached shells from Fossil Ridge, 5 miles south of Fort Collins, Colo. U. S. Nat. Mus. catalogue No. 73606	271

EXOGYRA OLISIPONENSIS SHARPE AND EXOGYRA COSTATA SAY

ADDITIONS TO THE FLORA OF THE GREEN RIVER FORMATION

By Roland W. Brown

This paper adds a number of new species to those already described by other workers as belonging to the flora of the Green River formation. Most of the new species were collected by Prof. O. M. Ball, of the Agricultural and Mechanical College of Texas, during the summers of 1924 to 1926, in the region between the headwaters of Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.[1]

The study of this new material further confirms the opinion expressed by Knowlton [2] that the Green River floral remains represent a mixture of elements from warm lowland and cool upland ecologic provinces. The presence of conifers in this flora, hitherto indicated only by pollen grains in the oil shale, is now further established by the finding of what appear to be coniferous leaves (pl. 70, fig. 4) and a winged seed (pl. 70, fig. 5). The leaves, which I have called *Taxites eocenica*, are suggestive of such genera as *Taxus*, *Taxodium*, *Tumion*, *Abies*, and *Pseudotsuga*. The seed resembles most closely those of living *Picea*, and I have called it *Picea pinifructus*.

The Green River is a middle Eocene formation, about 2,000 feet in thickness, and of threefold character, comprising a lower group of light-brown to buff sandy calcareous shale, a middle group of darker shale, and an upper group of light-colored sandy shale. The formation originally covered an area of about 300 by 150 miles in the contiguous corners of Colorado, Utah, and Wyoming, but erosion subsequent to the time when this area ceased to be a basin of lacustrine deposition and was elevated several thousand feet has deeply dissected parts of it and has thereby isolated patches of the formation.

The most abundant plant fossils are found in the upper part of the formation and are most readily collected at the test pits made by oil-shale prospectors. The principal localities where fossil plants have been found are Green River and Alkali Station, Wyo.; Cathedral Bluffs (20 miles west of Rio Blanco post office); the Smith ranch (on Greasewood Creek 40 miles southwest of Meeker); and on Carr Creek and Brush Creek (30 miles northwest of De Beque), Colorado; and north of White River, Utah.

Lesquereux [3] included the first description of the Green River in his "Tertiary flora" and devoted a chapter to it in his later volume, "Cretaceous and Tertiary floras," but many of the plants which he regarded as belonging to the Green River formation have since been found by a strict definition of the formation to belong at other horizons.

Newberry [4] added a number of species to Lesquereux's list.

Knowlton [5] in 1923 assembled the scattered information on this flora, passed critical judgment upon it, and placed it upon a satisfactory systematic basis for future study. Knowlton's list included 81 species. To that list Cockerell [6] in 1925 added the following new species or new combinations:

- Lejeunea eophila Cockerell.
- Populus wilmattae Cockerell.
- Bumelia coloradensis Cockerell.
- Amorpha utensis Cockerell.
- Clethra? lepidioides Cockerell.
- Potentilla? byrami Cockerell.
- Alsinites revelatus Cockerell.
- Lomatia obtusiuscula Cockerell.
- Banksites lineatulus Cockerell.
- Liquidambar callerche Cockerell.
- Firmianites aterrimus Cockerell.
- Dalbergia knowltoni (Knowlton) Cockerell, n. comb. for Dalbergia retusa Knowlton. Proposed because D. retusa is preempted for a living species.

Berry [7] in 1924 added the new combination *Sparganium antiquum* (Newberry) Berry to include *Brasenia? antiqua* Newberry [8] and *Pontederites hesperia* Knowlton.[9]

[1] The first consignment of this material was studied by me and described in a dissertation for the degree of doctor of philosophy in the department of geology, Johns Hopkins University, May, 1926.

[2] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 147, 1923.

[3] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, 1878; and vol. 8, pp. 127–213, 1883.

[4] Newberry, J. S., U. S. Geol. Survey Mon. 35, pp. 140–151, 1898.

[5] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, pp. 133–182, 1923.

[6] Cockerell, T. D. A., U. S. Nat. Mus. Proc., vol. 66, art. 19, pp. 1–13, 1925.

[7] Berry, E. W., A *Sparganium* from the middle Eocene of Wyoming: Bot. Gaz., vol. 78, pp. 342–348, figs. 1–7, 1924.

[8] Newberry, J. S., U. S. Nat. Mus. Proc., vol. 5, p. 514, 1882; U. S. Geol. Survey Mon. 35, p. 93, pl. 68, fig. 7, 1898.

[9] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 154, pl. 36, fig. 6, 1923.

From the O. M. Ball collections the following new species or new combinations are hereby proposed:

Thallophyta:
- Caenomyces planerae Brown.

Pteridophyta:
- Aneimia delicatula Brown.

Arthrophyta:
- Equisetum winchesteri Brown.

Spermatophyta:
- Taxites eocenica Brown.
- Picea pinifructus Brown.
- Sparganium eocenicum Brown.
- Myrica torreyi Lesquereux.
- Myrica alkalina Lesquereux.
- Hicoria juglandiformis (Sternberg) Knowlton.
- Betula eocenica Brown.
- Planera nervosa Newberry.
- Celtis debequensis Brown.
- Ficus mississippiensis (Lesquereux) Berry.
- Ficus omballi Brown.
- Lomatia coloradensis (Knowlton) Brown.
- Lomatia acutiloba Lesquereux.
- Banksia cockerelli Brown.
- Oreodaphne knowltoni Brown.
- Chrysobalanus lacustris Brown.
- Mimosites debequensis Brown.
- Mimosites falcatus Brown.
- Cassia hesperia Brown.
- Banisteria bradleyi Brown.
- Rhus balli Brown.
- Schmaltzia vexans (Lesquereux) Cockerell.
- Anacardites schinoloxus Brown.
- Celastrophyllum lesquereuxii Brown.
- Celastrophyllum emarginatum Brown.
- Maytenus berryi Brown.
- Thouinia eocenica Brown.
- Ilex affinis Lesquereux.
- Grewiopsis cissifolius Brown.
- Sterculia coloradensis Brown.
- Ternstroemites viridiflumensis Brown.
- Fraxinus petiolata Brown.
- Apocynophyllum wilcoxense Berry.
- Apocynospermum coloradensis Brown.
- Cucurbita glandulosa Brown.

Objects of uncertain identification:
- Phyllites juncoides Brown.
- Carpolithus cassioides Brown
- Carpolithus ellipticus Brown.
- Carpolithus capsularis Brown.
- Carpolithus palmites Brown.
- Carpolithus serratifolius Brown.
- Antholithes vitaciflora Brown.
- Antholithes dubia Brown.
- Antholithes polemonioides Brown.
- Antholithes pendula Brown.
- Caulinites acanthus Brown.
- Caulinites prehensus Brown.
- Rhizocaulon natans Brown.
- Rhizocaulon dichotomum Brown.

Exclusive of the objects of uncertain identification, the grand total of species in the Green River flora is now 130. The distinctly new genera in this flora having living species are as follows:

Aneimia, 50 tropical American species, one reaching the southern part of Florida, types of coastal or even drier regions.

Taxites, which may represent a Temperate Zone coniferous tree growing in a moist situation, like *Taxodium* or *Tumion* on the western slopes of the Sierra Nevada, or *Taxus*, a subordinate forest shrub or tree of the Old and New Worlds.

Picea, 37 species in the colder and temperate regions of the Northern Hemisphere. In the United States the southern limit is northern New Mexico and Arizona and the southern Appalachians. The spruces prefer well-drained mountain slopes or moist situations on elevated plateaus.

Sparganium, 10-12 species rather discontinuously distributed in temperate and cool regions, and growing in wet or in some cases, in submerged situations; 5-6 species range from Newfoundland to British Columbia and south to Florida, Louisiana and California.

Betula, 28-30 species from the Arctic Circle to Texas, to southern Europe, the Himalayas, China, and Japan, and found on alluvial bottoms and mountain slopes.

Planera, a monotypic genus in the warm and wet regions of southeastern North America.

Celtis, a large genus distributed over the world.

Banksia, 50 species confined to Australia in a variety of habitats.

Cassia, 300-400 species in the warmer regions of both hemispheres, some in the temperate zones.

Chrysobalanus, 2-3 species on the sandy coasts of the tropics and subtropics.

Banisteria, 70 species of climbing shrubs from southern Mexico to the West Indies and Brazil.

Schmaltzia, partly synonymous with *Rhus* and of no special significance.

Anacardites, a form-genus for plants assigned indefinitely to the Anacardiaceae.

Celastrus, 27 species in the tropics and subtropics of both hemispheres, but especially in the uplands of southeastern Asia and the East Indies.

Celastrophyllum, a form-genus for indefinite Celastraceae.

Maytenus, 70 species in the Tropics and subtropics of America from southern Florida to Brazil and Chile, inhabitants of coasts and low situations.

Thouinia, 14 species of shrubs and trees in Mexico and the West Indies, growing in rocky coppices and scrub lands.

Grewiopsis. *Grewia* has 80 species, distributed from Arabia to China and Japan, Malaysia, and Australia, and from Abyssinia to South Africa, of mesophytic type.

Sterculia, 100 species in the warmer regions of the world, particularly in the East Indies.

Ternstroemites. *Ternstroemia* has 45 species in tropical America and the warmer parts of Asia and the East Indies, of mesophytic habit.

Fraxinus, 40 species in the temperate regions of both hemispheres and within the Tropics (Cuba and Java), in a variety of habitats.

Cucurbita, 10 species in the warmer regions of America, of mesophytic habit, with a preference for rich, well-drained sandy soil.

Apocynospermum, which includes the fruits of Asclepiadaceae and Apocynaceae.

Forms of uncertain identity can, of course, have little significance in this connection until their identification is more complete.

A glance through the total list of Green River genera and their modern representatives shows, in regard to water requirements, an overwhelming proportion of broad-leaved, mesophytic types. I find no strictly xerophytic types in this flora, although a number of the drier mesophytic forms indicate by their thick, coriaceous foliage an ability to withstand strong insolation and perhaps periods of drought as well as temperatures close to 0° C., without injury. The hydrophytes include microscopic aquatic algae, fungi, and such near-shore plants as *Equisetum*, *Sparganium*, *Arundo*, *Cyperus* (probably), and *Juncus* (probably).

Such a preponderance of subtropical mesophytes and especially the presence of many forms like palms, *Planera*, and *Acrostichum*, which require an abundance of rainfall and a warm climate, but the presence also of temperate forms like *Quercus*, *Populus*, *Betula*, *Juglans*, and *Liquidambar*, point to the conclusion that this flora grew in a warm temperate region, a part of which, at least, received a plentiful supply of rain. It must not be concluded, however, that all the species found fossil together in one locality necessarily grew close together in a comparatively small area. On the contrary, winds and streams conspired to bring together a mixture of types from widely separated localities.

The general region in which this flora flourished was an inland mountain basin, the site of a body of water or series of bodies of water—ponds, lakes, and meandering streams—the whole of which extended at one time or another over a length of some 300 miles north and south and a width of 150 miles east and west. This makes a difference of 4° of latitude between the upper and lower ends of the basin. It seems quite conceivable that local conditions of climate, influenced in part by the mountains that flanked the basin on the north, east, and west, might vary considerably in such a basin. The occurrence of mud cracks locally in this formation is taken to mean playa deposits and periods of drought. Mud cracks, however, are not uncommon in valley and bottom flats in regions that have abundant rainfall but are subject to short periods of drought. It may be that parts of the Uinta Basin area, where the mud cracks are principally found, were subject to more severe droughts than other parts of the Green River Basin and that the evaporation of shallow pools caused the water to become alkaline and to deposit salt in the mud cracks at the next period of flooding and evaporation.

Although local conditions varied throughout the basin, it yet seems possible to formulate a general conclusion concerning the nature of the total environment. I picture a broad, low-lying warm inland region, with shallow ponds, lakes, and marshes, fed by slow streams, which meandered through muddy and sandy swamps as they flowed out of the distant cooler foothills and surrounding mountains. In these waters or in the adjacent open marshes grew *Sparganium*, *Cyperus*, *Arundo*, *Juncus*, *Equisetum*, and no doubt *Potomogeton*, *Alisma*, and other plants whose remains have not yet been found or identified. On the sandy or muddy flats farther back grew palms, *Acrostichum*, *Aneimia*, *Ficus*, *Sophora*, and other Leguminosae, together with such lianes as *Dalbergia* and *Cucurbita*. These were succeeded gradually on drier ground by *Oreodaphne*, *Zizyphus*, *Planera*, *Ternstroemia*, *Maytenus*, *Cinnamomum*, *Lomatia*, *Banksia*, *Myrica*, *Cassia*, *Mimosites*, *Sapindus*, *Celastrus*, *Euonymus*, *Pimelea*, *Thouinia*, *Rhus*, *Taxodium* (if *Taxites* is interpreted as that), and such lianes as *Banisteria*, *Cissus*, and the fern *Lygodium*. Along the streams and adjacent meadows higher in the foothills flourished willows, poplars, *Aralia*, *Ilex*, Apocynaceae, *Clethra*, *Sambucus*, *Juglans*, *Hicoria*, *Liquidambar*, *Potentilla*, *Betula*, *Alsinites*, *Acer*, *Quercus*, *Fraxinus*, species of *Rhus*, *Ailanthus*, and the vine *Parthenocissus*. Oaks and maples finally gave way to forests of pine and spruce at higher altitudes.

Of such an environment as I have conjured up for the Green River flora there is perhaps no exact duplicate on the earth to-day, but the climatic conditions of the southeastern Gulf States plus those of parts of the Great Valley of California would, it seems to me, roughly approximate those of the Green River Lake area.

Phylum THALLOPHYTA

Class FUNGI

Series ASCOMYCETES

Order LABOULBILIALES

Family LABOULBILIACEAE

Genus CAENOMYCES Berry

Caenomyces planerae Brown, n. sp.

A leaf of *Planera nervosa* shows three circular impressions such as have been described by other authors as leaf-spot fungi. The marginal spot is the most conspicuous. It is 2 millimeters in diameter. The center is depressed, as if a heavy mass of material had been there but had been removed with the counterpart to this imprint. No details of structure are distinguishable.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Phylum PTERIDOPHYTA

Order FILICALES

Family SCHIZEACEAE

Genus ANEIMIA Swartz

Aneimia delicatula Brown, n. sp.

Plate 70, Figures 1–2

This fragment is a portion of a bipinnately or perhaps tripinnately divided frond. The lanceolate pinnules are attached by their entire bases, whose margins are decurrent on the rachis and join the pinnules above and below. Distad the pinnules tend to become fused and pass into an acuminate tip. They diverge from the rachis at angles of 45° below but at more acute angles distad. The pinnules are sharply acuminate, with margins carrying few subopposite to alternate, usually simple serrate pointed teeth. Rachis prominent, flexuous. Midrib of pinnules diverges from the rachis at a very acute angle but soon curves outward and branches, though remaining prominent almost to the apex. Few secondaries are given off from the midrib, but these diverge at narrow angles, pursue almost straight courses, and branch dichotomously, the lower branch remaining simple, the upper branch dividing before reaching the margin in a notch or tooth.

A. eocenica Berry,[10] from the Wilcox and Claiborne of the southeastern United States, is very closely comparable to this species but is larger and coarser.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Phylum ARTHROPHYTA

Order EQUISETALES

Family EQUISETACEAE

Genus EQUISETUM Linné

Equisetum winchesteri Brown, n. sp.

Plate 70, Figure 3

This fragment represents a sheath at a node. Length 2 centimeters; width 2 centimeters. There are 30 attenuated teeth, each 7 millimeters long, around the sheath. This is a larger species than *Equisetum wyomingense* Lesquereux [11] but compares in size with the rhizomes of *E. haydenii* Lesquereux.[12] The two may be identical species.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Phylum SPERMATOPHYTA

Class GYMNOSPERMAE

Order CONIFERALES

Family TAXACEAE

Genus TAXITES Brongniart

Taxites eocenica Brown, n. sp.

Plate 70, Figure 4

Small, linear coriaceous leaves, 2.3 centimeters long and 3 millimeters wide, slightly narrowed to the blunt-pointed apex. Base abruptly cuneate or rounded inequilateral. Petiole 2 millimeters long, somewhat curved. Midrib prominent, but no further details of venation are distinguishable. Margin entire, revolute, decurrent, forming a narrow wing on the petiole.

These leaves are suggestive of such coniferous genera as *Taxus*, *Taxodium*, *Tumion*, *Abies*, and *Pseudotsuga*. They differ from *T. olriki* Heer [13] in being more prominently petiolate.

Occurrence: Between Carr and Brush Creeks. 30 miles northwest of De Beque, Colo.

Family PINACEAE

Genus PICEA Link

Picea pinifructus Brown, n. sp.

Plate 70, Figure 5

A winged seed, 1 centimeter long. Boundaries of the seed itself very clearly defined. The seed is elliptical in outline, pointed, and about one-third the length of the entire object. The wing is membranaceous, but no venation is distinguishable. Maximum width of the wing 3 millimeters, near the distal end. Upper margin straight for half its length, then sharply curved downward to the distal point. Lower margin widened about one-third the distance from the distal end, then gradually narrowed toward the seed. Proximal end obliquely truncated and pointed. The upper margin of the wing is slightly more angular than that of living *Picea* seeds, and the maximum width of the wing is slightly more distad.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Subclass MONOCOTYLEDONES

Order PANDANALES

Family SPARGANIACEAE

Genus SPARGANIUM Linné

Sparganium eocenicum Brown, n. sp.

Plate 71, Figure 1

A fragment of a stem, 2 millimeters thick, bearing two mature leaves and the beginning of a third around the growing point. Leaves linear, lanceolate, 10 to 12 centimeters long and 1 centimeter wide medianly, joining the stem by a broad, somewhat expanded, sheathed base. The venation is so obscure that details are indistinguishable, but the stem shows faint parallel striations.

In appearance this form is like some recorded fossil species of *Cyperacites*, *Potamogeton*, and *Poacites*. It resembles most closely *Sparganium valdense* Heer [14] but is somewhat smaller.

Berry [15] has demonstrated clearly that the material described by Newberry [16] as *Brasenia? antiqua* is the

[10] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 164, pl. 9, fig. 7; pl. 10, fig. 2; pl. 11, figs, 1, 2, 1916; U. S. Geol. Survey Prof. Paper 92, p. 41, 1924.

[11] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 69, pl. 6, figs. 8-11, 1878.

[12] Idem, p. 67, pl. 6, figs. 2-4.

[13] Heer, Oswald, Flora fossilis arctica, vol. 1, p. 95, pl. 1, figs. 21-24; pl. 45, figs. 1a b, c, 1868.

[14] Heer, Oswald, Flora tertiaria Helvetiae, pt. 1, p. 100, pl. 45, figs. 6-8; pl. 46, figs. 6, 7, 1855.

[15] Berry, E. W., A *Sparganium* from the middle Eocene of Wyoming: Bot. Gaz., vol. 78, pp. 342-248, 1924.

[16] Newberry, J. S., U. S. Nat. Mus. Proc., vol. 5, p. 514, 1882; U. S. Geol. Survey Mon. 35, p. 93, pl. 68, fig. 7, 1898.

fruiting portion of a *Sparganium* stem and may belong to leaves described by Knowlton [17] as *Pontederites hesperia*. This new combination is called *Sparganium antiquum* (Newberry) Berry. The species I have here described is not well preserved but differs from *Sparganium antiquum* (Newberry) Berry in having narrower leaves.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Subclass DICOTYLEDONES

Order MYRICALES

Family MYRICACEAE

Genus MYRICA Linné

Myrica torreyi Lesquereux

Myrica torreyi Lesquereux, U. S. Geol. Survey Terr. Rept. for 1872, p. 392, 1873; U. S. Geol. Survey Terr. Rept., vol. 7, p. 129, pl. 16, figs. 3–10, 1878.
Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 551, pl. 40, fig. 4, 1886; U. S. Geol. Survey Bull. 37, p. 32, pl. 14, fig. 5, 1887.
Knowlton, U. S. Geol. Survey Bull. 163, p. 34, pl. 6, figs. 1–3, 1900; U. S. Geol. Survey Prof. Paper 98, p. 90, pl. 17, fig. 7, 1915; pl. 86, fig. 1, 1916; U. S. Geol. Survey Prof. Paper 101, p. 256, pl. 37, figs. 2–4, 1918.
Cockerell, Colorado Univ. Studies, vol. 7, p. 150, 1910.

Coriaceous leaves, lanceolate, elongated above the middle to an obtusely acuminate apex. Length 10 centimeters; maximum width, below middle of the blade, 2.3 centimeters. Margin undulate to crenate-serrate below, becoming merely undulate toward the apex. Base cuneate, slightly decurrent. Midrib strong, curved. Secondaries thin, numerous, with intermediaries, diverging from the midrib at wide angles, running almost straight to within a short distance of the margin, some of them forking. Short branches from the secondaries unite to form a thin intramarginal vein and send nervilles into the teeth. Finer nervation not distinguishable.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Myrica alkalina Lesquereux

Plate 71, Figures 2, 3

Myrica alkalina Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 149, pl. 45a, figs. 10–15, 1883.

This specimen tallies very well with Lesquereux's material and seems to be identical or at least very little different, especially in comparison with Lesquereux's Figure 15. That material came from Alkali Station, Wyo.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

[17] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 154, pl. 36, fig. 6, 1923.

Order JUGLANDALES

Family JUGLANDACEAE

Genus HICORIA Rafinesque

Hicoria juglandiformis (Sternberg) Knowlton

Plate 71, Figures 4, 5

Hicoria juglandiformis (Sternberg) Knowlton, U. S. Geol. Survey Bull. 152, p. 117, 1898.
Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 80, 1908.
Phyllites juglandiformis Sternberg, Versuch einer geognostich-botanischen Darstellung der Flora der Vorwelt, vol. 4, index 40, pl. 36, fig. 1, 1825.
Juglans bilinica Unger, Genera et species plantarum fossilium, p. 469, 1850.
Carya bilinica (Unger) Ettingshausen, Die fossile Flora des Tertiär-Beckens von Bilin, pt. 3, p. 46, pl. 51, figs. 4–6, 13–15; pl. 52, figs. 3, 4, 7–11, 1869.
Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 191, pl. 39, figs 1, 2, 13, 1883.

Coriaceous, lanceolate-elongate leaflets, 10 centimeters long, 3 centimeters wide just above the base. Inequilateral, rounded at the base of the wider portion of the blade, cuneate at the base of the narrower portion. Petiole 1 centimeter long, 1 millimeter thick. Margin finely serrate throughout except for a short distance near the base. Midrib prominent. Secondaries numerous, thin, obscure in these specimens, diverging from the midrib at an angle of almost 90°, little curved until near the margin, then abruptly camptodrome. Finer nervation not distinguishable.

This species, new to the Green River flora as now conceived, coincides with the form described by Lesquereux as *Carya bilinica* from Florissant, where it is fairly abundant. *Hicoria juglandiformis*, if not identical with *Carya bilinica*, would certainly seem to be ancestral to it. Both Unger and Ettingshausen, referred to above, show excellent figures of what seems to be the same species.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order FAGALES

Family BETULACEAE

Genus BETULA Linné

Betula eocenica Brown n. sp.

Plate 71, Figure 6

Slightly equilateral leaves of fine texture, ovate outline, and pointed apex. Length, 3 to 5 centimeters; width, 2 to 4 centimeters below the middle of the lamina. Petiole apparently short. Margin sinuate-dentate with few, widely spaced, blunt teeth. Midrib prominent, flexuous. Secondaries, five pairs, alternate, diverging from the midrib at 50°, almost straight near the base of the leaf but becoming gradually curved toward the apex, all of them craspedodrome to the blunt teeth, occasionally branching to a subordinate tooth. Finer areolation indistinct.

This form resembles *B. heterodonta* Newberry,[18] from the upper Clarno beds of Oregon and the Oligocene of Quilchena, British Columbia. It is not unlike *B. gracilis* Ludwig, described by Lesquereux [19] from Golden, Colo., but doubtfully referred to *Betula*.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order URTICALES

Family ULMACEAE

Genus PLANERA Gmelia

Planera nervosa Newberry

Plate 71, Figures 7–9

Planera nervosa Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 508, 1882; U. S. Geol. Survey Mon. 35, p. 83, pl. 67, figs. 2, 3, 1898.

Myrica praedrymeja Knowlton, U. S. Geol. Survey Prof. Paper 131, p. 157, pl. 36, figs. 1–3, 1923.

Leaves of firm texture, variable in size and shape but nevertheless retaining certain specific distinguishing characteristics. Length, 2 to 7 centimeters; maximum width median, from 6 millimeters to 2.7 centimeters. Linear-elliptic or ovate-elliptic to broadly lanceolate. Apex acute or rounded; base equilateral to slightly inequilateral, cuneate to cuneate-rounded. Petiole stout, 2 to 6 millimeters long. Margin entire for a short distance above the base, then undulate to crenulate-serrate, with large, rounded, sometimes minutely pointed teeth. Midrib strong, straight, or curved. Secondaries numerous, 12 to 18 pairs, alternate, parallel, equidistant, diverging from the midrib at 45°, straight or slightly curved but curving perceptibly upward into the teeth. Finer nervation of transverse connections between the secondaries, and a network of irregular quadrate meshes.

These leaves suggest very strongly the foliage of the Ulmaceae, and on the basis of foliar resemblance alone they might perhaps better be designated *Zelkowa* than *Planera*. The four living species of *Zelkowa* are distributed in the region of the Caspian Sea, the Caucasus, and Japan. *Planera* is a monotypic genus restricted to the Atlantic Coastal Plain of the southern United States. The leaves of *P. aquatica* differ from those of *P. nervosa* in being more inequilateral and in having usually doubly serrate teeth.

This species is less inequilateral than *Planera inaequilateralis* (Lesquereux) Knowlton.[20] It may be that *P. inaequilateralis* represents extreme variants in leaf form of *P. nervosa*. In some variants of these leaves there is a strikingly close approach to those Florissant forms described by Lesquereux [21] as *Planera longifolia*. The chief interest in this connection is that *Planera longifolia*, because of the finding of fruits with the leaves, has turned out to be closely related to if not identical with *Fagus* and has been renamed *Fagopsis longifolia* (Lesquereux) Hollick.[22] No fruits of *Ulmus*, *Planera*, or *Fagus* have come to light in the Green River formation; but it is hoped that such evidence may be found and that it may clarify our knowledge as to the exact generic identity of these forms. *Myrica praedrymeja* Knowlton [23] matches in figure and description a number of specimens of *P. nervosa* in this collection and therefore comes under this new designation.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus CELTIS Tournefort

Celtis debequensis Brown, n. sp.

Plate 72, Figure 1

Leaf of fine texture, lanceolate, somewhat pointed, inequilateral. Length 5 centimeters, width 1.75 centimeters just above the base. Apex acute, base rounded to cuneate. Margin serrate with fine teeth. Petiole 1 centimeter long, thin. Midrib slender. Secondaries 7 or 8 pairs, alternate, branching from the midrib at angles of 40° or less, slightly curved, ending in the marginal teeth. Nervilles connecting the secondaries transverse. Further nervation irregular quadrate meshes.

This species seems to have been a forerunner of *C. mccoshii* Lesquereux,[24] from Florissant, Colo., and Uinta County, Wyo.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family MORACEAE

Genus FICUS Linné

Ficus mississippiensis (Lesquereux) Berry

Ficus mississippiensis (Lesquereux) Berry, U. S. Geol. Survey Prof. Paper 131, p. 9, pls. 6, 7, 8, 1923. See synonymy given by Berry.

In the reference given above Berry has discussed the genetic interrelationship of a number of similar species of fossil *Ficus* and has proposed the new combination to include the forms listed in his synonymy. One specimen in this collection conforms to the description and figures given by Lesquereux for *Ficus pseudopopulus*, and that, being included in Berry's

[18] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 64, pl. 44, figs. 1–4; pl. 45, figs. 1, 6, 1898.

[19] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 138, pl. 17, fig. 20, 1878.

[20] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 161, 1923.

[21] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 189, pl. 27, figs. 4–6, 1878.

[22] Knowlton, F. H., U. S. Nat. Mus. Proc., vol. 51, p. 265, pl. 20, fig. 5, 1917.

[23] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 157, pl. 36, figs. 1–3, 1923.

[24] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, p. 163, pl. 38, figs. 7, 8, 1883.

synonymy, therefore comes under this new designation.

This species resembles at once *Cinnamomum*, *Zizyphus*, *Populus*, and *Ficus*, a fact that Lesquereux remarked. It differs from *F. wyomingiana* Lesquereux [25] by the presence of secondary nerves in the upper half of the leaf. However, *F. wyomingiana* may be only a variety or even abnormal form of *F. pseudopopulus* and therefore may also be classed under *F. mississippiensis*. *F. pseudopopulus* has been described as being abundant in the Raton formation. It is also found in the Wilcox group of Tennessee.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Ficus omballi Brown, n. sp.

Plate 72, Figure 2

A fine, large, ovate-lanceolate leaf of firm texture. Length 14 centimeters; width 4.2 centimeters about 4 centimeters above the base. Apex not present in this specimen but apparently acute; base equilateral, rounded. Midrib prominent, secondaries numerous, with scattered intermediaries, diverging from the midrib at right angles, parallel, slightly curved and united near the margin to form a conspicuous intramarginal vein. The nervilles between the secondaries form a network of large irregular meshes.

This species resembles closely the living *F. glabrata*, of Panama, and also an apocynaceous form, *Ranwolfia tetraphylla*, of Cuba. Among closely related fossils is *F. newtonensis* Berry.[26]

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order PROTEALES

Family PROTEACEAE

Genus LOMATIA Robert Brown

Lomatia coloradensis (Knowlton) Brown

Plate 72, Figures 3–6

Phyllites coloradensis Knowlton, U. S. Geol. Survey Prof. Paper 131, p. 176, pl. 38, fig. 3, 1923.
Lomatia obtusiuscula Cockerell, U. S. Nat. Mus. Proc., vol. 66, art. 19, p. 7, pl. 1, fig. 4, 1925.

Coriaceous leaves, pinnately once or twice compound, the ultimate leaflets themselves entire or irregularly lobed. The terminal leaflet is generally larger and more lobed than the laterals. Lobes pointed or obtuse. Angles between lobes rounded or acute. Margins entire, decurrent, forming a narrow alation on the rachis. Petiolules of the terminal leaflets 1 centimeter or less in length. Lateral leaflets ovate-lanceolate, sessile or nearly so. Rachis slightly alate, heavy, flexuous. Midrib of leaflets strong, curved. Secondaries to lobes distinct, diverging from the midrib at 50°, straight or slightly curved, sometimes excurrent into a blunt point. Subordinate secondaries of the lobed leaflets and secondaries of the entire leaflets obscure, but from 4 to 6 pairs, alternate, diverging from the midrib at wide angles, each arching well within the margin to the secondary next above. Minute areolation not distinguishable.

The generic reference for these forms is somewhat doubtful. In the living Proteaceae, the name of which indicates their great diversity of characters, the forms of the leaves vary so much that differentiation on that basis is of uncertain validity. The leaves of some genera simulate those of *Myrica*, *Sapindus*, *Phacelia*, and others. In venation and form some of the specimens in the collection resemble certain living species of *Sapindus* and such fossil species as *S. affinis* Newberry and *S. angustifolius* Lesquereux.[27] Some of the elongated, lobed terminal leaflets may also be compared with *Myrica oeningensis* Heer.[28]

This species was evidently closely related to *Lomatia tripartita*, *L. terminalis*, and *L. spinosa* Lesquereux,[29] from Florissant. Cockerell remarked on the compoundness of the leaves of *L. tripartita*.[30]

From the evidence shown by material in this collection it seems altogether justifiable to include *Phyllites coloradensis* Knowlton under this designation, as in the synonymy above.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Lomatia acutiloba Lesquereux

Lomatia acutiloba Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 167, pl. 43, figs. 11–16, 20, 1883.
Cockerell, Am. Naturalist, vol. 42, p. 579, fig. 10,1908.

A coriaceous, deeply divided leaf. Lobes linear-lanceolate, blunt at the apex, sessile along the entire base, which is decurrent to the lobe next below. The lobes spread away from the main axis at narrow angles and are widely and alternately spaced. Margins entire. Main axis slender and flexuous. Midribs of lobes prominent, diverging from the axis at acute angles, bending upward in the lobes and extending to their apices. Secondary venation not observable.

This specimen resembles most closely the type to which it is referred, which comes from Florissant. It is also like *Lomatia* (*Todea*) *saporteana* Lesquereux.[31]

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

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25 Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 205, pl. 34, fig. 3, 1878.
26 Berry, E. W., U. S. Geol. Survey Prof. Paper 92, p. 58, pl. 9, figs. 1–3, 1924.
27 Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 116, pl. 30, fig. 1, 1898. Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, 265, pl. 49, figs. 2–7, 1878.
28 Heer, Oswald, Flora tertiaria Helvetiae, pt. 2, p. 33, pl. 70, figs. 1–4, 1856.
29 Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, pp. 166, 167, pl. 43, figs. 1–10, 1883.
30 Cockerell, T. D. A., Am. Naturalist, vol. 42, p. 577, figs. 8–9, 1908.
31 Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 6, p. 48, pl. 29, figs. 1–4, 1874.

Genus BANKSIA Forster

Banksia cockerelli Brown, n. sp.

Plate 72, Figure 7

Coriaceous, linear leaves, at least 11 centimeters long and 1 centimeter wide at about the middle of the leaf. Apex acute, base narrowly cuneate. Nature of petiole not known, because lower part of leaf is missing. Margin sinuate, minutely and distantly dentate. Midrib strong, flexuous. Secondary venation scarcely distinguishable from finer areolation. Numerous branches come off from the midrib at or near 90° and branch irregularly toward the margin, where they curve upward and unite in an intramarginal network that runs the length of the leaf.

This species resembles *B. saffordi* Berry,[32] from the Wilcox group, but differs in having much larger angles for the divergence of the secondaries.

The seed *Banksites lineatulus* Cockerell [33] may belong to this species. If this well-defined seed does nothing more, it at least adds substantially to the evidence that Proteaceae were present in the Green River flora.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order THYMELEALES

Family LAURACEAE

Genus OREODAPHNE Nees

Oreodaphne knowltoni Brown, n. sp.

Plate 72, Figure 9

A coriaceous leaf with entire margin; ovate-lanceolate, 9 centimeters long and 3.5 centimeters wide medianly. Apex elongated and probably bluntly acuminate; base rounded gradually to a stout petiole, of which the portion present is 1.5 centimeters long. Midrib heavy below but very thin toward the apex. All the secondaries are irregularly spaced and diverge from the midrib at varying angles. The first secondaries to come off from the midrib near the base are subopposite, weak, but loop upward in broad arches well within the margin to the secondaries next above, which are alternate and stronger and which almost reach the apex of the blade. From the middle of the leaf upward the secondaries again thin out into a tertiary meshwork of irregularly quadrangular meshes.

This species differs from *O. viridiflumensis* Knowlton,[34] of the Green River formation, in being more ovate toward the base and in having more regularly disposed secondaries. It is closely similar to if not identical with *O. puryearensis* Berry,[35] from the Wilcox group of Tennessee.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order ROSALES

Family ROSACEAE

Genus CHRYSOBALANUS Linné

Chrysobalanus lacustris Brown, n. sp.

Plate 72, Figure 8

An orbiculate, emarginate leaf of medium texture. Length 3 centimeters; width 3 centimeters. Apex notched, rounded; base round. Petiole thick, 4 millimeters long. Margin entire. Midrib strong, inclined to be straight. Secondaries 8 or 9 pairs, diverging from the midrib at right angles near the base but with increasingly smaller angles toward the apex, each recurved upward near the margin to join the secondary next above. Some secondaries may be bifurcated. Intermediate nervation irregularly transverse, and finer areolation indistinct.

The leaves of the living *Chrysobalanus icaco*, of the extreme southern United States, are in general somewhat larger than this specimen.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family LEGUMINOSAE

Subfamily MIMOSACEAE

Genus MIMOSITES Bowerbank

Mimosites debequensis Brown, n. sp.

Plate 73, Figures 1–3

Thick-textured leaflets, 3 to 4.5 centimeters long and 1 centimeter wide just above the base. Lanceolate, slightly falcate. Apex narrowed, pointed or blunt; base inequilateral, rounded on both sides. Margin entire, somewhat undulate in a few forms. Petiolule stout; 1 to 2 millimeters long, oblique. Midrib prominent, curved. Secondaries, 9 to 12 pairs alternate, thin, diverging from the midrib at wide angles, straight or slightly curved for some distance, then each camptodrome well within the margin to the secondary next above. Finer nervation obscure.

The general form of these leaflets refers them to *Mimosites*. They also bear a close resemblance to *Gleditsiophyllum eocenicum* Berry [36] but are smaller and have more inequilateral bases.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

[32] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 208, pl. 36, figs. 5, 6, 1916.
[33] Cockerell, T. D. A., U. S. Nat. Mus. Proc., vol. 66, art. 19, p. 8, pl. 2, fig. 3, 1925.
[34] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 131, p. 163, pl. 38, fig. 6, 1923.
[35] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 301, pl. 83, fig. 1, 1916.
[36] Idem, p. 238, pl. 46, figs. 1–7.

Mimosites falcatus Brown, n. sp.

Plate 73, Figures 4, 5

Thick leaflets, 3 to 4 centimeters long, and 4 to 6 millimeters wide medianly. Linear, falcate. Apex acuminate; base cuneate, equilateral or only slightly inequilateral. Petiolule 2 millimeters long, oblique, stout. Margin entire. Midrib prominent. Secondary venation not distinguishable.

This species may be a variety of *M. coloradensis*, as some of those forms approach a linear falcate outline. A closely similar form is *M. linearifolius* Lesquereux,[37] from Florissant, but that species is somewhat smaller.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Subfamily CAESALPINIACEAE

Genus CASSIA Linné

Cassia hesperia Brown, n. sp.

Plate 73, Figure 6

Leaflets subcoriaceous, 3.8 centimeters long, 1.3 centimeters wide just below the middle of the blade. Ovate-lanceolate, with a narrowed but blunt emarginate apex and a broadly cuneate base. Margin entire, slightly undulate. Petiolule 2.5 millimeters long, stout. Midrib stout but relatively slender. Secondaries thin, 6 to 8 subopposite to alternate pairs, diverging from the midrib at angles of about 50° running straight for two-thirds of the distance to the margin, then each camptodrome to the secondary next above.

This species resembles *C. glenni* Berry [38] but has a longer petiolule and is smaller.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order GERANIALES

Family MALPIGHIACEAE

Genus BANISTERIA Linné

Banisteria bradleyi Brown, n. sp.

Plate 73, Figure 7

Leaves thick, 2.7 centimeters long, 1.4 centimeters wide below the middle of the blade. Ovate. Apex narrow, rounded, base broadly cuneate. Margin entire. Petiole oblique, relatively stout, enlarged at the point of attachment like the pulvinus on some Leguminosae. Midrib not prominent, thin. Secondaries, 7 to 9 alternate pairs, thin, irregular, diverging from the midrib at 60°, each curving upward and anastomosing with the secondary next above close to the margin. Finer nervation a meshwork of quadrangular blocks.

There are 70 living species of *Banisteria*. They range from southern Mexico to the West Indies and Brazil. They are common in the oak forests of upland Mexico.

Occurrence: Piceance Creek, near junction with White River, Colo.

[37] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 300, pl. 59, fig. 7, 1878; vol. 8, p. 203, pl. 37, figs. 10-13, 1883.

[38] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 233, pl. 45, figs. 15, 16, 17a, 18; pl. 52, fig. 6, 1916.

Order SAPINDALES

Family ANACARDIACEAE

Genus RHUS Linné

Rhus myricoides Knowlton

Plate 73, Figure 9

Rhus myricoides Knowlton, U. S. Geol. Survey Prof. Paper 131, p. 168, pl. 37, fig. 9 [not figs. 10, 11, which are *R. variabilis* (Newberry) Knowlton], 1923.

This fine species resembles in some respects the living *Rhus typhina* and *R. glabra* of North America and *R. coriaria* of Europe. Among fossil species it is so like *R. coriaroides* Lesquereux,[39] of Florissant, that they may be identical, or at least one may be ancestral to the other.

Knowlton's Figure 9 is clearly different from his Figures 10 and 11, and it would seem best therefore to retain Figure 9 as the type of this species and to transfer Figures 10 and 11 to *R. variabilis* (Newberry) Knowlton, to which they seem most closely allied.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Rhus balli Brown, n. sp.

Plate 73, Figure 10

An odd-pinnate compound leaf with alate rachis and 5 or more pairs of lateral leaflets of almost uniform size and a terminal leaflet somewhat larger than the laterals. The paired leaflets are opposite, sessile or nearly so, attached at a wide angle, with internodes 1 centimeter long near the apex of the leaf but increasing in length toward the base. Length of entire leaf more than 8 centimeters; width 3 centimeters for most of the length. Leaflets 1.5 centimeters long and 1 centimeter wide, irregularly ovate and inequilateral. Margin entire on lower edge of leaflets, crenulate on the more or less truncate apices, and beset with few, relatively large and variable crenate-serrate teeth on the upper edges. Terminal leaflet obovate, with an elongated cuneate base. Wings of the alate rachis 1 millimeter wide at the top of an internode but decreasing to zero at the base. Midrib of leaflets straight, extending to the apex without forking. Secondaries, usually 6 pairs, subopposite, thin, diverging from the midrib at wide angles, curving gradually upward into the teeth, sometimes forking and sending branches into the notches below the teeth.

This remarkably beautiful species bears some resemblance to the living and variable *R. copallina*, or dwarf sumac, widely distributed on dry hillsides from north-

[39] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, p. 193, pl. 41, fig. 3, 1883.

ern New England to southern Florida and Cuba and west to Iowa, Nebraska, Kansas, and Texas. The leaflets of *R. copallina* are entire or nearly so for the most part, but in some varieties they are prominently serrated. They differ, however, from those of *R. balli* in having acuminate apices.

Casually observed this species might be taken for others belonging to other families and genera, such as *Dictamnus* (Rutaceae), *Athyana* (Sapindaceae), *Weinmannia* (Cunoniaceae). Of these *Weinmannia* seems to compare most closely with *R. balli*, but it differs markedly by several distinguishing characteristics, of which the principal one is that the secondary veins of the *Weinmannia* leaflets enter the notches between the teeth and the midrib forks near the apex without reaching the tip. Thus one can distinguish the two genera in specimens whose leaflets are toothed.

Lesquereux has described three species of *Weinmannia* from Florissant—*W. obtusifolia*, *W. haydenii*, and *W. integrifolia*. At first he was disposed to call these forms *Rhus*, but on the basis of some figures of *Weinmannia* (collected by Probst from the Tertiary of Biberach) communicated to Lesquereux by Heer, Lesquereux decided upon *Weinmannia*. If now we examine the specimens in the United States National Museum or Lesquereux's figures [40] we find that in *W. haydenii* and *W. integrifolia* the secondary veins enter the teeth. It seems clear, therefore, that these two forms at least are not *Weinmannia*. Concerning *W. obtusifolia* [41] the evidence is not so clear, because the leaflets have nearly if not quite entire margins, thus necessitating a different alinement of the secondaries from that which would occur in a toothed leaflet. I find, however, that even here the alinement simulates that of a *Rhus* in which the leaflets are entire and that the midrib of the leaflets terminates in the apex and does not divide as in typical *Weinmannia*. I should decide that this also is a *Rhus*.

A form that bears some resemblance to *R. balli* is the fragment described by Lesquereux as *R. rosaefolia* Lesquereux,[42] from South Park, west of Florissant.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus SCHMALTZIA Desveaux

Schmaltzia vexans (Lesquereux) Cockerell

Schmaltzia vexans (Lesquereux) Cockerell, Torreya, vol. 6, p. 12, 1906; Colorado Univ. Studies, vol. 3, p. 17, 1906.

Rhus vexans Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 195, pl. 41, fig. 20, 1883.

In form and details this leaflet of a trifoliate leaf conforms to the type described from Florissant and is similar to a living variety (*Rhus trilobata* Nuttall) of *Rhus aromatica*, now found in Texas.

Occurence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus ANACARDITES Saporta

Anacardites schinoloxus Brown, n. sp.

Plate 73, Figure 8

A winged fruit 3 centimeters long, resembling superficially a maple schizocarp. Boundaries of the seed itself indefinite, but about one-third the length of the entire fruit. Wing thin, 1 centimeter wide two-thirds distad. Upper margin not perceptibly thickened (as in *Acer*), bowed down slightly in the middle. Distal point rounded. Lower margin undulate, widened from the distal end to a point just short of the middle, then gradually narrowed and forming a border around the seed to the rounded base. Entire fruit supported by a clavate peduncle, 1 millimeter long. Veins thin over entire wing, close, and running parallel to the upper margin, curving downward and bifurcating toward the outer and lower margins. Intermediate areolation composed of irregular, elongated cells. Seed itself wrinkled or striated irregularly.

In casting about for a living fruit that might resemble this well-preserved specimen, I considered the following possibilities among genera: *Acer* (Aceraceae), *Banisteria, Heteropteris, Stigmatophyllum, Acridocarpus* (Malpighiaceae), *Securidaca* (Polygalaceae), *Thouinia, Atalaya* (Sapindaceae), *Embothrium, Hakea, Rymandra* (Proteaceae), *Pinus* (Pinaceae), *Schinopsis, Loxopterygium* (Anacardiaceae).

Because the peduncle protrudes forward in a characteristic manner and because no straight cleavage surface seems to be present on either side of the seed, as there would be in a schizocarp, it appears certain that this specimen is a single fruit and not a twin. That point being established, the following genera of those listed are automatically eliminated: *Acer, Banisteria, Heteropteris, Stigmatophyllum, Acridocarpus, Thouinia*, and *Atalaya*. On the basis of difference in form and venation the genera *Pinus, Embothrium, Hakea*, and *Rymandra* also drop out. *Securidaca* agrees in form but differs in having a thickened dorsal border and a seed which is less than one-third the length of the entire fruit and in not having a smooth, free peduncle when falling off at maturity. *Schinopsis* agrees in practically every respect except that the capsular fruit is smooth and shows no venation. *Loxopterygium* meets every requirement except that the venation is more open and the fruit is longer and narrower. It seems reasonable, therefore, to conclude that this fruit belongs within or close to the two last-mentioned genera. I have indicated the resemblance in assigning the specific name.

Loxopterygium is a genus inhabiting the Guianas. It has pinnately compound leaves with narrow lanceolate

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[40] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, p. 178, pl. 41, figs. 4–10; pl. 42, figs. 1–7, 8–13, 1883.

[41] Idem, p. 178, pl. 49, figs. 4–10.

[42] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 293, pl. 42, figs. 7–9, 1878.

leaflets. *Schinopsis* resembles *Loxopterygium* in habit and form and is found in Brazil, Paraguay, and Argentina.

It is possible that some of the leaflets found in this formation and described as *Rhus* may belong to a genus and species that produced this fruit.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family CELASTRACEAE

Genus CELASTROPHYLLUM Göppert

Celastrophyllum lesquereuxii Brown, n. sp.

Plate 74, Figure 1

Subcoriaceous leaves, 5 to 9 centimeters long, 1 to 1.7 centimeters wide medianly. Narrowly lanceolate, falcate, acuminate at the apex, cuneate at the equilateral base, which is decurrent on the petiole. Margin entire for one-third of the distance above the base, then serrate or crenate-serrate, with prominent, more or less aquiline teeth, becoming more widely spaced and low-dentate toward the apex. Midrib prominent, flexuous. Secondaries 5 or 6 subopposite to alternate pairs, emerging from the midrib at wide angles but rapidly curving upward, sending nervilles into the teeth. Finer nervation of irregular polygonal blocks.

This form is like *C. variabilis* Berry,[43] from the Ripley formation, but it is larger.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Celastrophyllum emarginatum Brown, n. sp.

Plate 74, Figure 2

A thick, inequilateral leaf, 2.3 centimeters long, 1.5 centimeters wide near the apex. Irregularly obcordate. Apex broadly rounded, emarginate; base narrowly rounded on the larger side, cuneate on the other. Margin entire except for two rounded, crenate lobes or teeth on the larger side, one on the smaller side, narrowly decurrent on the petiole. Midrib strong. Secondaries few, diverging from the midrib at 50°, curving upward and outward, forking, anastomosing, and finally disappearing in the leaf substance near the margin. Finer nervation indistinguishable.

This leaf resembles some living species of *Celastrus* from South America, particularly Brazil.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus MAYTENUS Molina

Maytenus berryi Brown, n. sp.

Plate 74, Figure 3

A thin-textured, linear-lanceolate, falcate leaf with pointed apex and narrowly tapered, decurrent base. Petiole not present on this specimen. Length 9 centimeters, maximum width 1.2 centimeters medianly. Margin entire for a short distance above the base, then beset with irregularly spaced and variable serrate teeth. Midrib stout, curved. Secondaries thin, 7 or 8 pairs, alternate, emerging from the midrib at 40° or less and each soon curving upward in an irregular loop well within the margin and joining the secondary next above. Finer nervation very irregular.

In venation this leaf suggests the living *M. boari*, of the West Indies. Among fossils it is like *M. puryearensis* Berry,[44] from the Wilcox of Tennessee.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family SAPINDACEAE

Genus THOUINIA Poiteau

Thouinia eocenica Brown, n. sp.

Plate 74, Figure 4

Inequilateral leaflets, 3 to 7.5 centimeters long, 1 to 1.8 centimeters wide medianly. Ovate-lanceolate. Apex elongated, blunt-pointed. Petiole stout, of variable length, modified somewhat by the decurrent margin of the inequilateral base. Margin distantly and minutely serrate. Midrib strong, flexuous. Secondary nervation of numerous thin veins, 10 to 12 pairs, alternate, with intermediaries, unevenly spaced, arising from the midrib at wide angles, straight or slightly curved till near the margin, then each looped upward to the secondary next above. Branches from the loops form a network next to the margin. Finer areolation composed of irregular meshes. Texture subcoriaceous.

This form compares well with such living species of *Thouinia* as *T. paucidentata*, of Yucatan and the West Indies, and *T. australis*, of the Dutch East Indies. In form it resembles *Thouinidium decandrum*, of Mexico, but differs markedly in venation.

Among recorded fossil species, which are few, *T. occidentalis* Engelhardt[45] is like this species but resembles the living *T. australis* more.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family AQUIFOLIACEAE

Genus ILEX Linné

Ilex affinis Lesquereux

Ilex affinis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7, p. 270, pl. 50, figs. 2, 3, 1878.
Berry, U. S. Geol. Survey Prof. Paper 91, p. 264, 1916.

These thick, broadly lanceolate leaves, with few, sharp, long-pointed or rounded teeth on the margins,

[43] Berry, E. W., U. S. Geol. Survey Prof. Paper 136, p. 65, pl. 13, fig. 1, 1925.

[44] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 264, pl. 61, fig. 5, 1916.

[45] Engelhardt, Hermann, Die alttertiäre Flora von Messel, p. 95, pl. 31, fig. 1, 1922.

compare well with those of certain living species and with *Ilex dissimilis* Lesquereux,[46] from Sage Creek, Mont.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order MALVALES

Family TILIACEAE

Genus GREWIOPSIS Saporta

Grewiopsis cissifolius Brown, n. sp.

Plate 74, Figure 8

Leaf 10 centimeters long, 5 centimeters wide medianly. Ovate-angular. Apex acute, base abruptly rounded, truncate, or slightly cordate. Margin revolute, thickened, sinuate-toothed, the larger teeth prominently but bluntly pointed by the excurrent secondary veins. What appears to be the beginning of a lobe is an extension of the blade on both margins at about the middle of the leaf. Petiole 12 millimeters long, stout, and thickened toward the point of attachment. The secondary veins curve upward slightly, some of them forking as they run out from the prominent midrib into the teeth, the angle of emergence ranging from a right angle at the base to 40° near the apex. The lowest secondaries are subopposite. The finer areolation is a net work of quadrangular meshes. Texture subcoriaceous.

This leaf belongs to a puzzling group of Eocene forms which simulate the leaves of many genera—*Grewia, Grewiopsis, Populus, Alnus, Cissus, Cissites, Quercus, Viburnum, Ficus, Platanus.* The specimen in hand differs little from *Fagus papyracea* Knowlton,[47] from the Raton formation. That specimen, however, can hardly be *Fagus* because of the forking veins and the nature of the tertiary venation.

This species differs only in the sharper teeth from *Grewiopsis populifolia* Ward,[48] from the Fort Union formation.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Family STERCULIACEAE

Genus STERCULIA Linné

Sterculia coloradensis Brown, n. sp.

Plate 74, Figures 6, 7

Long-petioled, simple leaves, entire or deeply lobed. The entire leaves or the lobes of the lobed leaves are generally lanceolate, tapering to an acute apex. Margin entire. Petiole 2.5 centimeters long, slender. From the base of the leaf arise primary and lateral veins, which are relatively clear and strong. From these principal veins diverge at wide angles numerous secondaries, which may be straight but are more generally irregular and curved upward near the margin. Many fork and lose themselves in the tertiary venation.

These specimens suggest very strongly the living *Sterculia diversifolia,* of Australia. *Sterculia* comprises about 100 species distributed in the warmer regions of the world.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order PARIETALES

Family TERNSTROEMIACEAE

Genus TERNSTROEMITES Berry

Ternstroemites viridiflumensis Brown, n. sp.

Plate 74, Figure 5

Coriaceous leaves, lanceolate to ovate-lanceolate, elongated above the middle to an acuminate apex. This fragment shows a conspicuous constriction near the apex, but whether this is a normal condition or not is uncertain. Length 10 to 12 centimeters; maximum width 2 centimeters at or below the middle of the leaf. Margin undulate to crenate-serrate to a point within a short distance of the apex. Petiole not present. Midrib strong, curved. Secondaries thin, numerous, diverging from the midrib at wide angles, straight or slightly curved, arched near the margin to the secondary above. Finer nervation not distinguishable.

This species resembles *T. preclaibornensis* Berry,[49] from the Wilcox formation, but differs in dentation of the margin and in texture.

Occurrence: On the eastern border of Carr Creek, Garfield County, Colo.

Order OLEALES

Family OLEACEAE

Genus FRAXINUS Linné

Fraxinus petiolata Brown, n. sp.

Plate 75, Figures 1–4

Leaflets coriaceous, 10 to 15 centimeters long, 2.5 to 4.5 centimeters wide at a point below the middle of the blade. Ovate-lanceolate. Apex tapering gradually, then abruptly and bluntly acuminate, as in some living species; base inequilateral, cuneate on the lower side, rounded on the other, or both sides rounded when nearly equal in position. Petiolule 2 centimeters long, inflated at the point of attachment. Margin obtusely dentate-serrate or merely undulate. Midrib prominent, flexuous. Secondaries strong, 10 to 12 pairs, sometimes with short intermediaries, diverging from

[46] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 177, pl. 50, figs. 7-9, 1878.

[47] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 295, pl. 68, fig. 1, 1917.

[48] Ward, L. F., U. S. Geol. Survey Sixth Ann. Rept., p. 556, pl. 55, figs. 8-10, 1886; U. S. Geol. Survey Bull. 37, p. 90, pl. 40, figs. 3-5, 1887.

[49] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 295, pl. 78, figs. 1-4, 1916.

the midrib at wide angles, nearly parallel, straight or slightly curved until well within the margin, then camptodrome, forming simple bows to the secondaries above. Nervilles from the bows enter the teeth. Transverse nervilles between the secondaries, finer areolation composed of irregular quadrate meshes.

This species is like *F. eocenica* Lesquereux,[50] from Golden, Colo., but has less rounded teeth and longer petiolules and is more lanceolate.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order GENTIANALES

Family APOCYNACEAE

Genus APOCYNOPHYLLUM Unger

Apocynophyllum wilcoxense Berry

Apocynophyllum wilcoxense Berry, U. S. Geol. Survey Prof. Paper 91, p. 342, pl. 103, figs. 2, 3; pl. 108, fig. 4.
Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 345, pl. 103, fig. 3; pl. 105, figs. 1, 2; pl. 106, fig. 1, 1917.

This form has been referred to *Apocynophyllum* because of its close resemblance to leaves of certain genera in the Apocynaceae, particularly to *Nerium oleander* Linné. A number of Apocynophyllums have been recognized in American Tertiary floras. This species has been described by Berry from the Wilcox group, and by Knowlton from the Raton formation.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus APOCYNOSPERMUM Reid

Apocynospermum coloradensis Brown, n. sp.

An elliptic, somewhat flattened, striated achene, 5 millimeters long, 2 millimeters in diameter, surmounted by a pappus 2 centimeters or more in length. This specimen is similar to numerous species described by Heer [51] and others as *Cypselites* or *Bidentites* of the Compositae. The probability however, is that most of these forms, as shown recently by Reid and Chandler,[52] belong either to the Apocynaceae or to the Asclepiadaceae.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Order CAMPANULALES

Family CUCURBITACEAE

Genus CUCURBITA (Tournefort) Linné

Cucurbita glandulosa Brown, n. sp.

Plate 75, Figure 6

A part of the basal portion of a large palmately lobed leaf. Veins very thick. Petiole stout and fleshy. Areolation of transverse nervilles and large quadrangular cells. The distinguishing charactertistic of this leaf is the minute punctation distributed over the surface of the vein and areolation. This seems to indicate that the leaf was hairy or glandular. Taking all the characteristics into consideration I conclude that this form is most like a *Cucurbita,* and it is so designated.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Phyllites juncoides Brown, n. sp.

Plate 75, Figure 5

A narrow, linear falcate leaf with entire margin. Without midrib, petiole, or evidence of venation.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus CARPOLITHUS Allioni

Carpolithus cassioides Brown, n. sp.

Plate 76, Figure 1

A small, flat, leathery leguminous pod, 1.5 centimeters long and 6 millimeters wide. Oblong in outline except that the base is the reverse of the apex. Pod attached by the lowest part of the rounded base.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Carpolithus ellipticus Brown, n. sp.

Plate 76, Figure 2

An oval elliptic flattened fruit, 12 millimeters long and 6 millimeters wide. Central ovoid mass apparently a stony seed, surrounded by a corona of pulp 1.5 millimeters wide. The whole is supported on a slender capitate pedicel of indefinite length.

Occurrence: On Piceance Creek near junction with White River, Colo.

Carpolithus capsularis Brown, n. sp.

Plate 76, Figure 3

An orbicular, flattened capsule, pod, or fruit, supported by a relatively thick, capitate pedicel. Diameter 7 millimeters.

Occurrence: On Piceance Creek near junction with White River, Colo.

Carpolithus palmites Brown, n. sp.

Plate 76, Figure 4

This broken specimen is apparently the fruit or husk of the fruit of some palmlike species. It resembles *Nipadites burtini umbonatus* Bowerbank,[53] from the Grenada formation of Mississippi.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

[50] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 229, 1878; vol. 8, p. 123, pl. 20, figs. 1-3, 1883.

[51] Heer, Oswald, Flora tertiaria Helvetiae, pt. 3, pp. 3-6, pl. 101, 1859.

[52] Reid, E. M., and Chandler, M. E. J., Catalogue of Cainozoic plants in the department of geology, vol. 1, The Bembridge flora, London, British Mus., 1926.

[53] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 176, pl. 112, figs. 13, 14, 1916

Carpolithus serratifolius Brown, n. sp.

Plate 76, Figure 5

A slender fruiting branch bearing two leaves and a raceme of small ovate fruits. The leaves are narrow, linear, alternate, petioled, 3.5 centimeters long and 2 millimeters wide. Margin finely but sparsely serrate. Midrib flexuous, prominent. Petiole 3 to 4 millimeters long. Secondary and tertiary venation not shown. Fruits 1 to 2 millimeters in diameter, ovate, thickened, borne on slender pedicels 2 to 4 millimeters long, the whole forming a raceme.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus ANTHOLITHES Brongniart

Antholithes vitaciflora Brown, n. sp.

Plate 76, Figure 8

A cymose cluster of flowers well advanced in the fruiting condition. Main stem and branchlets of the cyme relatively thick and fleshy. Pedicels of the flowers clavate, 2.5 millimeters long. Remains of perianth obscure. Ovary superior, flat spherical, narrowing abruptly into a persistent style, 1.5 millimeters long. These flowers seem to belong to some species of the Vitaceae.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Antholithes dubia Brown, n. sp.

Plate 76, Figure 7

A flower, 1 centimeter in diameter. Petals or lobes of the perianth present, 8, ovate. The center of the flower is a mass of carbonaceous material, of which the details are not recognizable.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Antholithes polemonioides Brown, n. sp.

Plate 76, Figure 6

A flower. Ovary superior, globular, 15 millimeters in diameter, apparently two-celled. Styles two, distinct, slender, 1 millimeter long, surmounted by short, broad, conical stigmas. Perianth, presumably the calyx, deeply divided, only two or three lobes being recognizable. Lobes 3 millimeters long, abruptly acuminate. The flower was supported on a clavate peduncle 2 millimeters long. No stamens or petals being present, it seems that they were removed together, as would occur with stamens inserted on a sympetalous corolla. The characteristics above set forth would seem to bring this specimen within such a group of families as the Ebenaceae, Convolvulaceae, and Boraginaceae.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Antholithes pendula Brown, n. sp.

Plate 76, Figure 9

This seems clearly to be a staminate catkin. At one end of the dense aggregation of flowers can be seen a short portion of the peduncle. Such a catkin would suggest *Salix*, *Populus*, *Betula*, *Alnus*, *Juglans*, *Hicoria*, etc.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus CAULINITES Brongniart

Caulinites acanthus Brown, n. sp.

Plate 76, Figure 10

A portion of a spiny stem with thorns of varying lengths, the largest 2.5 centimeters long, the shortest 5 millimeters long, relatively broad at the base and tapering gradually to a sharp point. Stem 3.5 millimeters thick.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Caulinites prehensus Brown, n. sp.

Plate 76, Figure 11

A tendril, 1.5 millimeters thick, belonging to one of the climbing plants, such as *Parthenocissus* or *Cucurbita*.

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

Genus RHIZOCAULON Saporta

Rhizocaulon natans Brown, n. sp.

Plate 76, Figure 13

A small rootlet with rhizoids like those occurring on the water chestnut (*Trapa natans*).

Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

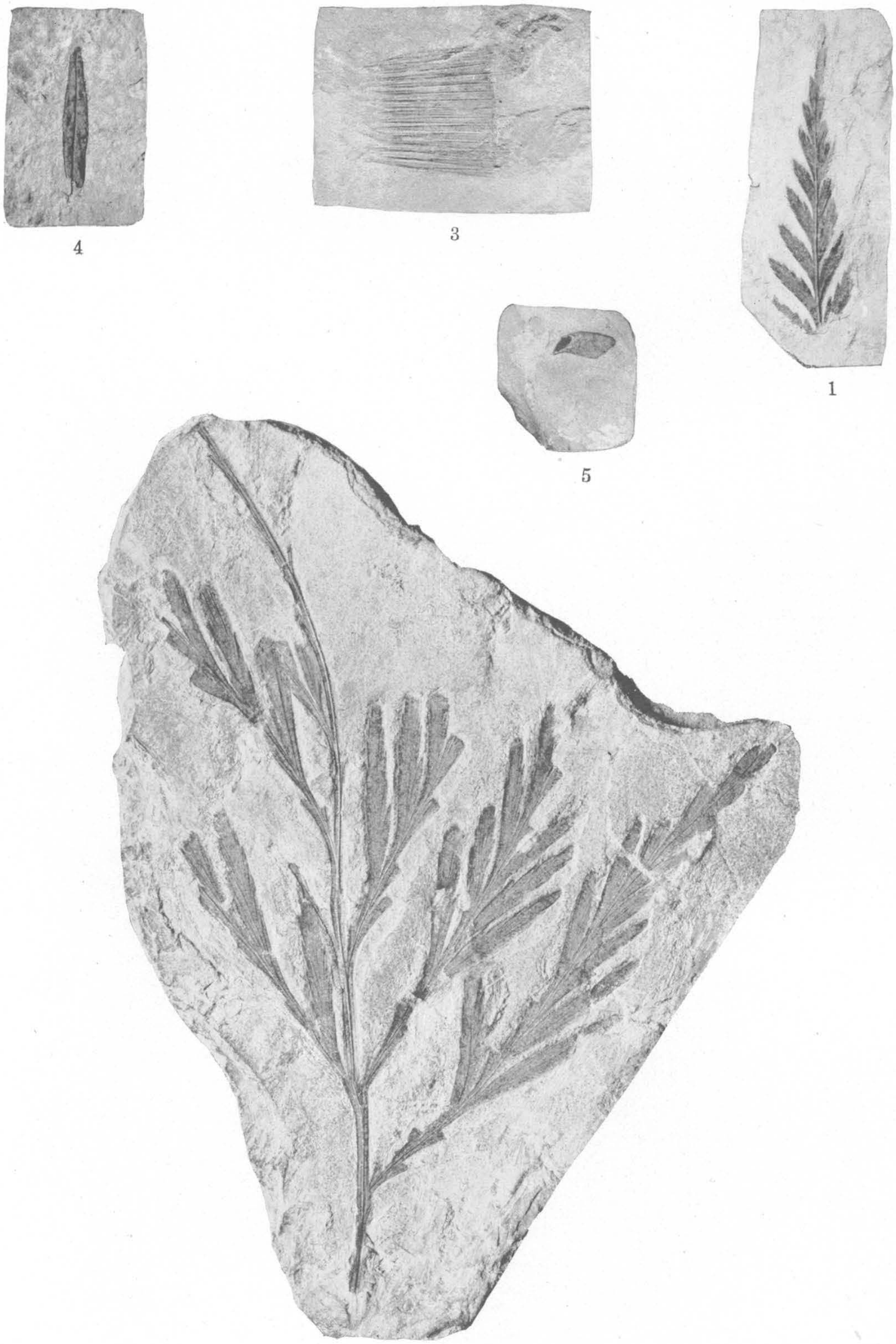
Rhizocaulon dichotomum Brown, n. sp.

Plate 76, Figure 12

A root or stem, showing one dichotomy.

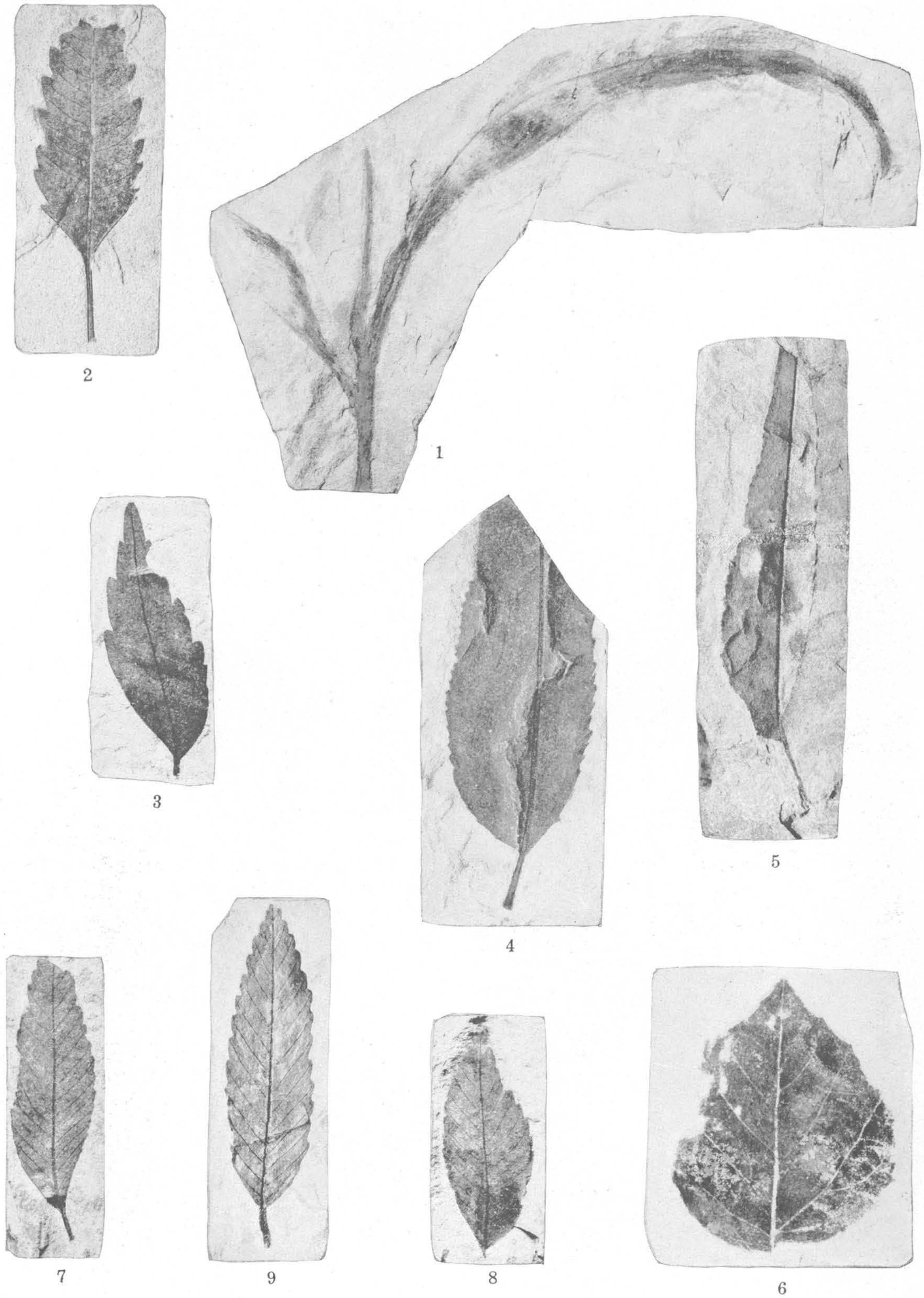
Occurrence: Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colo.

PLATES 70–76



FLORA OF THE GREEN RIVER FORMATION

1, 2. *Aneimia delicatula* Brown (p. 281).
3. *Equisetum winchesteri* Brown (p. 282).
4. *Taxites eocenica* Brown (p. 282).
5. *Picea pinifructus* Brown (p. 282).



FLORA OF THE GREEN RIVER FORMATION

1. *Sparganium eocenicum* Brown (p. 282).
2, 3. *Myrica alkalina* Lesquereux (p. 283).
4, 5. *Hicoria juglandiformis* (Sternberg) Knowlton (p. 283).
6. *Betula eocenica* Brown (p. 283).
7-9. *Planera nervosa* Newberry (p. 284).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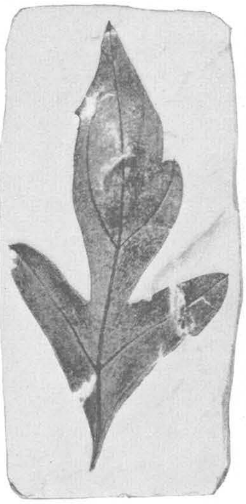
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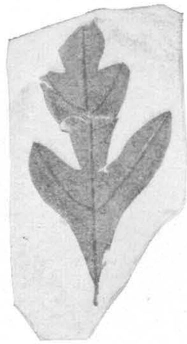
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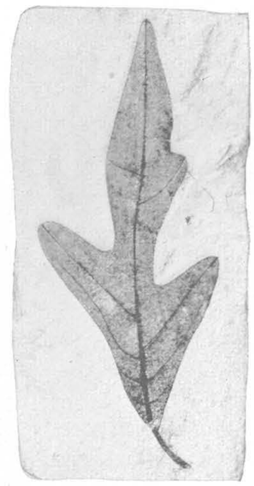
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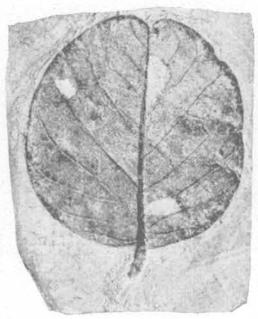
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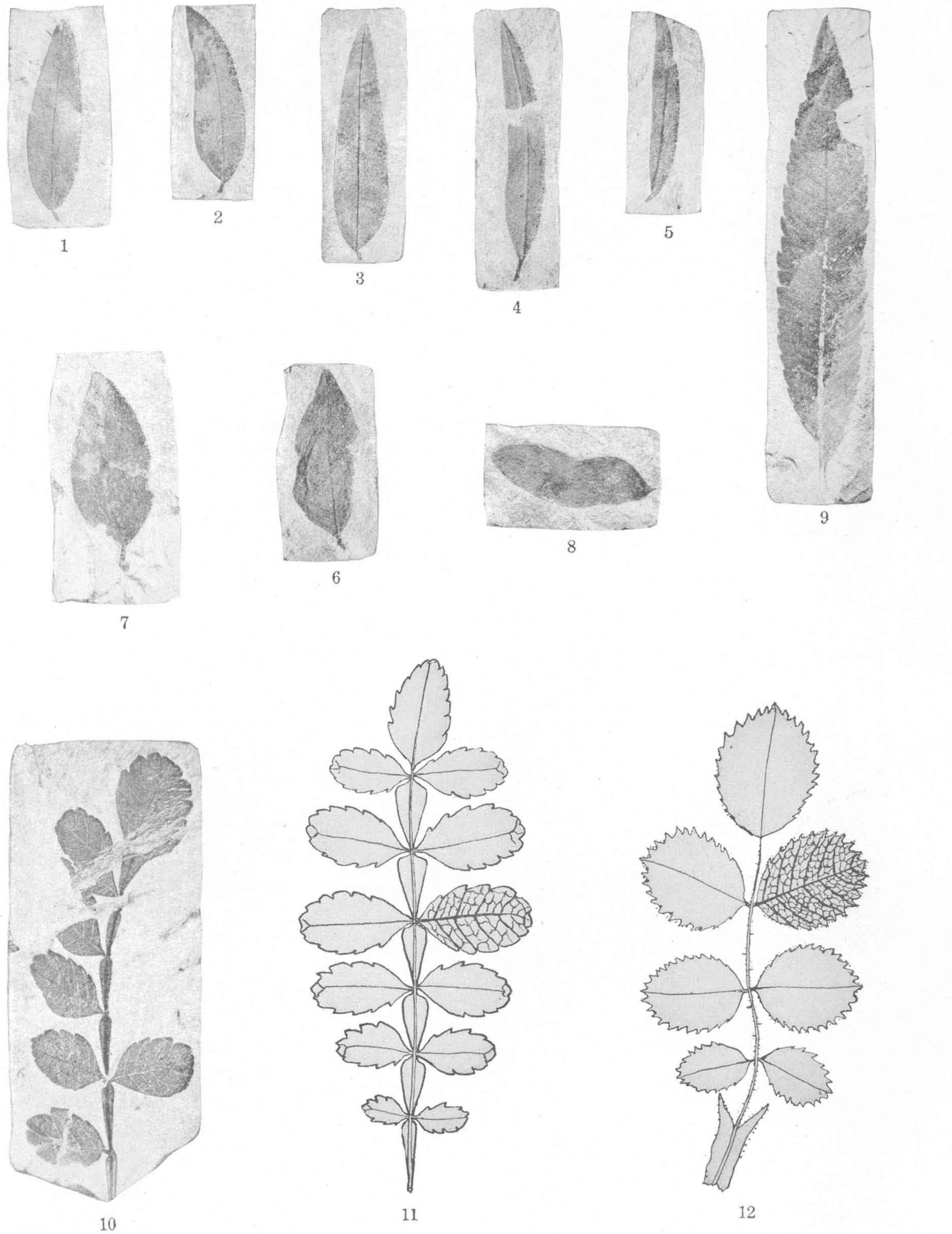
FLORA OF THE GREEN RIVER FORMATION

1. *Celtis debequensis* Brown (p. 284).
2. *Ficus omballi* Brown (p. 285).
3-6. *Lomatia coloradensis* (Knowlton) Brown (p. 285).
7. *Banksia cockerelli* Brown (p. 286).
8. *Chrysobalanus 'acustris* Brown (p. 286).
9. *Oreodaphne knowltoni* Brown (p. 286).



FLORA OF THE GREEN RIVER FORMATION

1–3. *Mimosites debequensis* Brown (p. 286).
4, 5. *Mimosites falcatus* Brown (p. 287).
6. *Cassia hesperia* Brown (p. 287).
7. *Banisteria bradleyi* Brown (p. 287).
8. *Anacardites schinoloxus* Brown (p. 288).
9. *Rhus myricoides* Knowlton (p. 287).
10. *Rhus balli* Brown (p. 287).
11. *Weinmannia pinnata*, of Mexico, introduced for comparison.
12. *Rosa rubiginosa*, of the eastern United States, introduced for comparison.

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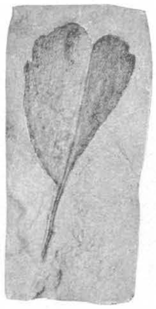

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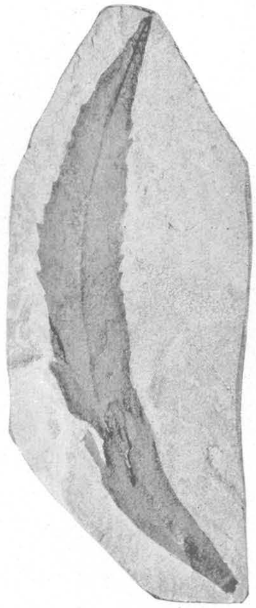

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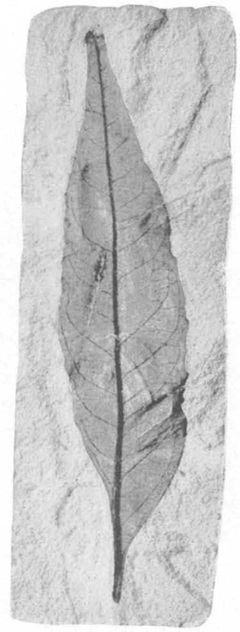

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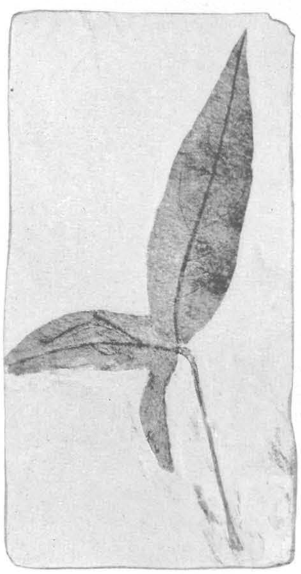

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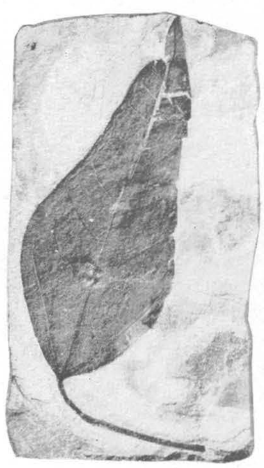

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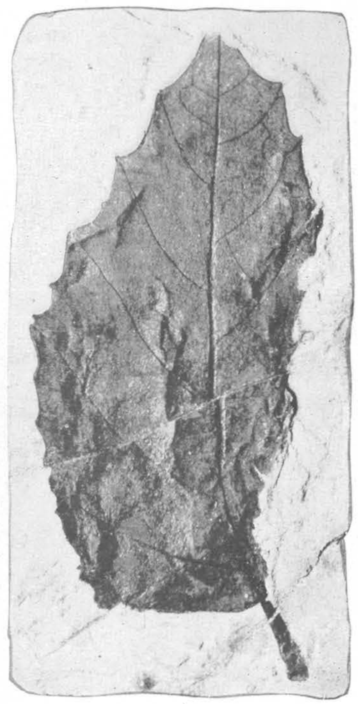

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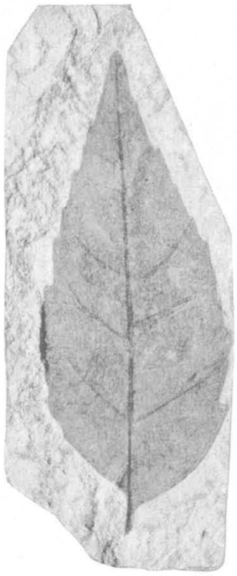
FLORA OF THE GREEN RIVER FORMATION

1. *Celastrophyllum lesquereuxii* Brown (p. 289).
2. *Celastrophyllum emarginatum* Brown (p. 289).
3. *Maytenus berryi* Brown (p. 289).
4. *Thouinia eocenica* Brown (p. 289).
5. *Ternstroemites viridiflumensis* Brown (p. 290).
6, 7. *Sterculia coloradensis* Brown (p. 290).
8. *Grewiopsis cissifolius* Brown (p. 290).



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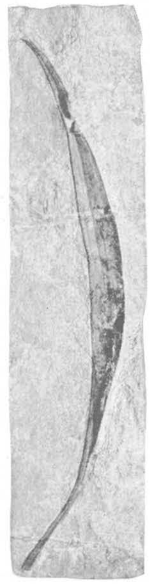

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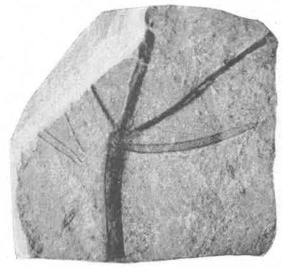

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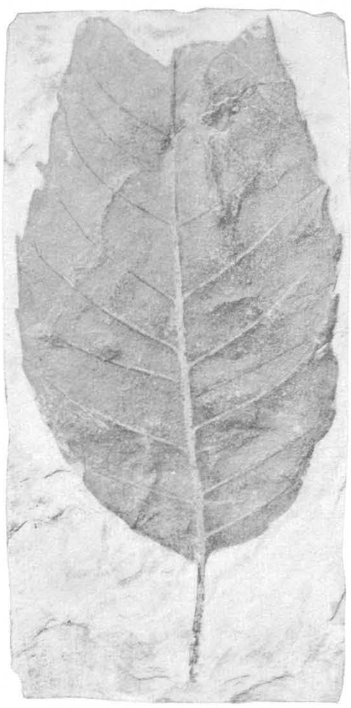

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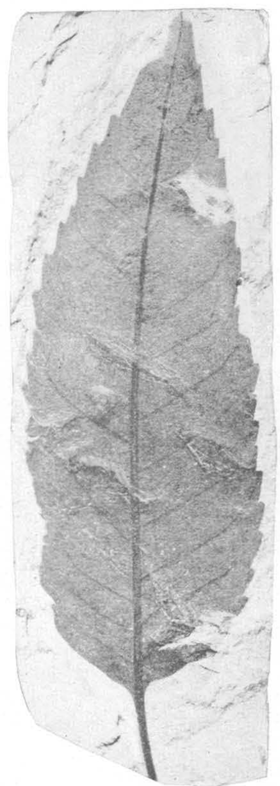

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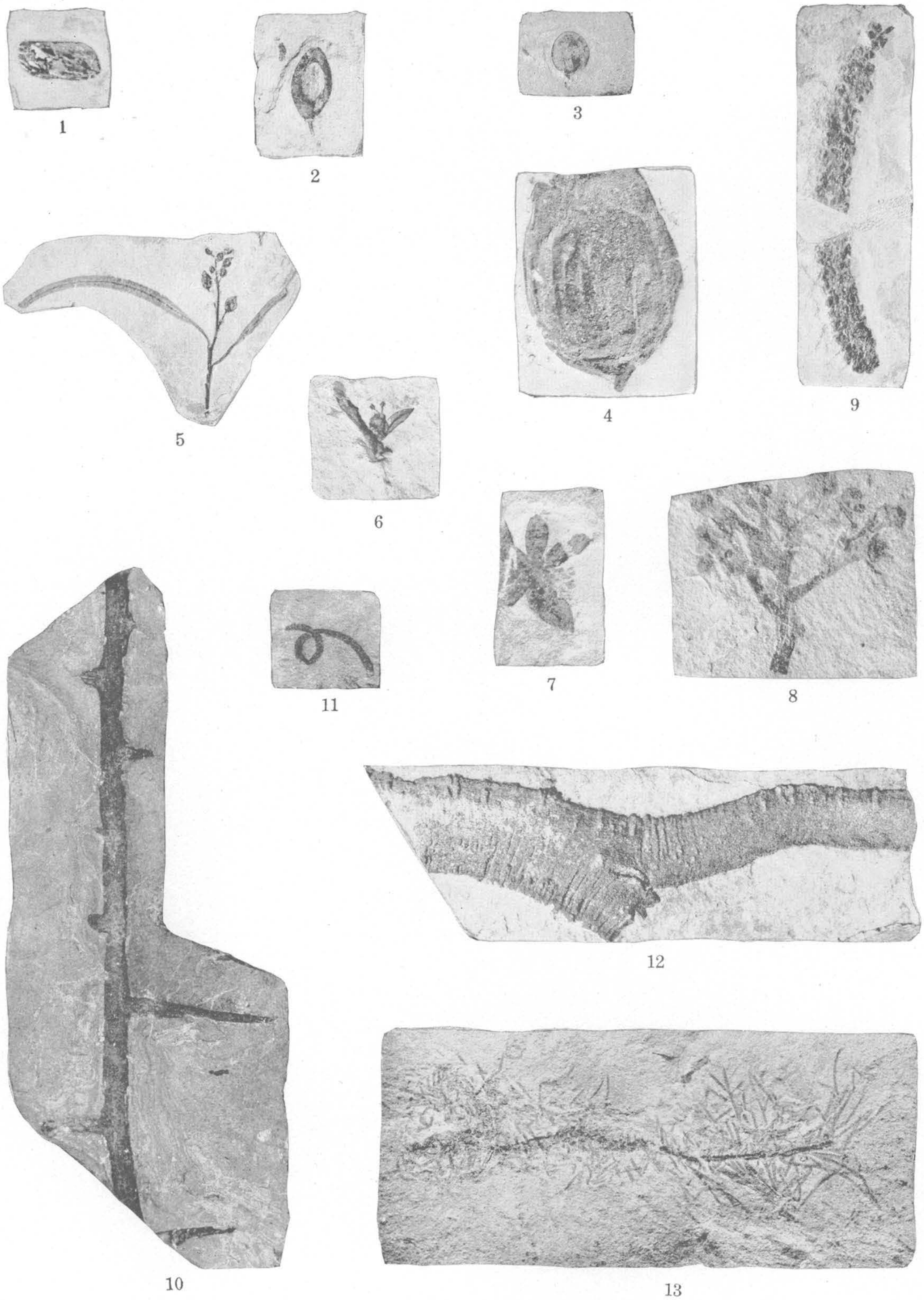
FLORA OF THE GREEN RIVER FORMATION

1–4. *Fraxinus petiolata* Brown (p. 290). **5.** *Phyllites iuncoides* Brown (p. 291). **6.** *Cucurbita glandulosa* Brown (p. 291).



FLORA OF THE GREEN RIVER FORMATION

1. *Carpolithus cassioides* Brown (p. 291)
2. *Carpolithus ellipticus* Brown (p. 291).
3. *Carpolithus capsularis* Brown (p. 291).
4. *Carpolithus palmites* Brown (p. 291).
5. *Carpolithus serratifolius* Brown (p. 292).
6. *Antholithes polemonioides* Brown, × 2 (p. 292).
7. *Antholithes dubia* Brown, × 2 (p. 292).
8. *Antholithes vitaciflora* Brown, × 2 (p. 292).
9. *Antholithes pendula* Brown (p. 292).
10. *Caulinites acanthus* Brown (p. 292).
11. *Caulinites prehensus* Brown (p. 292).
12. *Rhizocaulon dichotomum* Brown (p. 292).
13. *Rhizocaulon natans* Brown, × 2 (p. 292).

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