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FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

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DAVID WHITE, CHIEF GEOLOGIST

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PROFESSIONAL PAPER 108—A

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BY

G. SHERBURNE ROGERS

Published March 3, 1917

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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1917.

BAKED SHALE AND SLAG FORMED BY THE BURNING OF COAL BEDS.

By G. Sherburne Rogers.

INTRODUCTION.

The baking and reddening of large masses of strata caused by the burning of coal beds is a striking feature of the landscape in most of the great western coal-bearing areas. The general character and broader effects of the burning have been described by many writers,[1] but the fact that in places enough heat is generated to fuse and thoroughly recrystallize the overlying shale and sandstone has received less attention. Some of the natural slags thus formed simulate somewhat abnormal igneous rocks, but others consist largely of rare and little known minerals. A wide range in the mineral composition of such slags is to be expected, depending on the composition of the original sediment and the conditions of fusion and cooling. These products of purely thermal metamorphism offer a fertile field for petrologic investigation.

The writer has observed the effects produced by the burning of coal beds in several localities in Montana, particularly along upper Tongue River in the southern part of the State, in the district lying southeast of the mouth of Bighorn River, and in the Little Sheep Mountain coal field north of Miles City. A number of specimens of the rock formed have been examined under the microscope, though time has not been available for a systematic examination. The writer is greatly indebted to Mr. E. S. Larsen for assistance in the study of some of the minerals.

[1] Allen, J. A., Metamorphism produced by the burning of lignite beds in Dakota and Montana territories: Boston Soc. Nat. Hist. Proc., vol. 16, p. 246, 1874. See also Lewis, Meriwether, and Clarke, William, History of the expedition under the command of Lewis and Clarke, vol. 1, pp. 180, 189, Philadelphia, 1814; Hayden, F. V., Geological report of the exploration on the Yellowstone and Missouri rivers, pp. 56–103, 1869; and Dawson, G. M., Report on the geology and resources of the region in the vicinity of the forty-ninth parallel, pp. 164–169, Montreal, 1875.

CAUSES OF BURNING.

Most writers on the burning of coal beds have attempted to explain the mode of their ignition, which they usually ascribe to lightning, to prairie or forest fires, to the agency of man, or to spontaneous combustion. All these agencies have probably been effective in one place or another.

Lightning has doubtless ignited some beds, especially those exposed on the higher hills, but it is apparently inadequate to account for the burning of beds over great areas. There are also well-authenticated reports of the ignition of beds by prairie fires,[2] but it may well be doubted whether this agency has often been effective in the sparsely grassed badlands, where burning is so common. Similarly, the writer knows of one locality in which a bed of coal 11 feet thick was ignited by the camp fires of a round-up outfit, but much of the burning evidently took place many thousands of years ago and some of it probably dates back to Pleistocene time.[3] Ignition from an extraneous source is perfectly possible and may be the most plausible explanation in any given instance, but the fact that burning on the outcrop is so common as to be actually characteristic of the coal beds over an area greater than 200,000 square miles indicates a more widespread mode of origin and one less dependent on special local conditions.

Ever since coal first became widely used as fuel the possibility of its spontaneous combustion has been recognized. Disastrous fires have started through spontaneous combustion in mines, many others at the surface in piles of

[2] Allen, J. A., op. cit., p. 261.

[3] Idem, p. 258. Also Collier, A. J., and Smith, C. D., The Miles City coal field, Mont.: U. S. Geol. Survey Bull. 341, p. 45, 1909.

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culm or slack coal, and others in stocks of coal held in storage or undergoing shipment, especially at sea. Because of its economic importance the phenomenon has been carefully studied by many observers, and although there is considerable disagreement as to detail the main determining conditions have been well outlined. Thus, it is generally recognized that only coals that contain a moderate to high proportion of volatile matter are subject to spontaneous combustion; that the more finely divided the coal the more liable it is to ignite; and that a small increment of heat from an outside source is an important contributing cause.

Most of the coal in the Western States that has burned at the outcrop is of lignitic or sub-bituminous grade; this coal when exposed to the air loses moisture and tends to slack or crumble to fragments. All freshly mined coal absorbs oxygen and according to Lewes [1] may, if in fairly small fragments, absorb two to three times its own volume. This absorption of oxygen takes place at ordinary temperatures but proceeds more rapidly at higher temperatures, and as the process itself generates some heat it is self-accelerating. The heat first generated may be due merely to the compression of the gas, but a slow oxidation of resins or unsaturated hydrocarbons in the coal, with the formation of humic or other acids, probably soon begins. The elaborate experiments of Parr and Kressmann [2] indicate that this reaction assumes positive activity at about 80° C. With rise in temperature the occluded oxygen becomes more active, combining with certain hydrocarbons and converting them to carbon dioxide and water. According to Parr and Francis [3] this reaction begins only when the coal becomes heated to 120° to 140° C., but it represents a critical stage in the process of oxidation, for so much heat is generated that the temperature thereafter rises rapidly. At a little over 200° C. autogenous oxidation begins and at 350 to 450° C. actual ignition takes place. According to experiments by Fayol,[4] however, coal in a state of fine dust ignites at a much lower temperature, gas coal igniting at 200° C. and lignite at 150° C.

The oxidation of pyrite or marcasite in the coal was once considered the chief cause of spontaneous combustion, but it is now known that coals practically free from iron sulphides may spontaneously ignite. Some authorities therefore hold that the influence of pyrite is negligible and that at the most it merely increases the general rise in temperature and by swelling splits up the coal, thus exposing fresh surfaces to the action of atmospheric oxygen.[5] Parr and Kressmann find, however, that the oxidation of pyrite in the presence of moisture results in a distinct increment of heat, and as this reaction takes place at ordinary temperature they believe that it is one means by which the mass is heated to the point at which active oxidation of the coal itself commences. They state that the oxidation of one-fifth of the pyrite in a coal containing 6 per cent generates sufficient heat to raise the temperature of the mass 70° C., assuming no loss by radiation.[6] As the conductivity of coal is very low compared with that of the surrounding rocks, according to figures given by Prestwich,[7] it seems probable that loss of heat by radiation is slow and that small amounts of heat generated within the coal may well be conserved to produce far-reaching results.

It is generally recognized that the presence of moisture favors spontaneous combustion.[8] In fact, Dennstedt and Bünz,[9] as a result of experiments, conclude that "self-ignition increases in a ratio corresponding to the amount of moisture [water of constitution] in air-dry coal." Opinions differ, however, as to whether its action is chiefly mechanical, catalytic, or chemical. It is also known that inflammable gases are occluded in coal, and though it may be doubted that these gases are the direct cause of spontaneous combustion it is evident that if the coal is heated by oxidation to the temperature at which these gases can unite with atmos-

[1] Lewes, V. B., The carbonization of coal, p. 23, London, 1912. See also Parr, S. W., and Barker, Perry, The occluded gases in coal: Illinois Univ. Eng. Exp. Sta. Bull. 32, 1909; White, David, The effect of oxygen in coal: U. S. Geol. Survey Bull. 382, pp. 63–71, 1909; and Chamberlin, R. T., Notes on explosive mine gases and dusts: U. S. Geol. Survey Bull. 383, pp. 15, 60, 1909.

[2] Parr, S. W., and Kressmann, F. W., The spontaneous combustion of coal: Illinois Univ. Eng. Exp. Sta. Bull. 46, pp. 24, 52, 1911.

[3] Parr, S. W., and Francis, C. K., The modification of Illinois coal by low temperature distillation: Illinois Univ. Eng. Exp. Sta. Bull. 24, 1908.

[4] Fayol, Henri, Études sur l'altération et la combustion spontanée de la houille exposée à l'air: Soc. ind. min. Bull., 2d ser., vol. 8, pt. 3, 1879.

[5] Lewes, V. B., op. cit., pp. 21–22.

[6] Parr, S. W., and Kressmann, F. W., op. cit., p. 34.

[7] Boulton, W. S., Practical coal mining, vol. 2, p. 331, London, 1907.

[8] Parr, S. W., and Kressmann, F. W., op. cit., p. 52.

[9] Dennstedt, M., and Bünz, R., Die Gefahren der Steinkohle: Zeitschr. angew. Chemie, vol. 21, pp. 1825–1835, 1908.

pheric oxygen they may become an important contributing cause. Penhallow [1] believes that the burning of lignite beds is caused by the spontaneous ignition of escaping gases, particularly sulphureted hydrogen, carbureted hydrogen (methane ?), and phosphureted hydrogen.

Analyses of lignite and coal from Montana and Wyoming.

Made at the Pittsburgh laboratory of the Bureau of Mines; F. M. Stanton and A. C. Fieldner, chemists in charge.]

	10898	6469	17711	8465	14755
SAMPLE AS RECEIVED.					
Proximate:					
Moisture	42. 8	26. 8	22. 6	29. 4	19. 8
Volatile matter	25. 7	32. 8	31. 9	25. 4	30. 7
Fixed carbon	26. 9	27. 9	39. 5	38. 8	35. 2
Ash	4. 6	12. 5	6. 0	6. 4	14. 3
Sulphur	. 24	. 64	. 51	. 37	1. 50
Ultimate:					
Hydrogen	7. 21	6. 04	......	......	......
Carbon	36. 21	42. 72	......	......	......
Nitrogen	. 62	. 60	......	......	......
Oxygen	51. 08	37. 53	......	......	......
British thermal units	6, 110	7, 340	8, 811	7, 170	8, 579
Loss of moisture on air drying	35. 3	20. 5	3. 7	19. 3	8. 5
AIR-DRIED SAMPLE.					
Proximate:					
Moisture	11. 6	7. 9	19. 6	12. 5	12. 3
Volatile matter	39. 7	41. 3	33. 1	31. 4	33. 5
Fixed carbon	41. 5	35. 1	41. 1	48. 1	38. 5
Ash	7. 2	15. 7	6. 2	8. 0	15. 7
Sulphur	. 37	. 81	. 53	. 46	1. 64
Ultimate:					
Hydrogen	5. 09	4. 73	......	......	......
Carbon	55. 97	53. 74	......	......	......
Nitrogen	. 96	. 75	......	......	......
Oxygen	30. 44	24. 28	......	......	......
British thermal units	9, 440	9, 238	9, 153	8, 880	9, 376

LIGNITE OR COAL KNOWN TO BURN ON OUTCROP.

10898. Lignite from Culbertson lignite field, Mont. Red Bank open-cut mine, sec. 10, T. 28 N., R. 59 E. Fort Union formation.

6469. Subbituminous coal from Buffalo coal field, Wyo. Mitchell mine, sec. 26, T. 51 N., R. 82 W. Fort Union formation.

17711. Subbituminous coal from Tullock Creek coal field, Mont. Prospect in sec. 30, T. 1 N., R. 38 E. Fort Union formation.

8465. Subbituminous coal from Bull Mountain coal field, Mont. McCleary prospect, sec. 26, T. 9 N., R. 30 E. Fort Union formation.

COAL NOWHERE BURNED ON OUTCROP.

14755. Subbituminous coal from Tullock Creek coal field, Mont. Prospect 12 miles southeast of Bighorn. Lance formation.

It is evident from the foregoing summary that both chemical and physical factors enter into spontaneous combustion. As regards chemical composition, coals highest in volatile matter, moisture, and sulphur are most liable thus to ignite. In the accompanying table the chemical character of four typical coals that have burned extensively on the outcrop is shown by the first four analyses, and the character of a coal that has nowhere burned by the last analysis. A considerable range in composition is shown by these analyses, though all show high moisture and volatile matter but fairly low sulphur. It will be noted that the coal that has nowhere burned is much higher in sulphur than any of the others; whether its lack of tendency to burn is due to the offsetting of this factor by the low percentage of moisture and the high ash content is a matter of conjecture.

The physical factors promoting spontaneous combustion are a finely divided condition of the coal, a slight increment of heat from an outside source, and a sufficient volume of coal to retard loss of heat by radiation. A pile of coal exposed to the direct rays of the sun would thus be liable to become heated and finally ignite. In general, the outcrop of a coal bed, even in the arid western coal fields, weathers down slowly and is more or less covered by talus, so that the oxidation of the coal is too slow to generate much heat. Where a young, rapidly cutting gulch intersects a coal bed, however, a perpendicular face of coal may be formed, and as this is undercut by the stream a considerable mass of finely broken but fairly fresh coal may accumulate at the base of the bed. Under such conditions oxidation would be fairly rapid, especially as the normal temperature of the coal, if exposed to the direct heat of the sun, would reach 130° F. (55° C.), or more on summer afternoons.

In the writer's opinion most of the burning of western coal beds has been spontaneous and has originated under conditions similar to those just described. C. H. Wegemann,[2] who has studied particularly the relation of topography to burning, finds that burning is most prevalent along rapidly cutting streams and believes that it is partly a function of the character of the topography. The writer has observed beds actually burning at six localities, and in all of them combustion evidently started in a gulch on a small, rapidly cutting stream. Field studies indicate that two other generalizations can be made: First, thin beds are less commonly burned than thick ones, probably

[1] Penhallow, D. P., Tertiary plants of British Columbia: Canada Geol. Survey Pub. 1013, pp. 148–149, 1908.

[2] Personal communication.

because piles of coal large enough to retain self-generated heat can not accumulate along their outcrop; and second, beds of impure coal burn less commonly than those of clean coal.

GENERAL EFFECTS OF BURNING ON THE OVERLYING STRATA.

The rocks overlying a burned-out coal bed present widely different appearances, ranging from reddened and only slightly hardened shale or sandstone through vesicular glassy slag to gray medium-grained rock. These broader differences are due chiefly to the degree of heat to which the material has been subjected, and their relations to the coal bed may be more clearly understood if the process of burning is briefly considered.

Whatever the cause of ignition, the combustion apparently always starts at the surface and spreads first along the outcrop. The presence of the burning bed is disclosed by the smoke and fumes which rise from it, and by the heat at the surface of the earth near the outcrop or above the bed, which becomes so intense that all vegetation is killed. As the coal burns out the overburden generally caves, and large fissures may be opened in the surface of the ground above the bed. During this stage of the burning the heat is for the most part dissipated and the overlying strata are only slightly affected. However, thin red bands may be formed by the baking of clay partings in the bed, and as these slump down they become curiously contorted and form, with white bands of ash or cinders, a structure resembling somewhat that of a crumpled schist. Plate I, *B*, shows a burning coal bed 11 feet thick exposed on Custer Creek, near Yellowstone River, between Miles City and Terry, Mont. To the left the bed is slowly burning but has not perceptibly affected the overlying sandstone; to the right it is entirely consumed at the outcrop and the overburden has slumped down irregularly.

As the burning progresses back from the outcrop the heat is conserved and tends to act more strongly on the overlying rocks, until finally a point is reached where combustion is smothered by the lack of oxygen. The underlying strata are scarcely affected, if at all, and in many places the coal does not burn entirely to the base of the bed. Baking and hardening of the overlying strata doubtless begin a few feet back from the outcrop, and as the coal burns out and these beds cave they tend to break into irregular fragments. Incipient fusion may occur on the edges of these fragments, which therefore have a tendency to cohere and thus form a stable rock 30 or 40 per cent of whose volume is air space. It is chiefly through the crevices in this rock that oxygen is supplied to the coal burning farther back.

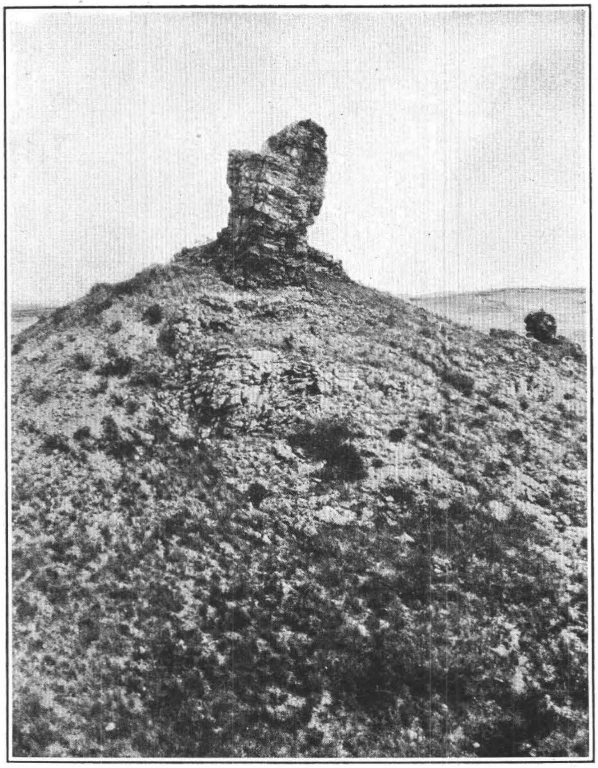
How far the burning extends back from the outcrop is a matter on which there is little positive information. Field studies indicate that a bed under 20 feet or less of cover may burn out completely under large areas, and similarly that all the coal underlying a small butte or a narrow neck of land may burn out even though the overburden is 100 feet or more thick. Bowie [1] cites an instance in which the coal burned out to a point almost 500 feet from the outcrop, as ascertained in the course of mining the unburned portion of the bed. According to F. R. Clark,[2] development at Sunnyside, Utah, has shown that burning may extend even farther back under high spurs jutting out from the main ridge. In general, however, where there is a cover of more than 50 or 100 feet, and where the outcrop of the bed is fairly straight, it seems probable that burning does not extend more than 200 or 300 feet back from the outcrop.

Although the rocks within a few feet of the top of the burning bed may be partly fused, those beyond are in general merely baked and still further up are only slightly reddened. The great bulk of the rock retains its original texture, and though much of the shale is vitrified or hardened the sandy strata may be only slightly affected. The most striking effect is the reddening of the rock, which is due to the action of moderate heat under conditions favorable to simple oxidation and which therefore implies no very extensive chemical changes.

Though fusion is for the most part confined to the rocks directly above the burning bed, it may locally extend many feet above. The gases formed during combustion of the coal escape chiefly through fissures in the overlying strata and apparently are hot enough to fuse the rock thoroughly along their paths of escape.

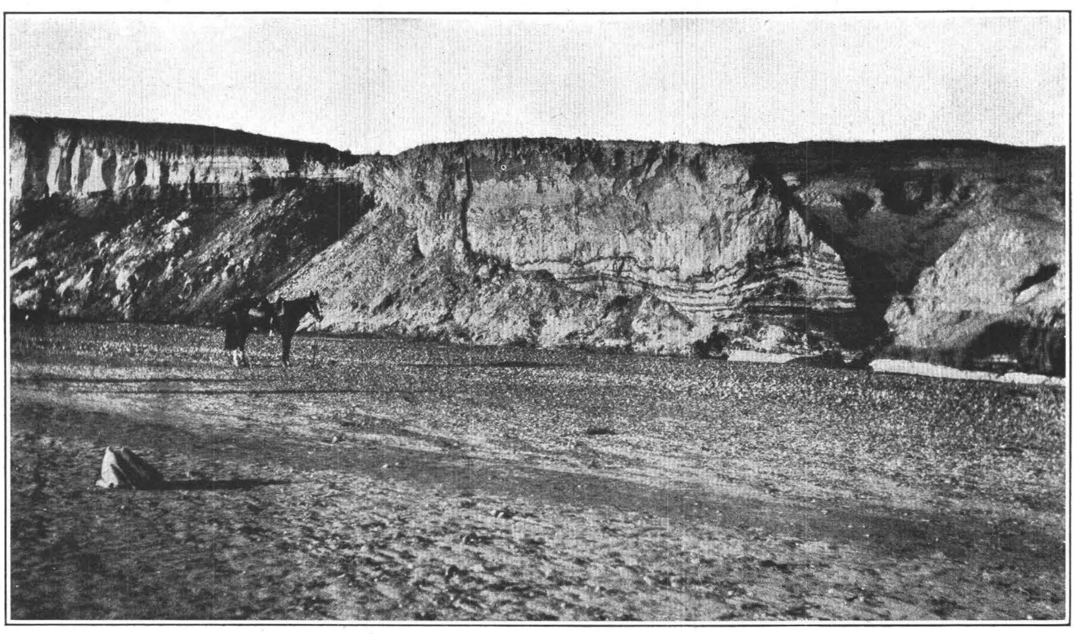
[1] Bowie, Alexander, The burning of coal beds in place: Am. Inst. Min. Eng. Trans., vol. 48, p. 181, 1915.

[2] Personal communication.



A. A CHIMNEY OR CORE OF HARD FUSED ROCK PROJECTING THROUGH PARTLY BAKED STRATA NEAR MILES CITY.

Photograph by C. D. Smith.



B. COAL BED 11 FEET THICK ON CUSTER CREEK NEAR YELLOWSTONE RIVER BETWEEN MILES CITY AND TERRY.

To the left the bed is slowly burning but has not yet perceptibly affected the overlying strata; to the right it is entirely consumed, leaving only contorted white bands of ash and darker bands formed by the baking of clay partings.

EFFECTS OF THE BURNING OF COAL BEDS IN EASTERN MONTANA.

As the melting point of silica is above 1,600° C., however, it is highly improbable that this action is accomplished by the spent gases, the products of combustion, alone. It is reasonable to suppose that the coal itself becomes highly heated, as well as the overlying rocks, and that considerable distillation goes on a short distance back of the burning face. According to Bowie,[1] in the King mine, on North Fork of Gunnison River, Colo.,

the coal adjacent to the burned-out area seemed to have its cohesive quality entirely destroyed. It was soft and very easily mined but could not be utilized even for steam fuel, as the volatile constituents of the coal seemed to have been expelled by the heat. We had a zone of several hundred feet of this kind of coal.

It is probable that the gases arising through fissures in the overlying rocks contain a considerable proportion of combustible matter, which explodes or burns on reaching a supply of oxygen, and that the intense heat necessary to fuse rock 75 feet or more above the bed is thus transmitted.

Apparently small fissures may control the paths of the gases and thus start the formation of well-defined chimneys. As the material forming the immediate walls of the fissures becomes molten it tends to sink and clog the passage, so that the gases may be slightly diverted and thus be caused to act on a greater volume of material. A similar effect is produced when a fissured zone rather than a single fissure controls the escape of the gases. In this case, however, the heat is less concentrated and may not be sufficient to melt more than the edges of the interfissural blocks. A single fissure may lead to the formation of a core of molten material extending many feet up through partly baked rock, whereas a fissured zone apparently produces a larger and less sharply defined core of partly fused fragments. On cooling, the fused or partly fused rock coheres and forms a roughly cylindrical mass of hard "clinker." Chimney-shaped masses of this kind resist erosion to a greater degree than the partly baked strata around them and weather to the curious pinnacles that commonly surmount clinker bluffs or buttes (Pl. I, *A*).

Aside from the strictly thermal effects of the heated gases, they also play an important part as reducing agents. As the combustion of the coal takes place in a scanty supply of oxygen, a considerable proportion of carbon monoxide is probably formed, and if the rock is ferruginous the reducing action may be very striking. Directly above the burning bed and along the paths of the escaping gases the iron is partly or wholly reduced and gray, green, yellow, or black slag is formed. When the reduction is partial magnetite may be produced, in some places in sufficient quantity to affect the compass needle. When the rock is thoroughly fused under reducing conditions, however, a great deal of the ferrous iron formed is taken up in the formation of new minerals and a light-colored slag results. A reducing atmosphere may also be developed in beds of carbonaceous shale that are highly heated by the burning coal bed, but most of the rock outside of the chimneys is merely baked under oxidizing conditions to the characteristic reddish color.

PETROLOGIC CHARACTER OF THE ROCKS FORMED.

CHARACTER OF THE ORIGINAL SEDIMENTARY ROCKS.

Although the degree of heat and the rapidity of cooling govern to a large extent the general character of the materials formed, the fundamental factor is of course the composition of the original rock. The coal-bearing formations of the Western States are made up largely of shale and sandstone. The shale may be yellow, bluish or greenish gray, or brown and carbonaceous; less commonly it is reddish. The sandstone, which is usually gray, yellow, or brown, is generally more or less arkosic and may carry 25 per cent or more of feldspar, hornblende or pyroxene, and mica. Under the microscope the rock from some localities or formations is seen to be made up of predominantly angular grains, and the feldspars and ferromagnesian minerals are surprisingly fresh. In other specimens, however, the grains are more rounded, the feldspars kaolinized, and the ferromagnesian minerals altered to chlorite or serpentine. Accessory minerals, such as garnet, zircon, and magnetite, are present in most of the sandstone in minor quantity, and there is usually much fine clayey interstitial material, commonly iron stained. Some of the rocks examined, notably those of the Lebo shale member of the Fort Union formation (Tertiary), are evidently derived from fairly basic

[1] Bowie, Alexander, op. cit., p. 182.

igneous rocks and contain as much as 50 per cent of chloritic material. Calcite occurs in many specimens, and in some localities the rocks are distinctly calcareous, though beds containing more than 20 per cent of lime carbonate are probably uncommon.

Although unfortunately only generalized data on the composition of the sedimentary rocks are available, the foregoing notes are sufficient to indicate that the rocks differ widely in mineral and chemical character. Moreover, variation in composition may be abrupt; contiguous beds may be very different in character and in many localities the same bed differs more or less from point to point.

BAKED ROCK.

Shale or sandstone more or less baked constitutes by far the largest part of the metamorphosed strata. Although the prevailing colors are pink, red, or purplish red, the rocks may be mottled in red and bright yellow, green, or black. The mottling is more common in baked shale; the sandstone is generally altered to a uniform pinkish red and is only moderately hardened. In general only the edges of the grains are fused and in many specimens no alteration can be detected under the microscope.

The shales apparently respond more readily to the heat, losing their original texture and becoming hard and massive. A splintery or conchoidal fracture is not uncommon, even where the rock retains clear impressions of fossil leaves or invertebrates. Many specimens resemble jasper, their appearance suggesting the terms porzellanit and porzellanjaspis, under which this material is described by Zirkel.[1] The mottled rock is probably produced by a higher temperature, though its colors are due primarily to irregular oxidation of the iron. As disclosed by the microscope the red color is due to the formation of minute scales of hematite, whereas the black and green areas contain abundant small grains of magnetite.

VITRIFIED SHALE.

In many localities the shale near the top of the burning bed or near the chimneys has been rendered pasty or molten and has flowed slightly. In some places the material has been rendered sufficiently fluid to develop a ropy surface on cooling, closely resembling that characteristic of certain lavas. The rock is irregularly banded red and green or black, and thin sections across the flow lines usually reveal the presence of hematite in the red areas and magnetite in the green and black. The rock is not smooth like ordinary baked shale but is rough and very finely vesicular like some kinds of brick. Ordinarily the grain is so fine that little can be made out under the microscope, though occasionally small areas of amorphous glass may be seen. Some varieties contain small grains of clayey material, reddish in the center and surrounded by a gray or black zone.

GLASSY SLAG.

Bodies of glassy slag large enough to be observable in the hand specimen apparently occur only near the top of the burning bed or in the chimneys. Entirely glassy slag is not common, for where the heat is sufficient to cause complete fusion cooling is generally slow enough to allow more or less recrystallization. Most of the true glass seems to occur as small veinlets penetrating crevices in the baked or vitrified rock. The rock around the chimneys is generally fractured or brecciated, and sudden settling or caving apparently forces some of the molten rock out into the crevices of this brecciated mass, where it is more rapidly cooled. In some places, however, conditions have led to the sudden cooling of larger masses of the molten slag and good-sized specimens may occasionally be found. Some of them resemble obsidian very closely, being perfectly glassy and in spots highly vesicular. All of the specimens seen by the writer are black, but translucent in thin splinters.

In thin section this material appears as an amorphous glass, generally containing a few minute grains of a black mineral that is presumably magnetite. One specimen is characterized by a kind of spherulitic structure, as shown in the accompanying photomicrograph (Pl. II, *A*). Another shows a few clusters of acicular crystals too small to be identified, thus illustrating the transition to the recrystallized phases described below.

RECRYSTALLIZED SLAG.

The rocks that have been thoroughly fused and cooled with sufficient slowness to allow complete recrystallization are of considerable petrographic interest, though constituting a

[1] Zirkel, Ferdinand, Lehrbuch der Petrographie, Band 3, pp. 75-76, 1894. References are given to earlier accounts, dealing mostly with occurrences in European coal fields.

minor facies of the metamorphic products. The recrystallized material is generally, if not invariably, confined to the chimneys. As a rule it is gray to dark greenish gray, and except for its vesicularity is very similar in appearance to a fairly basic igneous rock. The grain is generally fine, though in one specimen a crystal a tenth of an inch in diameter resembling pyroxene was observed. All gradations between holocrystalline material and glassy slag may be found, and in most of the specimens examined a small amount of interstitial glass occurs. In one slide remnants of the original quartz grains appear together with amorphous glass and small, slender newly formed crystals.

A specimen from Tongue River near the Wyoming-Montana line (T. 9. S., R. 40 E.) was studied under the microscope and found to consist chiefly of diopside and basic plagioclase. The mineral called diopside has the following optical characters: Biaxial positive; axial angle about 60°; dispersion weak with red greater than violet; extinction angle, 36°; and indices of refraction about 1.675 and 1.702. The plagioclase has a maximum extinction angle of 38° in microlites and refractive indices of 1.57 and 1.58, which indicate a basic labradorite or bytownite of the approximate composition Ab_1An_3. As shown in the accompanying photomicrograph (Pl. II, *B*), the diopside crystals have a tendency to form radiating groups, and the plagioclase occurs in well-formed laths and microlites. Some garnet, apparently almandite, was observed, and magnetite in small grains is fairly abundant. As near as can be ascertained the rock from which this material was derived is a sandy shale, consisting largely of kaolin, feldspar, and altered ferromagnesian minerals, together with subordinate quartz and some calcite.

A specimen collected near the head of Sarpy Creek (T. 1 N., R. 37 E.) resembles the specimen from Tongue River megascopically, but under the microscope appears to be a very different rock. A larger number of minerals are present and the characters of the most important of these do not correspond with those of any of the ordinary rock-forming minerals. The rock consists largely of greenish phenocrysts—at first sight suggesting epidote—set in a mosaic of colorless grains resembling melilite. The optical characters of the green mineral are as follows: Biaxial positive; axial angle nearly 90°; dispersion strong, and red greater than violet; extinction angle 23°–25°; and indices of refraction about 1.655 and 1.675. The mineral is pleochroic, deep yellow to apple-green. These properties indicate that it is not epidote and suggest that it may be clinoenstatite. The colorless mineral is biaxial negative in character, has a large axial angle, and has strong dispersion, red being less than violet. Its birefringence is about that of quartz, and its refractive indices are about 1.615 and 1.625. These properties suggest andalusite or some form of wollastonite, though the mineral does not resemble either of these in habit. Two other minerals are present that could not be identified. One is pleochroic, yellow to colorless; it is uniaxial negative in character and its refractive indices are about 1.62 and 1.64. The other, which is not abundant, is isotropic, colorless, and lacks cleavage; its index of refraction is about 1.61. In addition the rock contains a basic labradorite, occurring in small but well-twinned laths, magnetite, and a few grains of garnet, probably almandite. Several rounded xenoliths of shale surrounded by contact rims of the yellow and white minerals already described were observed. (See Pl. III.)

A specimen collected in T. 1 N., R. 36 E., not far from the one just described, appears to have been derived from a more highly aluminous shale. It is only partly recrystallized and consists largely of glass, but acicular crystals of sillimanite (fibrolite) are abundant, and several grains of what seem to be cordierite were observed. Spinel may be present but could not be positively identified. Close to the chimney in which this mineral occurs a mass of specular hematite about a foot in diameter was found. The hematite appears to be closely associated with the chimney, although it lay rather in the partly baked shale through which the chimney projects. This remarkable occurrence is discussed on pages 9–10.

All the rocks described appear to be irregular in composition, and different portions of the same specimen may contain different minerals. It is probable that a detailed study would reveal many more species, and some have indeed been reported by other observers. In slags from eastern Wyoming

Bastin [1] finds oligoclase, pyroxene, and cordierite, in addition to magnetite and hematite. He describes a vein of slag about one-tenth of an inch in diameter penetrating red argillite as follows:

> In passing from the reddish argillite toward the center of the vein the contact zone shows a gradual decrease in the normal shale constituents and a development, in increasing amount and coarseness, of purplish-blue pleochroic cordierite. Next the coarser part of the vein this mineral is present to the exclusion of all others. In this contact zone the red iron oxide of the argillite has been wholly reduced to magnetite. The central portion of the vein is a somewhat vesicular, holocrystalline mass, consisting of abundant magnetite in irregular masses, some hematite, usually lining the vesicles and following fractures, and abundant cordierite, feldspar, and pyroxene.

Hibsch [2] has described similar material from the Mittelgebirges (northern Bohemia) under the name Kohlenbrandgesteine. In the recrystallized specimens he finds magnetite, cordierite, epidote in well-formed crystals, plagioclase, tridymite, and abundant dark grains that may belong to the spinel group.

CHEMICAL CHANGES.

The most widespread chemical change produced in the overlying strata by burning coal beds is dehydration under conditions favorable to oxidation. This change affects chiefly the limonite and the siderite or other ferrous iron compounds, which are converted into hematite, with consequent reddening of the rock. Some of the hydrous silicates may be partly or wholly dehydrated without fusion under some conditions, but if this change takes place it is difficult to detect. In one specimen, however, the writer observed a large fresh grain of green augite in a sandy shale that had been baked but not fused. The augite could not be a product of secondary crystallization, and all the other constituents of the rock were considerably altered. This suggests that it may have been re-formed by the dehydration of alteration products, such as chlorite or serpentine, though the writer is aware that such a process is not well supported by laboratory results.[3]

Within the chimneys and directly above the burning bed, where the rocks are fused under conditions favorable to reduction, more extensive changes take place. The conditions are, of course, very different from those under which igneous rocks are formed, and are analogous rather to those in the slag furnace. The pressure is low, mineralizing agents are absent, and much of the water that the rocks contained is doubtless quickly driven off. The material involved, however, is different from that which enters into the composition of most furnace slags, being generally argillaceous rather than calcareous, and many of the minerals formed are therefore probably unlike those common in artificial slags. In this connection the classic researches of Vogt and Morozewicz, on prepared slags of known composition, are of interest.

It is impracticable to correlate many pieces of slag with the unaltered rock from which they were derived, owing to the irregularity in composition of the strata. Furthermore, unless fusion is very complete and the molten mass is well mixed its mineral composition may also be irregular. However, the diopside-plagioclase rock described above is evidently derived from a sandy shale, and after microscopic study a sample of this shale was analyzed by the writer in the hope that the analysis as recast might explain the mineral character of the slag. The composition of the shale is shown by analysis 1 in the accompanying table.

The sample analyzed had been partly baked, which explains the ferric condition of nearly all the iron. The analysis accounts in a general way for the mineral composition of the slag, indicating rather high iron, lime, and magnesia. According to Morozewicz,[4] diopside or hedenbergite is formed in a slag in which the molecular ratio of $Fe+Mg:Ca$ is less than 3 : 1. This analysis shows a ratio of only 94 to 89, or if all the iron is calculated as ferrous, of 140 : 89, and pyroxene of the diopside-hedenbergite type is therefore to be expected. According to the same investigator,[5] augite is generally formed when the melt contains more than 50 per cent of silica, and though no augite was observed in this slag it might, if irregularly distributed, easily escape observa-

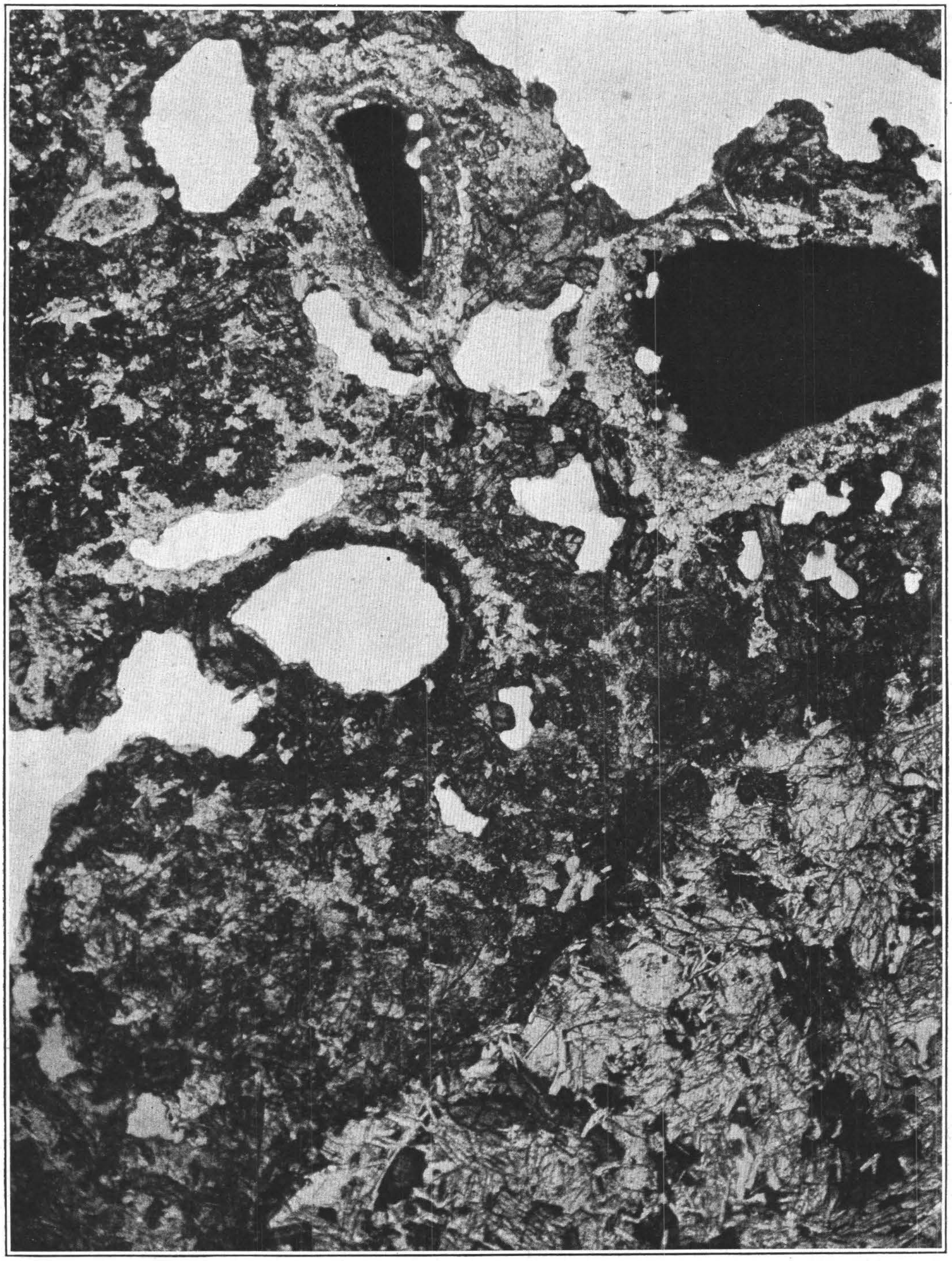
[1] Bastin, E. S., Note on baked clays and natural slags in eastern Wyoming: Jour. Geology, vol. 13, pp. 408–412, 1905.

[2] Hibsch, J. E., Geologische Karte des böhmischen Mittelgebirges: Min. pet. Mitt., vol. 27, pp. 35–40, 1908.

[3] Clarke, F. W., and Schneider, E. A., Experiments upon the constitution of certain micas and chlorites: U. S. Geol. Survey Bull. 113, pp. 27–33, 1893.

[4] Morozewicz, Josef, Experimentelle Untersuchungen der Minerale im Magma: Min. pet. Mitt., vol. 18, pp. 113–128, 1898.

[5] Idem, pp. 113, 120, 123–124.



PHOTOMICROGRAPH OF HOLOCRYSTALLINE SLAG.

tion. The analysis, however, indicates a more acidic plagioclase than that found in the slag and suggests that an excess of silica would probably be left to crystallize as quartz or tridymite, which are apparently absent. These discrepancies are presumably due to irregularities in the composition of both the shale analyzed and the slag.

Analyses of baked shale from Fort Union formation, Montana.

[G. S. Rogers, analyst.]

	1	2
SiO_2	65.41	58.30
TiO_2	1.17	.28
Al_2O_3	11.94	20.50
Fe_2O_3	7.38	4.23
FeO	.76	.46
MnO	....	.18
MgO	1.50	1.31
CaO	5.02	4.40
K_2O	1.96	2.28
Na_2O	2.83	1.46
H_2O-	.08	1.03
H_2O+	.50	1.90
CO_2	1.57	3.37
SO_3	.22	.19
P_2O_5	Trace.	Trace.
	100.34	99.89

1. Sandy shale from upper Tongue River, T. 9 S., R. 40 E.
2. Clay shale from T. 1 N., R. 36 E.

The third specimen described, containing sillimanite, cordierite, and probably spinel, is of interest as indicating the minerals that form in a melt more highly aluminous than any normal igneous magma. The composition of the shale from which this slag is derived is shown by analysis 2. The specimen analyzed had been moderately baked. It is uniformly fine grained and under the microscope appears to consist largely of clayey material together with a few grains of quartz and some calcite.

The analysis indicates a slag similar in composition to some of those studied by Morozewicz,[1] who was able to formulate the conditions under which the several aluminous minerals form. If the molecular ratio of alumina is greater than the sum of the ratios of lime, soda, and potash, the magma is supersaturated with respect to alumina. If the general formula of the magma is written $1RO.mAl_2O_3.nSiO_2$ the following rules apply: When magnesia and iron are very low, if n is less than 6 corundum will form, but if n is greater than 6 sillimanite will crystallize out. When magnesia and iron are present in appreciable amount, if n is less than 6 corundum and spinel are produced, but if n is greater than 6 spinel and cordierite will form. Analysis 2 indicates the formula $125RO.201Al_2O_3.971SiO_2$, or $1RO.1.6Al_2O_3.7.7SiO_2$; as m is greater than 1 and n is greater than 6 the melt is supersaturated with respect to alumina, and the alumina should form spinel, cordierite, and sillimanite. The sum of the molecular ratios of iron and magnesia is 64, or less than the difference between those of RO and Al_2O_3. It may be supposed that cordierite and spinel would be formed until the magnesia and iron were nearly exhausted, and that the balance of the alumina would then be consumed in the formation of sillimanite. Unfortunately the slag examined was incompletely crystallized, and the order of formation of the minerals could not be determined. Cordierite is reported by both Bastin and Hibsch, and a mineral resembling spinel was found by Hibsch, which indicates that the aluminous silicates are probably common in the slags formed by the fusion of shales, and as magnesia and iron are generally present in considerable amount cordierite and spinel are doubtless more common than sillimanite or corundum.

[1] Op. cit., pp. 22–83.

As already mentioned, a mass of hematite weighing several pounds was found close to the chimney from which the slag described above was taken. A partial analysis of the hematite is as follows:

Analysis of hematite from T. 1 N., R. 36 E., Montana.

[Chase Palmer, analyst.]

Ferric iron (Fe_2O_3)	83.57
Sulphur (S)	Traces.
Chloride (insoluble) (Cl)	Traces.
Metallic iron (Fe)	None.
Ferrous iron (FeO)	None.

The origin of this mass of hematite is not easy to understand. So far as the writer knows hematite has never been observed elsewhere in these flat-lying and only partly consolidated strata, and the specimen described must therefore have been formed in some way through the agency of the burning coal. It might be ascribed to the oxidation of a large pyrite or ironstone nodule, but a careful search failed to reveal any such nodules in the unaltered beds near by. On the other hand, if it is considered to have resulted from segregation during heating or fusion, the details of the process are very difficult to explain. As shown by analysis 2 (p. 9), the surrounding rock contains less than 5 per cent of iron, and rather extensive concentration would therefore have to be postulated. According to Vogt,[1] hematite rarely occurs in ordinary furnace slags, as it can crystallize only when ferrous compounds are present in very subordinate amounts. In the surrounding rock ferrous iron is practically absent, but in order to concentrate the ferric iron complete fusion would appear to be necessary, and as this seems always to take place under conditions favorable to reduction, much of the ferric iron would become ferrous. If the iron had occurred directly in the chimney as native iron, or even as magnetite, it might therefore be supposed that a smelting process akin to that in the ordinary blast furnace had taken place, but as it was found at the edge of the chimney and is completely oxidized to hematite this view does not appear to be tenable.

A third hypothesis that might be suggested is that the hematite formed as it forms around volcanoes, through the decomposition of ferric chloride or sulphate by steam or heated air. The ground water of the region in which the hematite was found carries a considerable proportion of sodium chloride and of sodium, calcium, and magnesium sulphate, and as these salts are not uncommon as incrustations on the rocks an adequate supply of chloride or sulphate is undoubtedly present. On the assumption that hydrated ferric oxide (limonite) is capable of uniting with sodium chloride under the influence of intense heat, it seems probable that the ferric chloride so formed would ascend as vapor with the other gases and would be deposited as hematite in the upper part of the chimney. It is by no means certain that the primary reaction between disseminated limonite or siderite and soluble chlorides or sulphates is chemically possible under the conditions prevailing, but the presence of traces of basic (insoluble) chloride in the hematite is difficult to explain on other grounds and therefore tends to support this hypothesis.

Native iron of secondary origin has been observed near coal beds in other localities. On North Saskatchewan River, 70 miles above Edmonton, Alberta, lignite beds have burned and have reduced the large clay ironstone nodules in the overlying strata to metallic iron, masses of which weighing from 15 to 20 pounds have been found.[2] At three localities in Missouri drill holes have penetrated small masses of soft malleable iron in the sedimentary rocks above coal beds,[3] but the genetic relations of the iron and coal in this case are not so clear.

[1] Vogt, J. H. L., Beiträge zur Kenntniss der Gesetze der Mineralbildung in Schmelzmassen, pp. 215-217, 1892

[2] Tyrrell, J. B., Naturally reduced iron: Am. Jour. Sci., 3d ser., vol. 33, p. 73, 1887.

[3] Allen, E. T., Native iron in the coal measures of Missouri: Am. Jour. Sci., 4th ser., vol. 4, pp. 99-104, 1897.

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THE NEWINGTON MORAINE

MAINE, NEW HAMPSHIRE, AND MASSACHUSETTS

BY

FRANK J. KATZ AND ARTHUR KEITH

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THE NEWINGTON MORAINE, MAINE, NEW HAMPSHIRE, AND MASSACHUSETTS.

By Frank J. Katz and Arthur Keith.

INTRODUCTION.

The present paper embodies the results of brief studies in 1915 and some earlier observations (1911–1914) on glacial and associated deposits in Maine and New Hampshire. It is preliminary in character, and the work was incidental to more extensive and detailed studies of the Pleistocene geology of southwestern Maine and vicinity, which will be the subject of later publications.

The fact that a belt of gravelly and sandy ridges in southwestern Maine and adjacent New Hampshire has the character of a terminal moraine was recognized by the authors while they were together engaged in geologic reconnaissance. The moraine was first noted in Biddeford and Wells, Maine, and in Newington and Portsmouth, N. H. Mr. Keith traced the course of the moraine from Rye, N. H., to Newbury Old Town, Mass.; the portion in Newbury and Newburyport, Mass., had been noted by Sears.[1] Mr. Katz subsequently studied the moraine from Saco, Maine, to Rye, N. H. The late Prof. C. A. Davis was for a time in the field with the authors and contributed to the results here announced. His familiarity with the geography and geology of the region about Portsmouth was of assistance in tracing the moraine.

Earlier geologic writings that are of interest as discussions of Pleistocene geology of the same region are limited to three—Warren Upham's chapter, "Modified drift," in Hitchcock's "Geology of New Hampshire," volume 3; J. H. Sears's "Geology of Essex County, Mass.," cited by full title below; and F. G. Clapp's "Complexity of the glacial period in northeastern New England."[2]

The name here adopted is taken from the town of Newington, N. H., in which the moraine is characteristically developed and forms a prominent topographic feature. The time of the Newington moraine will be designated the Newington substage.

GENERAL CHARACTER OF THE REGION.

The region in which the Newington moraine is situated is a coastal lowland from 12 to 20 miles wide, bounded on the landward side by an upland that rises inland by a series of thoroughly dissected rock platforms or terraces. The coastal lowland, which also includes several similar but lower terraces, is a hilly, heavily drift-mantled rock surface, rising from below sea level to about 300 feet above sea level. The rock floor of this terraced surface is thoroughly dissected into ridges separated by wide, open valleys, some of which are in part worn to depths below the present sea level. Some ridges, for example the Bauneg Beg Ridge, project from the upland terraces into the lowland area, and some monadnock-like rock hills or outliers of the higher terraces, notably Mount Agamenticus, rise above it.

The entire region has been rigorously glaciated and abundantly supplied with glacial deposits of many kinds. During part of the glacial epoch the coastal terraces were submerged beneath the sea, but since then they have emerged. During the period of subsidence marine clays and sands were deposited in the depressions, and these deposits are now to be seen as broad, flat areas only slightly dissected by a very young drainage system. Davis[3] has shown that "The present shore line is therefore not the direct result of submergence of a rugged land, but of the emergence of an uneven sea

[1] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., pp. 296, 301, map, Essex Institute, Salem, 1905.

[2] Geol. Soc. America Bull., vol. 18, pp. 505–556, 1907.

[3] Davis, W. M., Physiography, in Grabau, A. W., and Woodman, J. E., Guide to localities illustrating the geology * * * of the vicinity of Boston, p. 5, Am. Assoc. Adv. Sci., 1898.

bottom—uneven because the marine clays that were spread upon it had not been deposited in sufficient quantity to smooth over its previous inequality."

The glacial and marine deposits have modified and in general softened the relief of the region and have deflected many of the streams from the preglacial rock valleys. Nevertheless, the general trend of the principal drainage lines is now, as formerly, southerly to east-southeasterly. The marine deposits increase in breadth and thickness and indicate greater submergence toward the north and northeast. The surface of these deposits now slopes southeastward (toward the sea), and, furthermore, the broad plains of marine clay and sand lie at higher elevations in the northern part of the region than in the southern part. There appears, then, to have been some tilting. These relations, however, may be in part explained as due to differences in the degree of filling caused by differences in the quantity of material discharged into the sea at different localities and in the distance of the several localities from the shore line and the sources of the materials. The Pleistocene marine sediments of this region and the associated problems of coastal movements and delineation of shore lines are now being studied.

LOCATION AND DISPOSITION OF THE MORAINE.

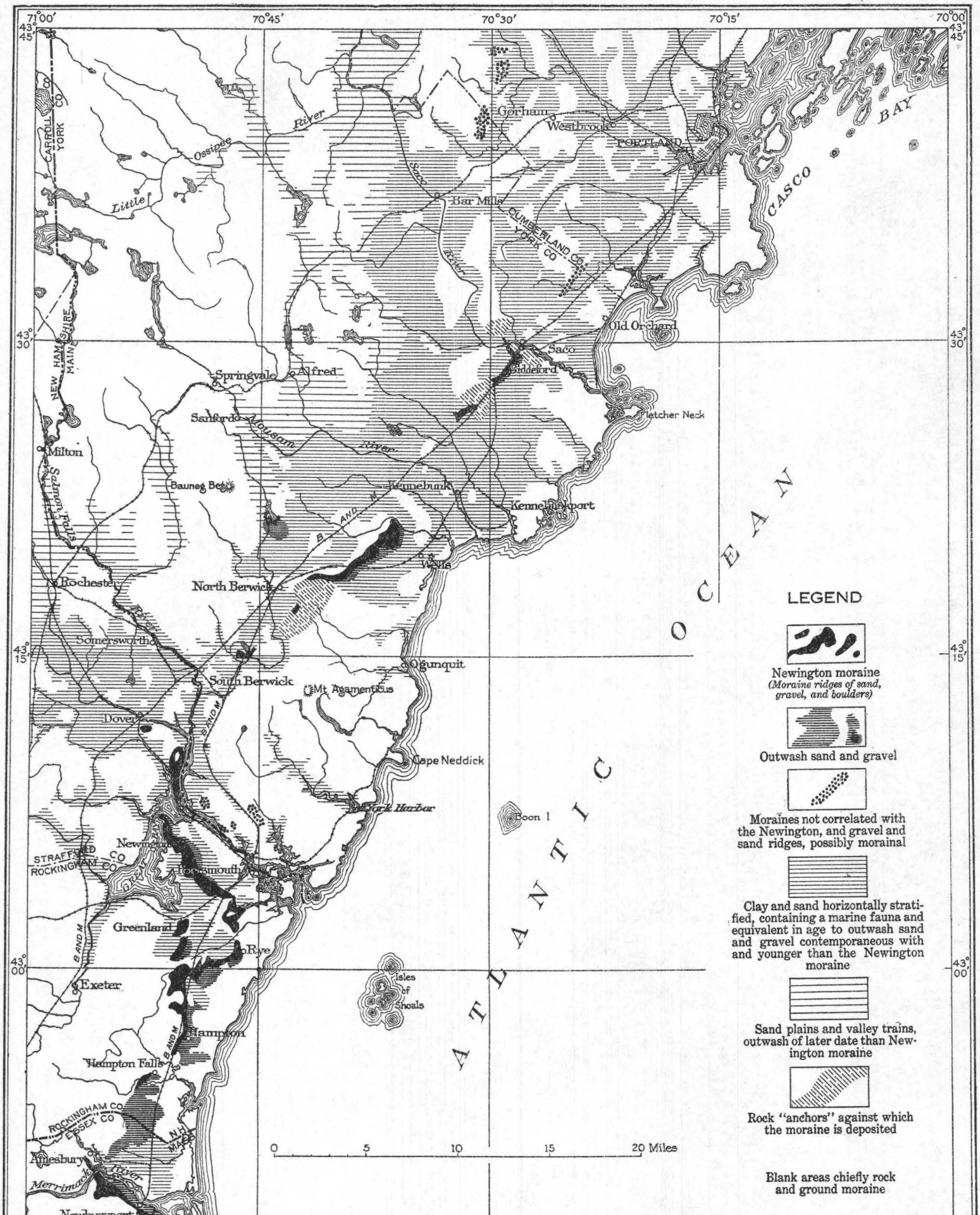
The drift formations here considered are distributed along a sinuous 60-mile course in York County, Maine, Strafford and Rockingham counties, N. H., and Essex County, Mass.[1] They lie nowhere more than 9 miles from the present Atlantic coast and in some places are adjacent to tidewater. Their distribution is shown on the accompanying map (Pl. IV).

The moraine does not form a continuous ridge but is made up of a number of segments, more or less widely separated by intervals in which no deposits belonging to a terminal moraine have been found. Nevertheless, there is a conspicuous alignment of the segments, as displayed on the map (Pl. IV), which supports the conclusion that all are parts of the same moraine. The arrangement and extent of the several segments and intervals are as follows:

Beginning at the north, the first is the Saco segment, in the western part of the city of Saco, Maine, on the north bank of Saco River just west of Deep Brook. It is a little less than a quarter of a mile long and trends southeast. Between the Saco segment and the next one, the Biddeford segment, is a short interval occupied by Saco River and its flood plain. The Biddeford segment has its north end south of the Saco segment, on the south side of Saco River, in Biddeford, and extends south-southeast for nearly a mile, and thence west of south along the west side of the post road for 1½ miles, finally turns southwestward and ends near the granite hills in the southern part of the town of Biddeford. Beyond an interval of 1¼ miles to the southwest, across granite hills, is the next segment, the Kennebunkport, which is a ridge 1½ miles long with southwest trend. About 7 miles to the southwest, across Kennebunk, Mousam, and Branch rivers and the flat lowlands adjoining them, is the Wells segment or Merriland Ridge. This ridge has a sinuous course about 7 miles long, trending south for a mile, then swinging westward and finally southwestward and terminating about 2 miles east of North Berwick village, against a massive hill of granite. About 2½ miles southwest of this point there is a small area of probably morainal sands and gravels. Two miles farther south is the Knights Pond segment, a crescentic ridge inclosing the southeast end of Knights Pond, in the northwest corner of the town of South Berwick. The succeeding interval, measured to either the Dover or the Dover Neck segment, is approximately 8 miles across areas of ground moraine (till), marine clay and sand, and rock ledges.

The Dover segment, including Pine Hill Cemetery, in the city of Dover, is an irregular area from half to three-fourths of a mile wide. This is separated by an interval of clay plain and till-covered rock hills, 1 mile wide, in a southeast direction from the Dover Neck segment, which is a north-south ridge 2½ miles long between Little John Creek on the north, Dover Point on the south, and Piscataqua and Bellamy rivers on the east and west, respectively. Across Little Bay, 1 mile south of the end of the Dover Neck ridge, is the north end of the Newington and Portsmouth segment, which extends south about 2¼ miles along or near the eastern shore of Great Bay, thence east three-fourths of a mile to Newington Town

[1] This region is represented on the following maps of the United States Geological Survey's topographic atlas: Portland, Biddeford, and Kennebunk, Maine; Berwick and Dover, Maine and N. H.; and Newburyport, N. H. and Mass. All these maps, except that of the Portland quadrangle, are of reconnaissance grade, and therefore too much generalized to bring out features like those described.



MAP OF NEW ENGLAND COASTAL REGION FROM PLUM ISLAND, MASS., TO CASCO BAY, MAINE, SHOWING DISTRIBUTION OF MORAINE AND OUTWASH DEPOSITS.

Hall, southeast 3 miles to Portsmouth Plains, south 1 mile to Peverly Hill, and south into the swamp along Berrys Brook. The part of the moraine between Newington and Peverly Hill is shown on Plate IX (p. 18). The Rye, North Hampton, and Hampton segment, beginning south of Berrys Brook opposite the end of the Newington and Portsmouth segment, extends west-southwest through Rye Center and West Rye 2 miles to Breakfast Hill, south and west of which, in North Hampton, morainal deposits are irregularly distributed over a broad area of several square miles. North of this area, in the town of Greenland, is an outlying moraine ridge 1¾ miles long from north to south. From North Hampton the moraine continues southward through Hampton village into Hampton Marsh, north of Taylor River. The Hampton Falls, Seabrook, and Salisbury segment begins in Hampton Falls, 1½ miles southwest of the preceding segment, and extends south and south-southwest through Seabrook and Salisbury to Merrimack River. The Newburyport segment begins in Amesbury and runs southeast across Merrimack River and for 7 miles in a nearly straight course into Newbury village, whence it extends south-southwestward for a short distance to Parker River. The moraine has not been traced beyond this point.

The above-outlined disposition of moraine segments indicates that the ice front of the Newington substage from Saco, Maine, to Newbury, Mass., a distance of 59 miles, had a general south-southwest course, though it was not straight. From Saco through Wells the line indicated by the segments was nearly 15 miles straight southwest. Beyond Wells, through North Berwick and South Berwick, Maine, and Rollinsford and Dover, N. H., the front was bowed 2 miles westward through another stretch of 15 miles around the Mount Agamenticus mass, which was a barrier to eastward ice movement. From Dover it swung southeasterly for 8 miles through Newington and Portsmouth into Rye, being held south of Piscataqua River, probably by the influence of both the Agamenticus highland and the Piscataqua estuary. This southeasterly stretch and the succeeding west-southwesterly course of 4 miles in Rye and North Hampton outline a small lobe, caused by the Great Bay depression. From North Hampton the general course of the ice front was south-southwest for 11 miles to Merrimack River, with a slight easterly bowing. South of Merrimack River its course has been traced for about 8 miles in a southeasterly direction, determined by the river, from Amesbury to Newbury Old Town.

GENERAL CHARACTER OF THE MORAINE.

The Newington moraine is a ridge ranging in height from 40 to 100 feet above its base and in width from a few rods to a mile or more. It consists of a western inner or ice-contact slope, the summit or moraine crest, and in some places an outer slope with which is associated an outwash apron. These parts are not everywhere distinct. The inner side is generally steep, rising abruptly the full height of the moraine from ground moraine or marine clay plains. The crest, whether narrow or broad, is nearly everywhere flat and approximately level. It is hummocky in only a few places, nowhere markedly so. It does not exhibit the typical knob and kettle form of kame moraines, nor the rough surface of till and boulder moraines. Where kamelike forms have been developed, as in Newburyport, Kennebunkport, and Dover, and locally in Newington and Portsmouth, they are small and subdued in form and relief. As a rule, kettle holes are few, isolated, and small. In Newburyport and North Hampton, however, there are groups of good-sized ones. Where the moraine does not lie against rock hills the outer side is a moderate slope descending to clay plains or merging into an outwash apron or else a low scarp between the outwash and the moraine crest. Outwash plains were not formed everywhere, and some of them are not distinct from the moraine. They are smooth gentle slopes a few rods to 1½ miles wide and locally pass gradually in both slope and constitution into broad flats of marine clay and sand.

Within a moderate range the moraine ascends and descends with the relief of the floor upon which it stands. Thus it rises out of the valley of Saco River upon the small rock hills in Biddeford and descends again into the valley of Kennebunk and Mousam rivers. In Wells and South Berwick it attains its greatest elevation of about 200 feet on the flanks of a large obstruction of high ground. Southwest of this locality it descends to sea level in Piscataqua River. However, the maximum difference in altitude of different parts of the moraine does not exceed 200 feet.

The materials of the moraine are boulders, gravel, and sand. With the exception of some of those at one place, all the boulders and pebbles observed are foreign to the locality of the moraine. A very small amount of stratified clay has also been noted in the moraine, but no till has been identified in morainal deposits of typical Newington form. Boulders are not abundant as a rule but have been found in considerable numbers in the north end of Merriland Ridge, Rye Center, and Greenland. Gravelly sand and gravel made up of large cobbles, small pebbles, and sand predominate in the moraine. These materials are all more or less washed and water-rounded. The outwash materials are gravel and sand, dominantly of small size, and are progressively finer toward the farther limit of the outwash.

The moraine has in many places a well-developed internal structure consisting of a sorting and stratification approximately parallel to the cross profile of the moraine. Beds that are nearly flat in the center dip outward into and constitute the proximal part of the outwash plain. In several places in Biddeford, Newington, and Portsmouth the inner side of the moraine is made up of beds dipping strongly and in part parallel to the surface slope. These "backset" beds are well developed in the broader parts of the moraine and were deposited during slow retreat of the ice. In places in Newington the moraine contains structureless, unsorted sand and gravel. Irregularly distributed patches of sand and gravel were noted in Saco and Portsmouth.

LOCAL DETAILS.

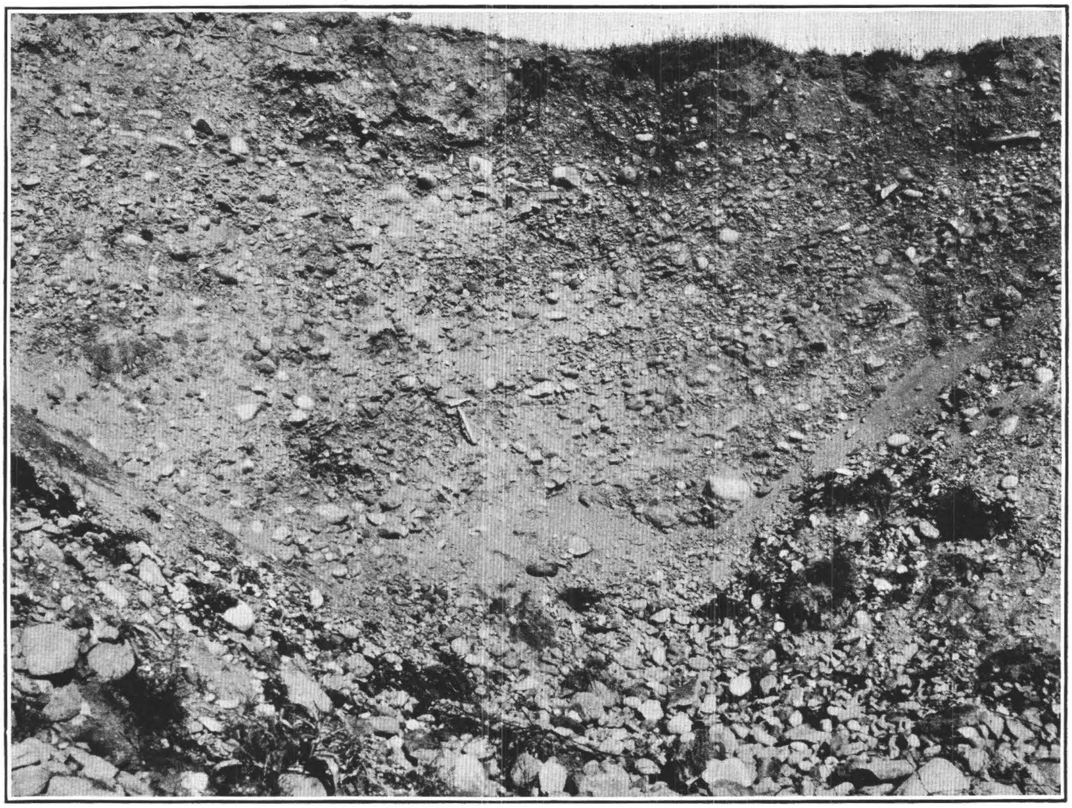
SACO SEGMENT.

The moraine in Saco is very narrow and inconspicuous; it consists of aligned sandy knolls almost covered by the surrounding clay and sand plain. The ridge extends northwest toward a till-covered rock hill, from which it is separated by nearly half a mile of horizontal sand plain. In two pits marine clay and overlying sand lie above the moraine material, which consists of waterworn sand, gravel, and boulders, not stratified but in pell-mell structure. Pebbles of moderate size predominate, although there are also numerous large boulders. The materials in these pits are not weathered.

BIDDEFORD SEGMENT.

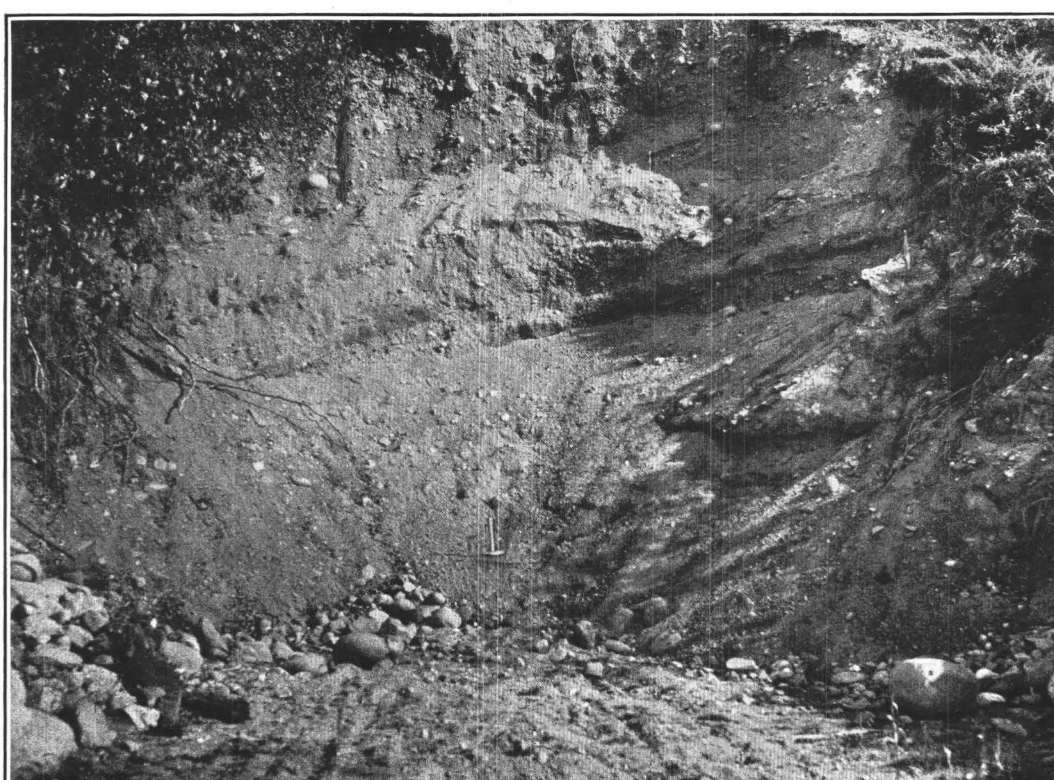
Opposite the Saco segment is the north end of the Biddeford segment, also covered by clay. A broad mound of stratified sand overlain by marine clay on the north side of Main Street, Biddeford, is the northernmost recognizable part. Thence the moraine continues southeastward, rises above the clay as a gravel cover on the south-southwest slope of the rocky hill in the center of the city, and extends as far as Elm Street (the post road), where it forms a flat-topped sand plain that on the east in part abuts against higher granite hills and in part grades into a clay plain. From this plain the moraine narrows to an even-crested ridge which trends southwest on the west side of the post road for about a mile. This ridge is 160 to 180 feet above sea level, and from it the descent to the northwest is moderately steep for about 50 feet to a low area floored by rock ledges, ground moraine, and marine clay. On the southeast side, however, the ridge is only locally marked off by a low scarp and slight change in slope from the bordering sandy outwash plain, which slopes gently southeastward and merges into a clay plain. The difference in slope and altitude between the two sides is a most striking feature in a view from the top of the moraine. From the post road the moraine turns westward and decreases in height. It trends toward the granite hills on the edge of the town of Kennebunkport but ends at the low pass immediately east of those hills.

The make-up of the Biddeford segment is disclosed in a number of gravel pits and sand banks from which material is taken for railroad, highway, and construction work in and around Biddeford. Two cuts on the summit and the large gravel bank worked by the railroad on the northwest side of the high ridge along the post road show that the material is made up of gravel and boulders packed in a sandy matrix without sorting or stratification and at least in part lying on granite ledges. The material is all more or less waterworn and rounded, and in the summit cuts it is iron stained and partly rotted. A sand pit near the junction of the post road and the Alfred pike, near the moraine border of the outwash plain, shows 20 feet of stratified and approximately horizontal sands. Pits in the northwest slope of the ridge and on the north side



A. UPPER PART OF PIT.

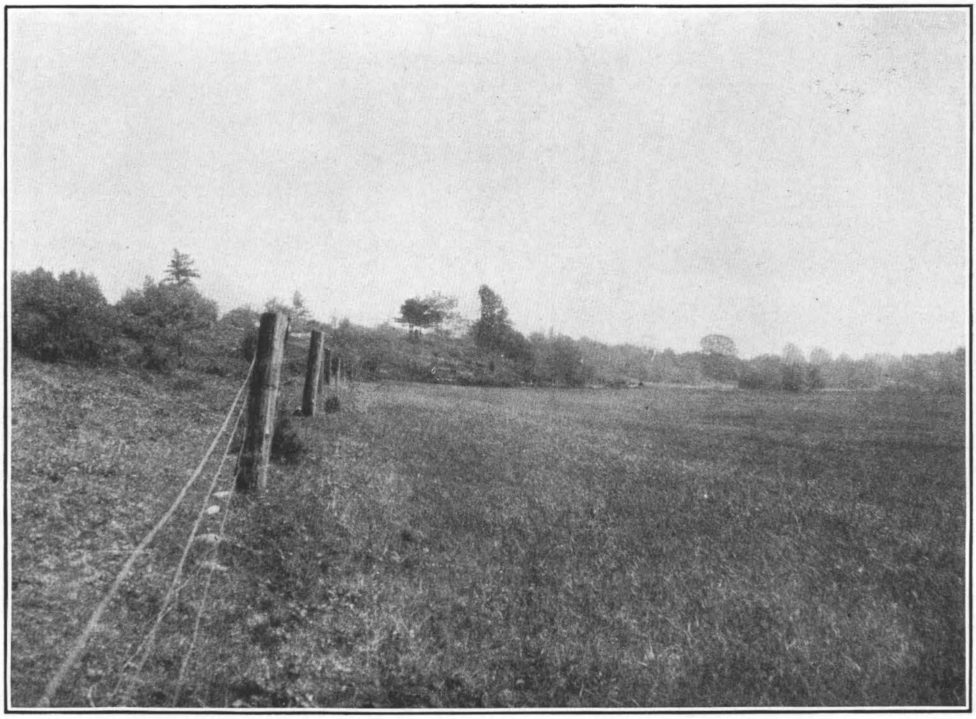
Shows 15 feet of rudely stratified moraine gravel.



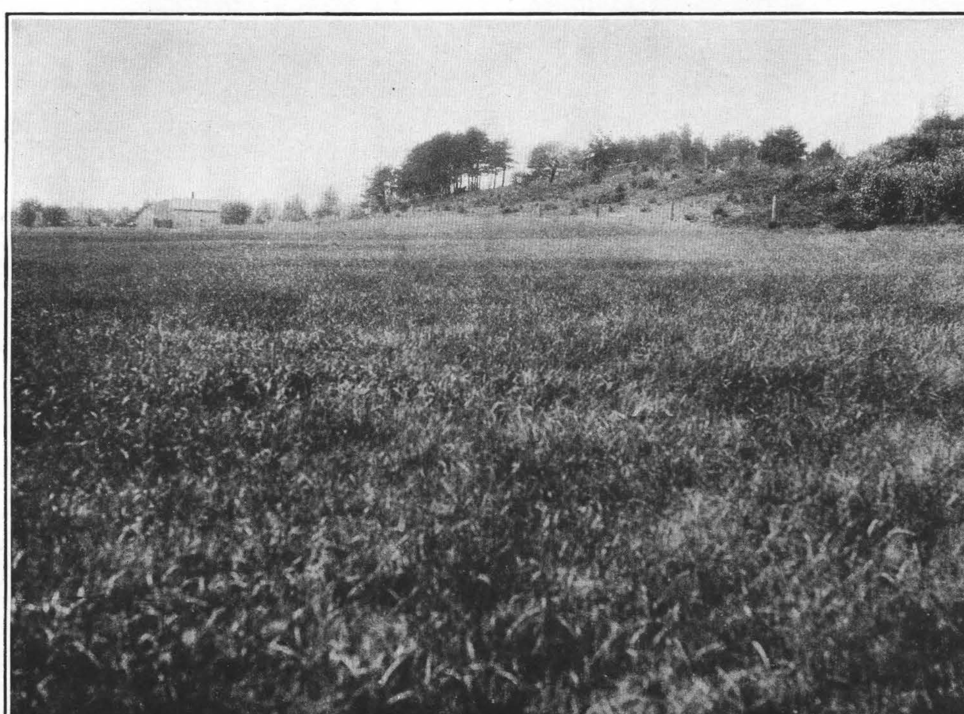
B. LOWER PART OF PIT.

Well-stratified sand and gravel on inner slope of moraine. These sands are overlain by the gravel shown in *A*.

GRAVEL PIT IN BIDDEFORD, MAINE.



A.



B.

MORAINE FRONT AND OUTWASH, MERRILAND RIDGE, WELLS, MAINE.

In the upper view the moraine front is fairly smooth and not sharply separated from the outwash. In the lower view the moraine is scalloped and more sharply separated from the outwash.

of the Alfred pike expose 15 to 20 feet of sand and gravel. (See Pl. V.) This material is for the most part stratified and sorted, although but poorly so, and the beds dip strongly 35°–45° W.—that is, they are "backset" beds. The pebbles and boulders, the latter not uncommonly 2 feet and rarely 3 feet in diameter, are almost all rounded. Although some of them are somewhat polyhedral, like faceted pebbles or soled boulders, they have been so much rounded off that plane surfaces, other than joint or cleavage faces, are scarce. In these exposures beds of sand or small pebbles containing a few scattered larger pebbles are overlain by gravel beds containing 4 to 6 inch cobbles and many boulders. In all the gravel beds there is a closely packed matrix of sand and small pebbles.

The prominent part of the Biddeford segment is the ridge along the post road. The southwest end of this ridge, which is low and inconspicuous, trends toward and terminates near rock hills that are higher than any part of the moraine. The northeast end of this ridge lies against the higher rock ledges in the city, and the morainal gravels and sands continue to the north as a cover on the flank of these ledges. The northern part of the Biddeford segment and the Saco segment connect rock hills on both sides of Saco River. It is clear that these rock hills determined the form and position of the ice front and that the low ground between them was the site of the discharge of the glacial drainage of Saco Valley.

Between the Biddeford and Kennebunkport segments is an interval of 1¼ miles occupied by hills of granite that stand about 50 to 100 feet higher than surrounding areas. These hills for the most part are bare rocks, but in places they have a drift cover, no part of which has yet been recognized as belonging to a terminal moraine.

KENNEBUNKPORT SEGMENT.

The Kennebunkport segment is a narrow southwestward-trending ridge 1½ miles long and for the most part only 30 to 100 rods wide, though it widens to nearly three-quarters of a mile at its southwest end. It is made up of a number of coalescent sandy kamelike knolls and includes in its higher and broader southern part a few small rock ledges. This segment of the moraine springs from the south side of the granite hills, against which on the north the Biddeford segment terminates. On the east, north, and west the Kennebunkport segment is bordered by wide plains of marine clay and sand. These deposits fill the valleys of Kennebunk, Mousam, and Branch rivers, and except for detached protuberant hillocks of rock and ground moraine they bury all other formations. It is 7 miles south-southwest across these filled valleys, in which no terminal-moraine deposits have been found, from the Kennebunkport to the next segment.

MERRILAND RIDGE (WELLS SEGMENT).

The moraine of Merriland Ridge is terminated at both ends by granite hills. The north end springs from a small, low granite knob on Merriland River, in the town of Wells, about 2 miles above the mouth of the river. From this rock knob the moraine extends southward for a mile as a generally flat but in a small way hummocky area one-fifth mile to 1 mile broad. Over this area are scattered numerous large boulders, which, however, are more abundant on the western part of the broadest portion; the eastern part has fewer boulders and is more sandy. Southwestward from this broad, flat part the moraine is narrower, higher, and more sharply ridgelike, and from a point about 1½ miles north of west of Wells Beach station through a distance of 3½ miles west-southwest the moraine is a prominent sigmoid ridge which rises abruptly 40 to 50 feet above low and wide meadows on the northwest. (See Pls. VI and VII.) Through this distance it has a nearly level and generally smooth or gently undulating crest, at an altitude of about 200 feet above sea level. The crest is in some places only a few rods in width and in others several hundred yards. The southeast slope of this part of the ridge is short, 10 to 20 feet high, and steep. It is in places somewhat irregularly scalloped or ribbed and breaks sharply into a very gently sloping outwash apron of gravel and sand. In other places this southeast slope is smooth and merges gradually into the outwash apron. (See Pl. VI.)

The moraine is prolonged 1½ miles farther west, retaining its sharp ridge form. In this stretch it approaches the nearly parallel north slope of a large granite hill, against which it ends at a point about 2 miles east of North Berwick village. Through this end of the moraine some ledges of granite protrude.

The material constituting the northern part of this moraine is largely bouldery gravel. Elsewhere, as seen on the surface, it is chiefly sand and gravel of moderate size. The only section found is the railroad cut through Merriland Ridge, the south bank of which is shown in Plate VII. The height of this section is about 35 feet. The material in it is stratified small gravel and sand, with a little clay and relatively few small and large boulders. The attitude of the beds, which is faintly indicated in the photograph, is in approximate parallelism with the front or east side of the moraine. The bedding has a low easterly dip under the outwash plain and rises to a greater inclination under the crest, and then with lessened dip the beds are cut off at the back slope. This attitude is shown in figure 1. The clay seam, visible as a dark streak at about the center of the section in the photograph, thickens very slightly eastward out to the limit of its exposure, and on the west it thins and is replaced by coarse sand. In appearance and composition this clay is very much like the marine clay of the region in general. The entire outwash apron along this part of the moraine slopes down to and grades into the low, flat sand and clay plains about the headwaters of Webhannet River.

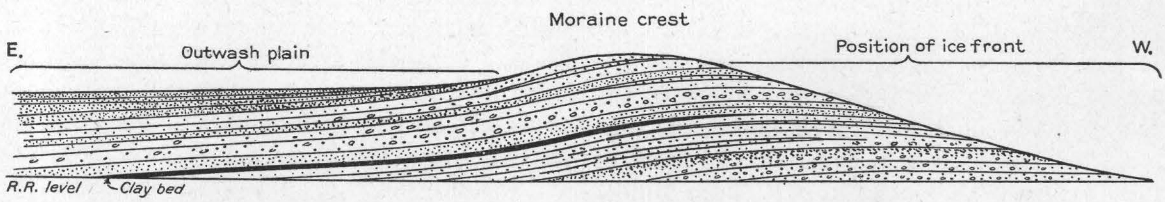


FIGURE 1.—Diagrammatic section of moraine and outwash deposits of Merriland Ridge, Wells, Maine, showing the structure of the moraine.

The continuation of the moraine was not sought in a southerly direction from the end of Merriland Ridge, because rock hills that are very much higher, culminating in Mount Agamenticus, 692 feet in altitude, extend for many miles southward and occupy a large area in the towns of Wells, South Berwick, and York. The westward swing of Merriland Ridge at nearly constant level against and around the north side of this high rock mass indicates that during the Newington substage the ice did not ascend these hills. A reconnaissance of the territory north and west disclosed no morainal deposits, but in South Berwick, at 2½ miles southwest of the end of the Merriland Ridge segment and on the west flank of the rock hills, was found the feature next described.

MORAINAL DEPOSITS IN SOUTH BERWICK.

In South Berwick, 1¾ miles southeast of North Berwick village, there is a small area of sand and gravel that fills a saddle between rock hills. No distinctly morainal features were noted here, but the position of this drift and its similarity in character to the drift of Merriland Ridge are suggestive of morainal origin. In 1890 Leonard H. Davis [1] regarded this drift as a moraine.

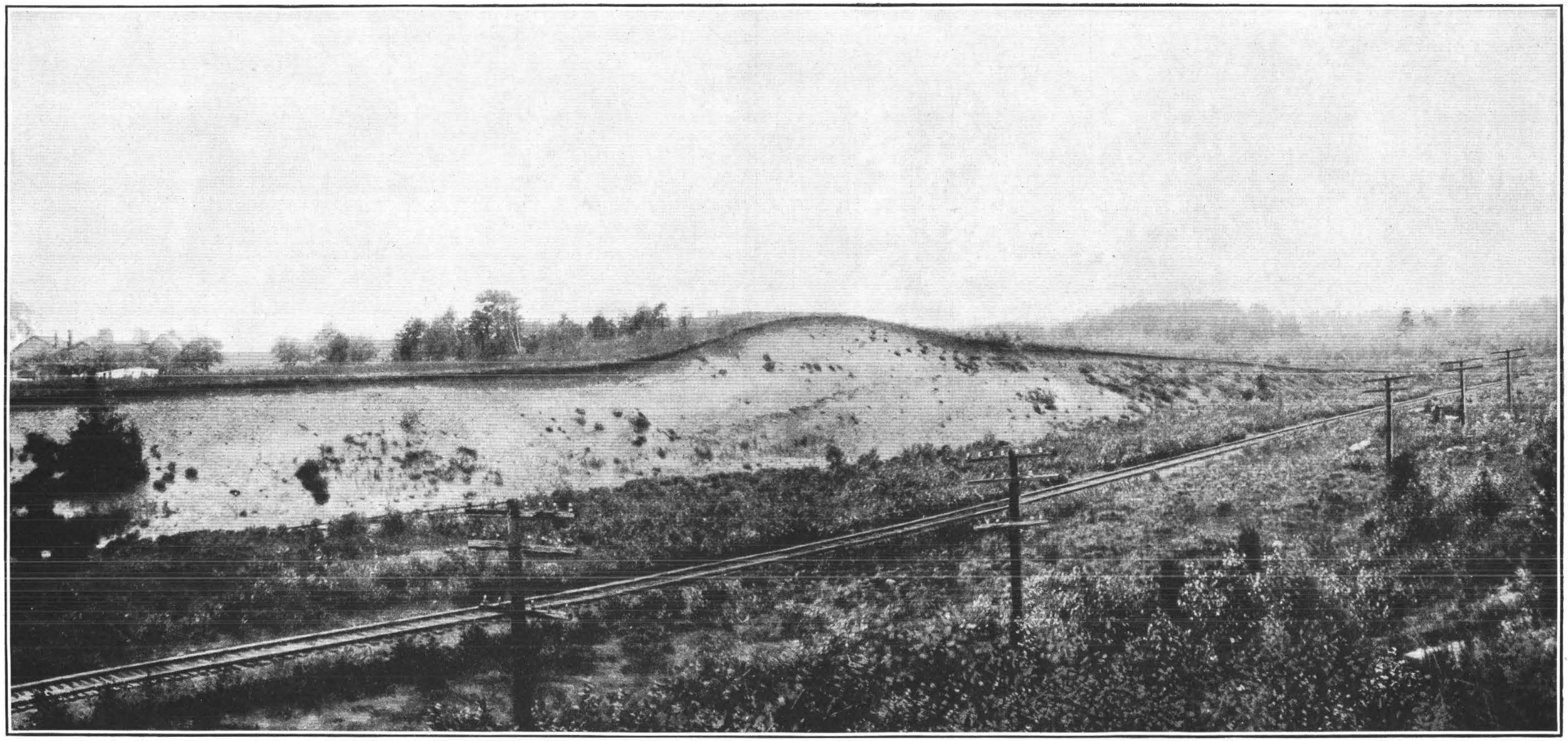
Three to four miles southwest of this area of sand and gravel is the ridge inclosing the south end of Knights Pond. This ridge is a crescentic belt, convex to the south, of small contiguous sand and gravel knolls which present a continuous smooth, even slope toward Knights Pond. There are no well-exposed sections in this ridge, and consequently its form and position with respect to the pond are the only evidence of its morainal character.

From Knights Pond to Dover, 8 miles southwest across the valley of Salmon Falls River, there are no known terminal moraine deposits.

MORAINAL DEPOSITS IN DOVER.

Pine Hill Cemetery, in Dover, N. H., is on a roundish kamelike hill 150 feet above sea level, or 60 to 70 feet above the adjoining plains of marine sediments. The hill extends east half a mile to a higher rock ridge and has a sloping southerly extension of 0.4 mile. A small rock ledge protrudes through gravels and sand 0.1 mile southeast of the summit of the hill. The higher central part of the hill is composed of unsorted gravels of moderate size in a sandy matrix. A gravel and sand pit in the cemetery, near the eastern limit of the kame area, ex-

[1] Unpublished notes filed in the U. S. Geological Survey.



SOUTH SIDE OF RAILROAD CUT ACROSS MERRILAND RIDGE, WELLS, MAINE.

Stratified gravels, sand, and clay constitute the moraine and outwash.

A. WEST SIDE OF INNER SLOPE OF NEWINGTON MORAINE ON BAY SIDE ROAD IN NEWINGTON, N. H.

The flat surface in the foreground is sandy marine clay.

B. SAND PIT IN PINE HILL CEMETERY, DOVER, N. H.

Shows irregularly bounded beds and pockets of sorted sands and fine gravel.

poses 15 feet of sandy material and has not cut through to the bottom. Plate VIII, *B*, shows a part of this section. Sand and fine gravel are very irregularly interspersed throughout the exposed section except at the top, which is clayey and more evenly layered; small gravel, in which the pebbles are less than half an inch in size, is more abundant toward the bottom. All the material is to some extent stratified, in general unevenly so, and as a rule the coarser material is the more uneven. The photograph brings out the irregular but sharp boundaries of the various kinds and grades of material. This is distinctly kame structure. Upham [1] refers to "the kamelike plain" of Pine Hill Cemetery and implies a connection between it and the sand and gravel plains north of Dover, which, however, are now believed to be outwash deposits of a later stage.

About 2 miles southeast of Pine Hill is the north end of the Dover Neck Ridge. This ridge is 2½ miles long, three-quarters of a mile wide, and 100 feet high near its north end, half a mile wide and 130 feet high 1 mile farther south, and about 100 yards wide and 40 feet high at its south end. The ridge is nearly symmetrical except in the broadest northern part, where the crest is nearer the west side and the eastward extension has the form of an outwash plain. The surface of the ridge is for the most part smooth, although in places it is very slightly hummocky. The material seen on the surface and also in small openings is gravel and sand. There are thin interstratified seams of sand and clay covered by small gravels in a cut near the summit, and near by is a small ledge of slate. On the sides are variously inclined sand beds which appear to grade toward and are not topographically distinct from the marine clay that fringes the ridge. The eastward expansion at the north end is a sandy plain that slopes toward and merges into a flat plain of marine clay.

NEWINGTON AND PORTSMOUTH SEGMENT.

The moraine has been more carefully studied in Newington and Portsmouth than elsewhere. Its form and constitution in those towns are described below.

Beginning on the shore of Little Bay east of Fox Point, the moraine extends 1.1 miles across Fox Point and south along the shore, rising abruptly to a height of 40 to 60 feet to a narrow ridge at about 500 feet from the bay. A recent sea cliff 25 feet in height has been cut along part of this slope. The eastward descent is gradual and smooth through one-eighth to one-fourth mile to the level of the bay, or to flat plains of marine clay approximately 20 feet above sea level. The materials making up this ridge, as shown in cliffs on the shores and gravel pits on the crest, are sand and abundant well-rounded gravel, generally of moderate size but grading from small pebbles to large cobbles and containing also a few boulders. However, in the north end, where the moraine directly overlies slaty rock, many angular fragments of that rock are mixed with the gravels. South of the above-described section the moraine is very much broadened, owing to the east-southeasterly trend of its outer (easterly) border, whereas the inner margin continues southward for 1½ miles. The principal axis or crest of the moraine in this part curves from a southward to a nearly eastward trend toward Newington Town Hall. In the part where the greatest width is nearly a mile the height of the moraine is 60 to 80 feet and the surface is hummocky, being composed of small kame knobs and kettles. The material here is gravel and sand, dominantly sandy on the surface, and unsorted gravels and sand were seen in one pit. From Newington Town Hall the moraine trends east of south 1⅛ miles along the Greenland road to Gosling Road. Its width is half to three-quarters of a mile, and its top is broad and flat and stands at an elevation of about 100 feet. The descent to the west is fairly steep and about 20 to 30 feet high (Pl. VIII, *A*), but the eastward descent is less in amount and gentle. Near the town hall a rock ledge included in the moraine makes two small outcrops. Elsewhere the surface is sandy and bears a few boulders. Unassorted sands, rounded gravels, and small boulders are exposed in a bank west of the town hall.

Plate IX shows the position and outline of the moraine from Gosling Road in Newington to Peverly Hill in Portsmouth. The westerly boundary of the moraine in this length is sharp and marked by an abrupt change in slope. In places, particularly near New Road and at Peverly Hill, the morainal gravels present to the west steep walls and buttress-like forms

[1] Upham, Warren, in Hitchcock, C. H., The geology of New Hampshire, vol. 3, pt. 3, p. 153, 1878.

that could have been made only by accumulation of the gravels against a retaining mold—the ice front. In two places, however, at the inner margin of the moraine there are flat or nearly flat-lying sands and gravels, which are not distinctly separated from morainal materials on the one side and from low clay plains on the other. Although the exact nature and origin of these sandy flats has not been determined, it seems probable that they are the result either of deposition in small bodies of water ponded between the moraine and the ice after the ice had locally melted away from the moraine, or else of reworking and redeposition of the morainic materials by marine waters that flooded the region after the withdrawal of the ice.

The summit of the moraine is about half a mile wide along Gosling Road, is smoothly level, sloping inappreciably east, and grades into a narrow eastward-sloping outwash apron. South of Gosling Road the moraine is both narrower and lower and is not distinct from outwash on the east and a flat sandy plain on the west. Farther south, however, it rises to a flat gravelly top 90 feet in elevation and 0.4 mile wide on New Road. Here it has a steep west side, rising 50 feet out of a clay meadow, and a sinuous east border marked by a low scarp between the moraine and its outwash, near which it is pitted by a few small kettle holes. The flat top is continuous from New Road southeast to Middle Road, a distance of $1\frac{1}{4}$ miles, in which it ranges from 1,000 to 3,000 feet in width and descends from about 90 feet above sea level to 75 feet. The western slope is steep but is in part mantled at its foot by a belt of sand on very gentle slopes. The frontal scarp is pronounced and 10 to 20 feet high in this reach but vanishes east of Sherburne Road. The outwash plain is continuous for 4 miles from a point north of Gosling Road to a point a quarter of a mile northeast of the corner of Sherburne and Middle roads. It is an almost perfectly smooth surface, having a very gentle eastward slope, through which there is a gradual transition from gravel and coarse sand to clay. There is no natural boundary between this clay and the outwash, and there is no other basis for the line on the map than the limit of the wet, dead-level area of the clay plain.

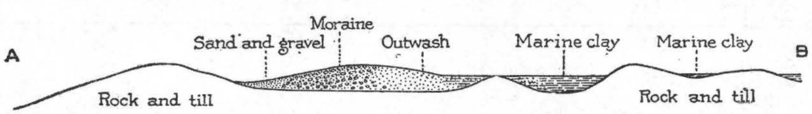
Along Middle Road the moraine trends eastward and is rather lower than the parts already described. Here its surface is composed of irregular knolls of small size. Its limits are sharply defined against rock, till, and clay surfaces on the south and a clay meadow on the north. Portsmouth Plains is a flat expanse of sands and gravels making the crest of the moraine, which north and east of Portsmouth Plains abuts against rock hills.

From Portsmouth Plains the moraine extends southward for about a mile to Peverly Hill. In that distance it is comparatively low and narrow, and north of Sagamore Creek is made up of small knobs of sandy gravel including a small, shallow, circular kettle. South of the creek the moraine is a flat-topped bench of gravel and sand about 40 feet in elevation, lying against the rock mass of Peverly Hill. In one place through a length of 100 feet or more the flat top of the plain does not quite reach the rock, there being a small and shallow depression or "foss" between them. The flat gravel bench extends along the northwest side of Peverly Hill and is continued eastward in a plain that surrounds the hill and descends by moderate slopes northward into the Sagamore Creek marshes and by gentle slopes eastward to rocky hills east of Lafayette Road. The moraine extends as a broad, smooth ridge of gravel southward from Peverly Hill across Lafayette Road to Bellyhack Swamp (Berrys Brook).

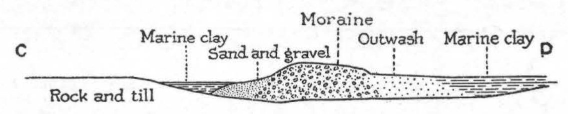
Gravel and sand pits and road cuts give the following data on the constitution of the moraine in Newington and Portsmouth:

At the junction of Sherburne and Greenland roads, in Newington, in that part of the moraine which has a high, broad, flat top, the 10 to 15 feet of material immediately next below the summit is gravel, for the most part well rounded but containing also many boulders that have planed surfaces. The pebbles are not assorted as to size, yet there is a distinguishable succession of layers dipping about 15° W., and of these the upper layers are more abundantly composed of finer gravel and sand and the lower of coarser stuff.

In the same part of the moraine, at the junction of Gosling Road and the Greenland road, in Newington, an excavation of 3 to 4 feet in a flat sandy plain (1, Pl. IX) contains fine yellowish sand with relatively few rounded peb-

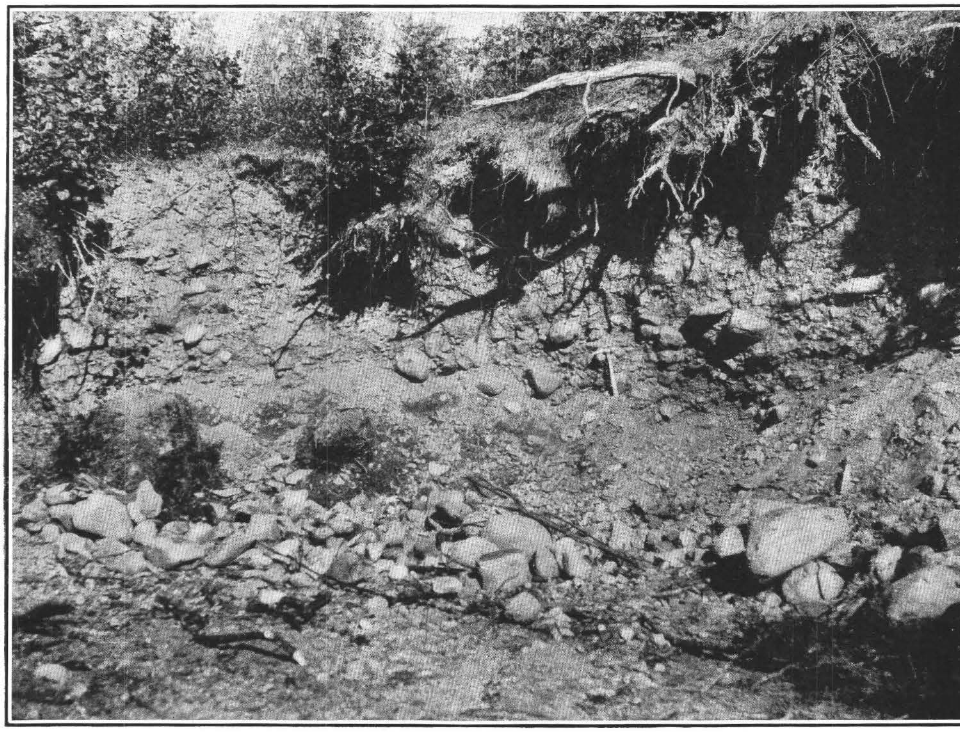


SECTION ALONG LINE A-B



SECTION ALONG LINE C-D

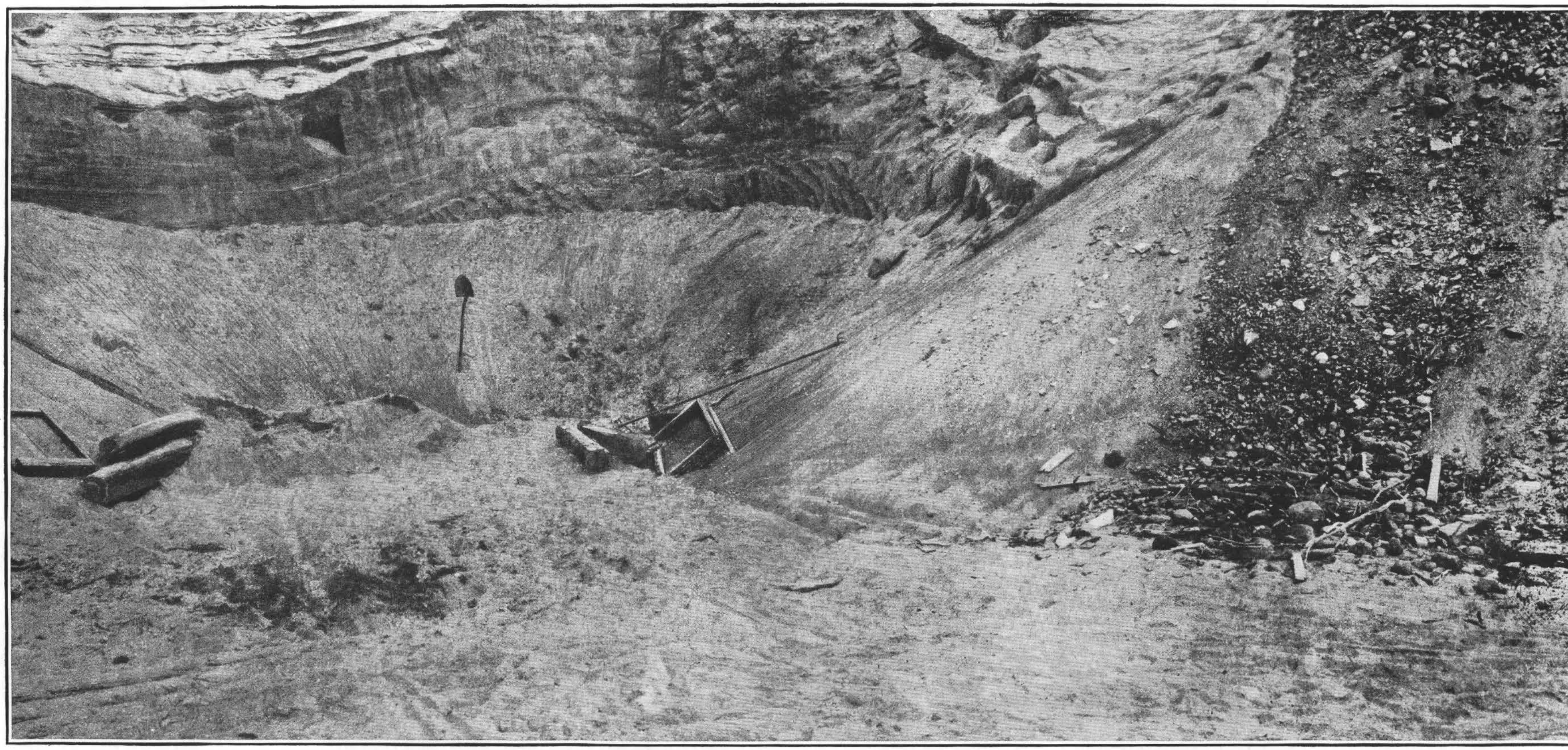
MAP OF PARTS OF NEWINGTON, GREENLAND, AND PORTSMOUTH, N. H., AND DIAGRAMMATIC SECTIONS SHOWING RELATION OF THE NEWINGTON MORAINE TO ROCK AND TILL AND PLEISTOCENE MARINE SEDIMENTS.



A. COARSE, PARTLY ROUNDED MATERIAL WITH RUDE STRATIFICATION.

B. COARSE MATERIAL, FAIRLY WELL ROUNDED, WITH NO SORTING OR STRATIFICATION.

MORAINE GRAVEL ON NEW ROAD, PORTSMOUTH, N. H.



WIGGINS GRAVEL PIT, PORTSMOUTH, N. H.

Shows undulating beds of clean, evenly stratified sand abutting against coarse, unsorted, and unstratified gravel.

bles or boulders and some rock fragments. No stratification is shown.

On the Sherburne road in Portsmouth, half a mile east of the excavation last noted, there are a pit (2, Pl. IX) and a road cut which show approximately 15 feet, measured down from the moraine surface, of large cobbles mixed with small pebbles and sand, which are like the material in excavation 1, but without apparent stratification. One-eighth mile to the south is a sand pit (3, Pl. IX), west of the Sherburne road, in the place where the moraine ridge is low and not distinct from the outwash plain. Here, the flat sandy top of the ridge shows 3 feet of yellow sand containing much dust and fine claylike rock flour, scattered pebbles 2 inches or less in diameter, and a few cobbles as large as 6 inches. This material is devoid of stratification and hence is not outwash but morainic dump.

In the cut on New Road (4, Pl. IX; see also Pl. X), at the west edge of the flat-topped moraine crest, there are exposed 10 to 12 feet of boulders and coarse gravel packed in fine gravel and sand, without clay or other cementing material. The material here, as in all but one other exposure, that near Little Bay, is dominantly of foreign origin, being composed chiefly of granite gneiss, pegmatites, basaltic porphyries, and much fine-grained micaceous graywacke gneiss, such as are not indigenous to the coastal towns of New Hampshire. Although there are many faceted boulders and pebbles, the dominant forms are round and subrounded, and none of them are striated. All the materials are surficially more or less iron-stained, giving to the bank as a whole a light rusty-brown color, and many of the pebbles and boulders are rotted. A small part of the west end of this exposure (Pl. X, *A*), through a thickness of 3 to 4 feet at the top, shows a faint trace of stratification parallel to the back slope of the moraine ("backset" beds).

In the Wiggins gravel pit, near Middle and Sherburne roads, in Portsmouth (5, Pl. IX; see also Pl. XI), there are undulating beds of interstratified clean sands and fine gravels which abut directly against unsorted coarse rusty gravels lightly packed with sandy material but not cemented. Weathering has produced a black rust varnish on pebbles and boulders and has rotted the gabbroid rocks.

The city gravel pit on Middle Road, Portsmouth (6, Pl. IX; see also Pl. XII, *A*, p. 24) shows stratified material consisting of gravel and sand beds and intercalated clay seams that have a southerly dip and are therefore "backset" beds. The gravel consists of pebbles, for the most part well rounded and under 6 inches in size, but the number of larger and only partly rounded and faceted cobbles is considerable, and they show prominently because of a lack of pebbles of intermediate sizes. The sand and gravel are loose and friable, but the clayey seams are stiff and project from the face of the bank.

On Peverly Hill Road low gravel banks (7 and 8, Pl. IX) show loose gravels and sands mostly unsorted and unstratified. A small cut on the north side of the road exposed in 1914 a vertical section of 8 to 10 feet of well-stratified small gravel, sand, and sandy clay, dipping 30° W. and about parallel to the surface of the moraine; the upper 3 to 4 feet was gravel and the lower part sand. A lens of finely laminated clayey sand lay between gravel beds near the top of the section, and these beds were in abrupt discordant contact with unsorted gravels that were all strongly iron-stained to the full depth of the exposure. Many of the pebbles had the form of faceted blocks whose edges and planes had been somewhat rounded. Immediately above this pit, in the flat summit of the moraine, where it lies against Peverly Hill, is another pit (10, Pl. IX) 8 to 10 feet deep, which shows evenly stratified, approximately horizontal sand and fine gravel lying on rounded glaciated ledges.

A short distance southwest of Peverly Hill, near the inner edge of the moraine, there is a shallow cut (12, Pl. IX), showing small rounded gravel and sand, stratified and dipping southwest, resting against glaciated ledges. The city gravel pit on Lafayette Road (the Boston post road) near Sagamore Creek (11, Pl. IX) contains about 20 feet of stratified gravels and sand.

The continuation of the moraine southward from the part shown in Plate IX has not been closely studied. It is, however, known south of Berrys Brook in Portsmouth and Rye. In Rye Center the moraine is a prominent boulder and gravel ridge, which is narrow and has steep sides, but it broadens and rises to the southwest, where it abuts against a rock butte east of West Rye. Thence the gravel ridge runs westward to Breakfast Hill, which is essentially a rock ledge but is partly mantled by the morainic materials. These materials are exposed in cuts along Lafayette Road, where they consist of stratified waterworn gravel and sand having a southerly dip. The moraine continues in a southerly direction from Breakfast Hill as a sandy gravel ridge with broad plainlike top extending to Hampton village.

RYE, NORTH HAMPTON, AND HAMPTON SEGMENT.

The portion of the moraine lying in Rye, North Hampton, and Hampton forms a flat-topped ridge running westward from Rye almost to Greenland depot and thence southward through North Hampton and Hampton, where it slopes southward and passes under Hampton Marsh. The morainal deposits of Greenland, described below, may be an outlying part of this segment. North and west of this segment lie low valleys along the heads of Berrys Brook and Taylor River, and the moraine stands above them with a well-defined scarp. These bounding valleys are floored in the main with rock covered with a thin coating of till and marine clay. Surfaces of this character practically surround the outlier near by in Greenland. The morainal ridge slopes gently eastward and merges very irregularly into the low till slopes with numerous rock ledges that extend to the sea.

Most of the ridge is more than 100 feet above the sea, as is also the Greenland section. The two highest points are a mile north of North Hampton village and in Hampton village. In outward form the morainal deposits of these towns are nearly everywhere outwash plains, made up of two distinct benches or terraces, from 15 to 20 feet apart, both of which are well seen in North Hampton and Hampton. In most places these terraces or plains have little visible slope, but locally they have a decided dip. This dip is best seen about a mile south of North Hampton village and also in the southerly part of Hampton village, where the plain slopes southward under the marsh. The westward scarp is usually to be seen and marks well the old position of the ice front. Along or near this are numerous kettle holes, a fine group of them appearing half a mile north of North Hampton village. The contrast between the flat-topped moraine and the valleys at the west is best seen in the village of North Hampton, where the moraine forms a westward-facing scarp of nearly 40 feet. Hummocky moraines, till ridges, or kames have not been found in this segment of the moraine. In the western corner of Rye, where the moraine turns southward, a rock hill projects 20 or 30 feet above the plain level and appears to have formed an anchor for the ice. Numerous other ledges project through the moraine, rising as high as any of its parts, as for instance in Hampton village.

The two terraces or benches mentioned above are formed by layers of hard gravel between the sandy portions of the morainal deposit. Although there are numerous minor exposures of these beds, there are no complete sections. A small pit at the west end of North Hampton shows about 20 feet of gravelly sand with waterworn pebbles. Usually the surfaces of the plains or terraces are sandy with scattered small pebbles, and as a rule even a small cutting below these surfaces exposes gravel. In general the amount of gravel appears to be somewhat greater in Hampton than it is farther south or east. The sections observed showed sorting and rough bedding of the materials.

MORAINAL DEPOSITS IN GREENLAND.

In Greenland, N. H., there are two areas of morainal deposits that extend south from the center of Greenland village along a course marked by the highway to North Hampton village. They are about 2 miles west of the Newington moraine in Portsmouth and, taken together, are in a general way parallel to it, but they also trend toward the broad area of morainal deposits in North Hampton, as if they formed a protrusion from that area. The deposit in Greenland village forms a broad, flat-topped ridge that descends to a narrow sag about half a mile south of the village which separates the northern from the southern part. The moraine rises southward rather steeply from this sag to a narrow, flat-topped ridge about 125 feet above sea level and 1½ miles long in a south-southwest direction. The west side of the moraine is a short and steep slope toward the low clay plain of Winnicut River, but the opposite side is a broad and gentle sandy wash slope which merges into the clay plains on the east.

Upham[1] describes the morainal deposits in Greenland as a "kame." He says:

> The academy in Greenland is built on a broadly rounded, kamelike ridge of gravel, which at a short distance to the southwest becomes a nearly level plain 40 or 50 rods wide [Greenland Parade] but still farther to the southwest is narrowed to a typical kame. The length of this deposit is a half mile. Its height is nearly 100 feet above the sea.
>
> At a schoolhouse half a mile south from the academy we rise to a plain about 125 feet above the sea, which extends a mile to the south and southeast, descending with a gentle slope 25 to 40 feet in that distance. This plain forms the highest land between Winnicut River and Berrys Brook. Its northwest portion is quite thickly strewn with boulders, the largest of which are 5 or 6 feet in diameter, and over nearly its whole extent these have been sufficiently abundant for walling the fields. Four wells, however, between the schoolhouse and the Eastern depot [Greenland depot, on the Eastern division of the Boston & Maine Railroad], varying from 20 to 30 feet in depth, passed all the way through stratified gravel, sand, and blue clay. In three of these wells the upper portion was fine gravel or sand. One of them, a half mile southeast, and a cistern a quarter of a mile south from the schoolhouse, showed at the top 10 feet of very coarse but waterworn gravel, which was underlain by clear sand.

The moraine in Greenland marks a halt of the ice at a short distance back from the small lobe of the Newington moraine in Rye and is seemingly very little younger.

HAMPTON FALLS, SEABROOK, AND SALISBURY SEGMENT.

Morainal deposits of the next segment consist almost wholly of outwash sand and gravel plains except in Hampton Falls, where a small ridge of till is exposed. This ridge starts in the center of the village and runs southwest for nearly a mile. Along its western border the sand plains of this segment pass very irregularly between a group of till-covered rock hills and drumlins in the town of Salisbury, Mass. In Seabrook, N. H., the moraine is bordered on the west by the low valley of Hampton Falls River, which is underlain mainly by till with scattered rock ledges. Eastward the sand-plain surfaces pass beneath the marshes of Salisbury and Hampton, except for a small area in South Seabrook, where till with scattered rock ledges rises a little above the general surface of the sand plain.

The sand-plain characteristics are very well marked, especially between Salisbury and East Salisbury, and there are also wide stretches of well-developed plain in Seabrook. Although these plains are in general nearly horizontal, there are locally strong dips—for instance, 1 mile southwest of South Seabrook, where there is a marked dip to the southeast. In Salisbury and East Salisbury there is a gentle though not obvious dip which results in the disappearance of the plain below the level of the salt marshes. Rock outcrops are comparatively common in these lower portions of the sand plains, but there seems to be no causal relation between the position of the rock surface and the plain.

The deposits of the sand and gravel plains of this segment lie in three benches or terraces, at the edges of which hard beds of gravel appear. Two of these benches are seen in most of Seabrook and in the northern part of Salisbury. The third bench is seen only in northern Salisbury about a mile west and southwest of South Seabrook. The lower two benches are about 20 feet apart; the upper two are about 15 feet apart and are separated by a heavy bed of fine white sand that is well exposed near the water tower a mile southwest of South Seabrook. The gravel is usually fine and makes a smaller proportion of the morainal deposits than the gravels of the Rye and Hampton segment. The gravels appear to rest upon marine clay along the edge of the marsh at East Salisbury and also along the small brook about a mile northwest of East Salisbury.

NEWBURYPORT SEGMENT.

The next segment of the moraine runs southeastward from Amesbury through Newburyport to Parker River in Newbury. Most of this segment is separated from the Salisbury segment by Merrimack River and the adjacent marshes. During the formation of this part of the moraine, however, the sand outwash plains probably extended northeastward into those of the south end of the Salisbury segment. The moraine in this segment in general takes the form of a distinct ridge bordered by gently sloping sand plains on the northeast. The Newburyport ridge is for most of its length flanked on the southwest by a low valley containing numerous rock outcrops or rocky hummocks

[1] Upham, Warren, op. cit., pp. 162-163.

thinly covered with till. In its northwestern part, however, the moraine abuts against a high rocky ridge through which the Merrimack has cut its course, thus separating about a mile of the moraine from the main part in Newburyport.

This segment of the moraine varies much in height. At its northwest end it forms a group of kames about 150 feet above the sea. These diminish in height within a short distance and pass southward and southeastward into a well-developed sand plain ("Grasshopper Plains") about 100 feet above sea level, which fills in the area between the rock ridge above mentioned and the morainic ridge.

"Grasshopper Plains" has a broad, nearly level surface of more than 1 square mile, which is markedly pitted near High Street in Newburyport by kettle holes ranging from a few yards to 200 and 300 yards across and reaching 40 or 50 feet in depth. The smaller kettle holes are round and regular in shape but some of the largest are less regular and have hummocky and ridged bottoms. From "Grasshopper Plains" southwestward through Newburyport the moraine is a narrow ridge with a definite southwestward-facing ice-contact scarp 30 to 50 feet in height. Part of this scarp, between 1 mile and 1¾ miles west of the railroad, is comparatively steep and is notably ribbed, with deep and sharp reentrants toward the north and northeast between the ribs, resembling the buttressed forms on the ice-contact side of parts of the moraine in Newington. Elsewhere this slope, although smoother and less steep, is well marked for a distance of over 4 miles, to the point where the ice front turned southwestward around the drumlins in the village of Newbury. In that distance its summit diminishes gradually in altitude from 80 feet above sea level at the northwest to 20 feet at the southeast. The crest of the moraine lies along and for the most part south of High Street in Newburyport. It is in general a smoothly shaped ridge decreasing gradually in height toward the southeast, but in it there are several large kettle holes. On the northeast side the morainic ridge is bordered by an outwash plain of sand which slopes eastward (in part northeastward to the tidal basin of Merrimack River). Through a distance of 2 miles between "Grasshopper Plains" and the freight railroad the moraine stands above the outwash plain and is set off from it by an abrupt frontal scarp, which in places is 15 to 20 feet in height and is slightly sinuous or scalloped in trend where best developed. To the northwest and the southeast there is less and in many places no topographic distinction between the moraine crest and the outwash. In the form of its slopes and in its relation to low meadows on the one side and higher, gently sloping sand plains on the other side, the Newburyport ridge presents features almost identical with those of Merriland Ridge and the moraine in Biddeford. The moraine in Newburyport extends, diminishing in width and height, to the drumlins in Newbury and appears also on the southeast side of these drumlins as a narrow gravel terrace from 10 to 20 feet above sea level.

The moraine is composed entirely of sand and gravel in this segment. The materials are not now well exposed at any point, but a thickness of about 40 feet is shown in the railroad cuts in the city of Newburyport. Upham reports that wells in Newburyport show a maximum depth of 90 feet of sand and gravel. The materials are waterworn and appear from the poor exposures to be stratified, with gentle northeasterly dips. A gravel pit just northeast of the drumlins of Newbury shows about 20 feet of sand and gravel in which the pebbles are as much as 6 inches in diameter. The beds are roughly stratified and approximately horizontal, and they rest directly on large ledges of bedrock. No bedrock projects through the moraine except at the border of the high sand plain in the western part of Newburyport and also at the turn of the moraine next to the drumlins in Newbury. At these two localities the bedrock hills seem to have checked the advance of the ice.

OBSERVATIONS BY UPHAM.

Upham[1] made the following observations on the features herein described as the Newington moraine and on associated deposits in New Hampshire. It must be remembered in reading these extracts that the term "kame" as used by Upham in 1878 connoted deposits that were supposed to have been laid down by streams flowing between retaining walls of glacial ice—that is, in crevasses or between ice

[1] Op. cit., pp. 150, 155-156, 164, and 170-172.

lobes—or between an ice wall and a valley wall from which the ice had withdrawn.

In Newington and Portsmouth a kamelike plain of gravel and sand is the highest land between Great Bay and the Piscataqua River, but their shores, with the islands of this river below Portsmouth, are almost everywhere gently sloping hills of till or ledge.

Marine shells and other organic remains have been found in the lower portions of this valley [Piscataqua basin], showing that the ocean stood at a higher level when the modified drift in which they occur was deposited. * * *

Kames and kamelike plains about Dover and southward.—Near the coast from Dover to Newburyport are frequently found massive kamelike deposits, consisting of high plains or broadly rounded ridges of gravel and sand, which often form watersheds between wide valleys 100 to 200 feet below. The absence in these valleys of the terraces which mark erosion through modified drift shows that they were never filled with the same materials and that these remarkable plains and ridges were deposited in their present isolated position, with wide areas of lower land at each side. How this took place we can only explain by referring the formation of these deposits to the same causes which produced the kames. The ice sheet still remained unmelted upon each side at the time of their deposition, filling the valleys and wide areas of lowland, over which this gravel and sand must otherwise have been spread by the current of the floods on which they were brought.

The most extensive of these plains occur * * * in Newington and the northwest part of Portsmouth. Broadly rounded deposits of the same class occur frequently in this district, and southward, along the seacoast, they form the elevations on which the villages of Rye, North Hampton, and Hampton are built. A very interesting ridge of this kind extends from northwest to southeast through Newburyport. * * *

The last of these kamelike deposits which remains to be described within the limits of Piscataqua basin is the extensive plain of Newington and the northwest part of Portsmouth. This is 3 miles long from north to south, and for most of this distance averages a mile in width, forming a plateau 60 to 100 feet above Great Bay and Piscataqua River on each side. Outcropping ledges and scattered boulders are seen in many places upon its surface, but numerous wells show only modified drift to depths of 30 or 40 feet, being first coarse gravel, 3 to 10 feet in thickness, succeeded below by interstratified fine gravel and sand. The entire western edge of this deposit is a gently sloping escarpment, which descends 10 to 30 feet. On the north and east it rests mainly on ledges but at one place falls in an abrupt slope more than 50 feet. A section at its base in the north part of Newington showed sand overlain by gray clay, as at Dover. Southward, near the Concord & Portsmouth Railroad, its surface is sand, obliquely stratified. Between this and the Eastern Railroad it is changed to a broad ridge, 25 to 30 feet high, composed mostly of pebbles 6 inches to a foot in diameter, packed as compactly as possible, with no layers of sand. This gravel is finely exposed in an excavation, from which it is teamed 2 miles for repairing streets in Portsmouth. The deposit terminates southeast from the Eastern Railroad in a small plain of horizontally stratified sand. * * *

Modified drift along the seacoast.—The oldest and most prominent deposits of modified drift near our coast are kamelike hills, elevated plains, and broad ridges, composed of gravel, sand, and clay. * * * The gently sloping hill on which Rye village is situated, nearly 100 feet above the sea, is mainly stratified gravel from 25 to 40 feet in depth. It is coarse for the first 10 feet, with the largest pebbles a foot in diameter; below, it is fine but has little clear sand. The character of these deposits will be seen from the following sections of wells, 1 to 1½ miles southwest from Rye village, on the watershed south of Berrys Brook, and about 100 feet above the sea:

1. At J. Philbrick's (county map) [on the northwest side of Washington Road, 1.05 mile west of Rye Center], said to be the deepest well in Rye, coarse gravel, 25 feet; sandy, gray clay, very compact, free from pebbles, 28 feet; total depth, 53 feet. The only rock found in the clay was an angular block weighing about 200 pounds, 40 feet below the surface.

2. Near L. Brown's [on the northwest side of Washington Road, 1.15 miles west of Rye Center], coarse gravel, 8 feet; sand, 8 inches; coarse gravel, 6 feet; very coarse gravel, 10 feet, much of it composed of rounded rocks of nearly uniform size, about a foot in diameter, with scarcely any earth, so that "one could look down among the pebbles;" ordinary gravel, with layers of sand, 20 feet, resting on ledge; total depth, 45 feet.

3. At R. Shapley's [about 1.4 miles S. 65° W. of Rye Center], coarse gravel, 10 feet; fine white sand, 15 feet, resting on till or ledge.

Several other wells in this neighborhood, 30 to 40 feet in depth, encountered nothing but stratified gravel, sand, or clay.

Breakfast Hill, about 150 feet above the sea, and the plain about 50 feet lower, which extends southward to the first railroad crossing in North Hampton, are composed of coarse gravel and sand. Thence similar deposits, 100 to 125 feet above the sea, extend in nearly level plains southwest to North Hampton village, forming the watershed between Winnicut River and the ocean. They are bounded in many places by escarpments which descend steeply 25 to 50 feet, and a hollow, about an acre in extent and 50 feet deep, is half filled by Knowles Pond. This formation continues southward with nearly the same height to Hampton village, where it terminates, falling in gentle slopes toward the sea.

Nine miles farther south part of the city of Newburyport is built on a broadly rounded ridge of gravel and sand, which, like the foregoing deposits, probably had a similar origin with the narrow and steep ridges of the kames, having been bounded by portions of the melting ice sheet. The series of kames noticed by Rev. Mr. Wright in Newton and Amesbury may be continuous southeast to the Newburyport ridge. So far as traced, this deposit appears first in the south part of Amesbury. It has been cut through by Merrimack River and on its opposite side rises to a height of about 150 feet in Moultons Hill. A quarter of a mile farther to the southeast it is depressed to 75 feet and shows the sharp ridges and knolls of typical kames. From this point it extends, with a nearly uniform height of about 100 feet, along High Street to the middle of the city and thence continues on the southwest side of this street to the Upper Green. Here it is interrupted for a little distance, beyond which it lies on the northeast side of this street, extending to within a half mile of Old Town Hill. It is thus at least 6 miles long. No other high deposits of modified drift are found in this vicinity, and wide areas of lowland lie on both sides. Excavations in the northwest part of the city show the ridge there to be composed mainly of waterworn gravel, with the largest pebbles about a foot in diameter. A railroad cut, known as Marchs Hill, 2 miles farther southeast, has only occasional layers of gravel, with the largest pebbles 6 inches in diameter, very irregularly stratified with sand, which is here four-fifths of the whole deposit. The depth of modified drift forming the ridge is shown by wells to be from 50 to 90 feet.

OBSERVATIONS BY SEARS.

Sears noted the ridge in Newbury and Newburyport and some sections in it that are not now exposed. He regarded it as partly moraine and partly barrier beach. The following quotation[1] shows that his interpretation of the position of the ice front with respect to the moraine differs from that of the present authors:

The Merrimack River was probably a halting place of the glacial ice in its retreat northward, for its southern shore, from the mouth of the Parker River to Pipestave Hill, marks typical ice contacts of morainal till and overwash gravels capped by sand and silt. High Street, in Newbury and Newburyport, is laid out upon the top of the terrace formed by this ice contact, a section of which shows it to be composed of boulder till and clay beds resting upon the glacial bedrock * * * in varying depths. At Grasshopper Plain it is at least 50 feet in thickness and is covered by 20 feet of coarse gravel with 25 feet of fine sand at the surface. * * * A section of this terrace across High Street extending from the river through Green Street to the frog pond by "the Mall" gives boulder till on High Street at an elevation of 80 feet above tidewater. The frog pond is the site of a small detached iceberg that was buried in the morainal till. South of "the Mall" the overwash and outwash gravels have formed a series of cones and short ridges or kames of sand and gravel extending southeasterly into Newbury. The tracks of the Boston & Maine Railroad cut through these gravels on the west, and the track of the City Freight Railroad cuts through them on the east. In 1898 this cut exhibited a good section of the deposits some 300 yards in length. The gravels and sands dipped to the south at an angle of 35° and were capped by a deposit of clay having sand partings every few inches. The greatest depth of the gravel and sand was 40 feet. North of the center of the hill there was a dip 20 feet deep filled with clay having fine sand partings, and under the clay, at the bottom of the dip, there was a mass of peat, probably the site of an iceberg in the gravel before the clay was deposited.

[1] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., pp. 296, 301, and fig. 169, p. 352, Salem, Essex Institute, 1905.

South of Oak Hill Cemetery there is a "kettle hole." * * * It is a typical small ice-block hole with southeastern outwash sand and gravel kames, probably deposited in cracks or gorges in the glacial ice which filled the whole valley of Little River.

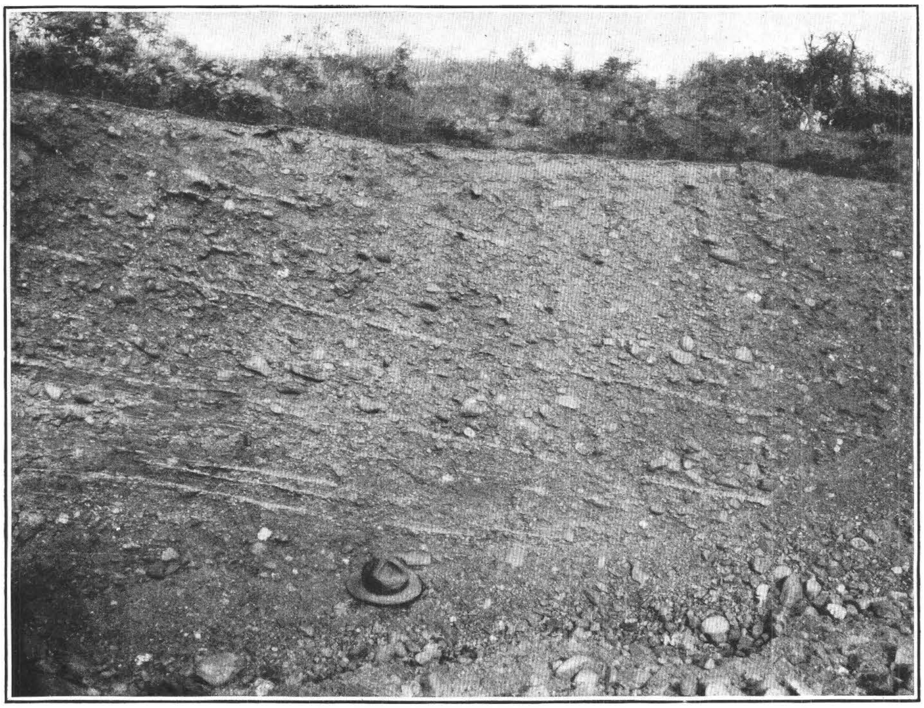
High Street, in Newbury, is built on sand and gravel that cap clay and till, a typical beach barrier sloping back to the lagoon at Four Rock Creek. The débris is washed away from the outcropping ledges that rise above the boulder till covering the surface. This beach barrier with the lagoon on the shore side occupied the whole of the Little River valley and was continuous on the southwest around Old Town and Little Old Town hills. A gorge between these hills, now filled with coarse waterworn gravels on top of boulder till, was the drainage outlet to the southeast. In front of the gravels the outwash sands spread out over Newbury Old Town, to the mouth of Parker River, where steep banks and fringing lobes extend into the salt marsh overlapping the boulder till.

OTHER ICE-FRONT DEPOSITS OF THE REGION.

In this region there are a few other ice-front or morainic deposits which do not seem to be related to the Newington moraine and yet are of interest in connection with the subject of this paper by reason of their bearing on the interpretation of the glacial history of the region. The most distant of these is the moraine which lies across the south end of Lower Bay, Sebago Lake, Maine, 18 miles north of the Saco segment. This is a gravel ridge trending southwest to west-southwest, rising steeply 50 to 60 feet from the lake level, and presenting a very gentle southward slope of gravel and sand in which there are several deep pits occupied by ponds. At the lake the outwash slope has an altitude of 300 feet above the sea and is composed of coarse sand and gravel. About 1½ miles southwest, at an altitude of 200 feet, the outwash is very fine sand which grades imperceptibly into marine clay.

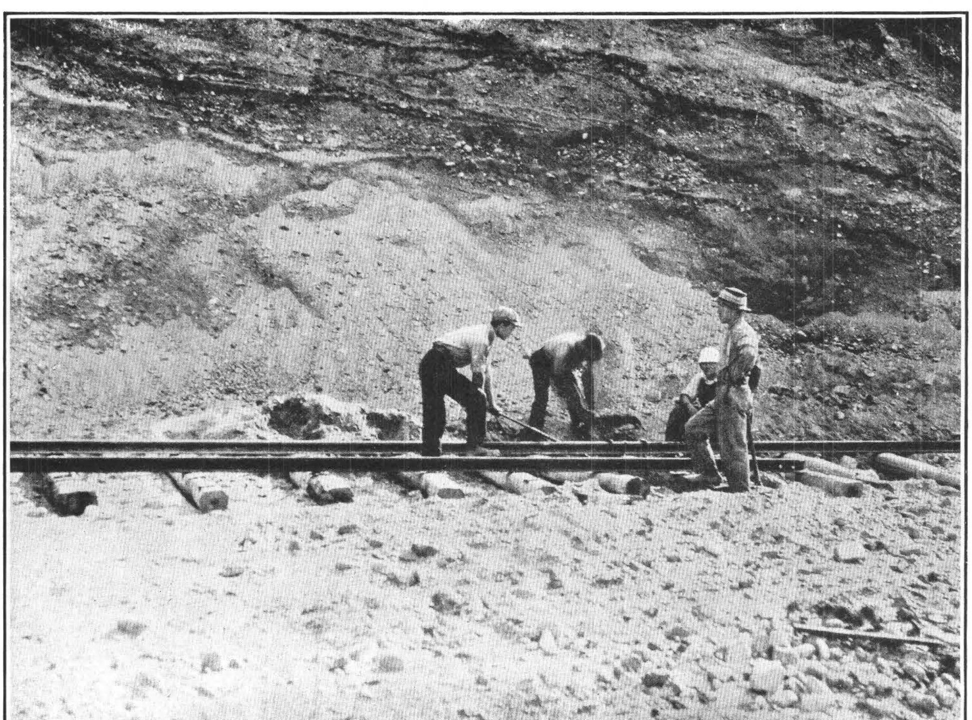
The moraine at Bauneg Beg Pond, 3½ miles north of North Berwick village (Pl. IV, p. 12), in the towns of North Berwick and Sanford, Maine, is several miles west of Merriland Ridge. It surrounds the south end of Bauneg Beg Pond as a hummocky, "knob and kettle" surface which grades eastward and southward into the broad sand plain that overlies marine clay in Wells and North Berwick.

The moraines at Bauneg Beg Pond and Sebago Lake lie several miles back from the Newington moraine, at the western edge of the coastal lowland. Besides these moraines and their outwash deposits, there are extensive sand



A. GRAVEL PIT ON MIDDLE ROAD, PORTSMOUTH, N. H.

Shows stratified gravel, sands, and clay in the inner side of the moraine, containing here and there larger but little-rounded cobbles.



B. GRAVELS AND SAND, PERHAPS OF KAME ORIGIN, IN SUNSET HILL, ELIOT, MAINE.

Poorly sorted, unevenly stratified gravel.

plains that front the highlands and valley trains in the valleys that debouch from the highlands upon the coastal lowlands, as, for example, in the valleys of Salmon Falls, Mousam, Little Ossipee, and Saco rivers, which seem to indicate other moraines or at least ice-front positions correlative with the moraine at Sebago Lake. The outwash from these later ice halts is larger in amount and more broadly and deeply spread over the region. In places the later outwash covers the Newington deposits and extends beyond them to the present shore line.

In Eliot and Kittery, Maine, there are a number of hills (indicated by moraine symbol on Pl. IV), wholly or in part composed of stratified drift, which lie a short distance east (outside) of the Newington moraine. The stratified gravels and sands of these hills are seemingly kame or other ice-front deposits which show no relation to one another nor to the Newington moraine. They do not appear to mark any definite or continued stand of the ice front. The following have been noted, and there are doubtless others in the region. In Kittery there is a broad, flat-topped ridge of gravels and sand in which the Boston & Maine Railroad Co.'s gravel pit exposes a thickness of about 40 feet of well-sorted and stratified materials. An area of stratified sands and gravels lies immediately east of Bolt Hill, a drumlin, in Eliot. At Greenacre, in Eliot, and including Frankfort Island, in Piscataqua River, is a narrow patch three-quarters of a mile long of low, hummocky knolls which are distinctly kamelike and are composed of waterworn gravel and sand. Sunset Hill, in Eliot, is probably composed largely of till but contains in its northern part thick deposits of stratified sands and gravel, perhaps of kame origin (Pl. XII, *B*).

These scattered kamelike or moraine-like deposits east of the moraine indicate no prolonged halt in the retreat of the ice before the front reached the Newington position.

NORTHWARD EXTENSION OF THE NEWINGTON MORAINE.

In the town of Saco (see Pl. IV and the map of the Portland quadrangle), from Goosefare Brook to Stuart Brook, for $1\frac{3}{4}$ miles along the Boston-Portland post road, is a line of smooth, flat-topped ridges about 100 feet in elevation, composed of sand and small gravel which is in part water-rounded, sorted, and stratified. These ridges rise only a few feet above the surrounding plains of marine clay and sand except where rock ledges having the same northeast trend protrude through the gravels. These ridges are 4 miles northeast of the Newington moraine at Saco River and are separated from it by a lowland consisting chiefly of clay. They may be an extension or an equivalent of the Newington moraine, but the observed facts indicate rather that these ridges are to be classed with other northeastward-elongated hills in the Portland quadrangle, such as part of Oak Hill, Pleasant Hill, and Sandy Hill, which are drift-covered ledges having superposed mantles of stratified gravels formed by the reworking of their till and other drift by the sea, which at the same time deposited clay in the low places around them. There are no other drift deposits farther northeast in the Portland quadrangle that can be regarded as morainal. If there were such a northeastward extension of the moraine it may have been destroyed after the Newington substage by strong streams that discharged from the Sebago Lake or younger ice fronts through the territory now largely covered by marine clays in Saco, Scarboro, South Portland, and Portland. It is more likely that any moraine deposited in this region, where the pre-Newington bedrock and till surface is generally low (being now in large part below or only slightly above sea level), would have been buried by the later marine deposits. Morainal material has not been observed where it might be expected on rock surfaces that protrude above the level of the marine clay and are in the line of general trend of the Newington moraine. It may be inferred, therefore, that the Newington ice front departed from this trend either seaward by the advance of a lobe through the Saco and Scarboro lowland or else northward. Southeastward lobation is not attested by any known deposits of morainic materials. To the north, on the other hand, in the northwest corner of the Portland and the northeast corner of the Buxton quadrangles, in Gorham and Buxton, there are gravel ridges and a kamelike gravel hill (Pl. IV) which may well be parts of the moraine. They are about 2 to 8 miles south of the moraine at Sebago Lake and approximately on the line between that moraine and the Saco segment of the Newington moraine, which is 12 miles farther south. On this line also is the rock ridge north of the Saco segment, which may be a link between moraine segments like the rock hills between the Biddeford and Kennebunkport segments. The conditions thus afford a weak suggestion of connection between the Newington moraine and the moraine at Sebago Lake. The latter, however, may belong wholly or in part to a later substage, for its gravel and sand outwash in the main is continuous with and in part overlies the clay and sand plains, which can be traced without interruption or break in their nearly plane surface to and over the moraine in Saco.

SOUTHWARD EXTENSION OF THE NEWINGTON MORAINE.

The Newington moraine was not traced southward and southwestward beyond Newbury. Very probably correlative deposits will be found when that region is studied.

RELATION OF THE MORAINE TO OTHER PLEISTOCENE FORMATIONS.

ROCHES MOUTONNÉES AND TILL.

All the moraine segments noted lie in part on roche moutonnée surfaces and by inference also on ground moraine, or till. They have not been found to overlie stratified drift or such marine sediments as abound in the region. Glacially sculptured ledges lie both inside and outside of the moraine—in fact, all the ledges in the region have been glaciated. Till also is found on both sides of the moraine, and there are no perceptible differences between any of the exposures of till seen in the region. No till has been found in or on the typically developed moraines.

MARINE SEDIMENTS.[1]

Marine clay and associated sand beds, in the main horizontally stratified and in a few places fossiliferous, form extensive plains of sedimentation throughout the region, both east (outside), and also north and west (inside) of the moraine. In a few places the clay is sandy or contains sandy lenses and beds, and over a large part of this region, particularly at the north and west, the top beds are clean sand.

Some of the clay lying outside of the moraine is contemporaneous with and stratigraphically equivalent to the moraine. This relation is best shown at Merriland Ridge, where, in the railroad cut (Pl. VII and fig. 1), a bed of clay identical with that in the broad plains of marine deposits is intercalated in the sand and gravel beds of the moraine and outwash. At that locality also the entire outwash plain slopes down to and grades into a low, swampy sand and clay plain about the headwaters of Webhannet River. It is clear that this clay bed records a period of quiet discharge of glacial waters during which they carried to and deposited on the moraine only the finest of glacial detritus—rock flour and mud. At other periods such materials were borne or drifted seaward and deposited in deeper or less disturbed waters than those at the ice front, and there formed the plains of which the flat in the valley of Webhannet River is one. This particular plain probably received no appreciable contributions of outwash during stages later than the Newington substage, because it is some distance away and cut off by rocky uplands from the Kennebunk and Mousam valleys on the north and the Great Works and Salmon Falls valleys on the southwest. It was from points farther up these valleys that the outwash of later stages came. On that account the marine clay deposits in the lower parts of these valleys are more extensive and at higher altitudes than in the coastal territory between the drainage basins of these streams. In other places the earlier clay deposits and some of the sandy outwash of the Newington substage are covered by more or less clay discharged into the sea from more northerly and later stands of the ice, during the time when clay was accumulating behind and upon the inner slope of the moraine. In Saco and Biddeford, along Saco River, excavations for gravel and sand show that the clay overlies the northwest side of the moraine and in places covers the crest. In most places where the marine clay borders the inner side of the moraine the surfaces of the two formations meet at an angle, and there is no significant mingling of their materials, as there is on the opposite side. Wells along the western base of the moraine in Portsmouth show that the clay does not pass under the moraine but lies against it. The inference to be drawn from this fact is that all the deposits of marine clay and sand lying inside the New-

[1] These formations, the so-called "Leda clay" and overlying sands, as developed in southwestern Maine and southeastern New Hampshire, are the subject of another paper, to be published later.

ington moraine are younger than that moraine. Furthermore, these deposits are traceable inland into the broad sand plains and valley trains shown on the map (Pl. IV), which are evidently glacial outwash from ice that stood some miles back of the Newington moraine. However, all the clay in this region, from the lowest and oldest bed to the highest and youngest, must, for the following reasons, be regarded as a stratigraphic unit that was deposited uninterruptedly during a period perhaps beginning before the Newington substage but certainly continuing through and after it. First, the clay can be traced as a continuous deposit from points well inside of the moraine through such breaks as are made by Saco, Kennebunk, and Salmon Falls rivers in the moraine ridge to areas outside of the moraine. Second, careful scrutiny of the surface forms of the clay deposit,[1] of sections in the clay, and of the physical character of the clay itself fail to reveal any basis for subdivision of the clay into younger and older deposits.

EVIDENCE THAT THE MORAINE WAS LAID DOWN IN THE SEA.

The foregoing observations on the relation of the Newington moraine to marine sediments indicate that the ice front stood in the sea at the time and place of deposition of this moraine. This conclusion is established by the following evidence:

1. The surface of the moraine, as shown above, is in most places fairly smooth or is hummocky only in a small way by reason of knolls that are low and have gentle slopes, in contrast to the characteristically knobby kame forms, and in large part the crest of the moraine is broad and flat. Furthermore, although the material of the moraine is predominantly rounded, water-transported, and accumulated by glaciofluvial discharge, the form is not that of moraines accumulated subaerially but is like that of a delta or a line of many laterally confluent deltas, as for example in Biddeford, Wells, Newington, North Hampton, and Seabrook.

2. These very nearly level and broad, flat delta-like tops are all near the sea and are not separated from it by any present obstructions as high as the moraine. Therefore, unless it is postulated that an ice block, of which there is no evidence, or some high land not now remaining separated the moraine area from the ocean, there could have been no body of standing water not part of the sea at the required place and altitude to determine the form of the moraine.

3. In Merriland Ridge the interlamination of clay with moraine and outwash material, and the continuity there indicated of the sand and gravel beds in the moraine with marine clay beds in the plains to the east show that the débris from the glacier was discharged directly into the ocean.

4. Although the wide, level plains of marine clay were deposited in situations open to the disturbing influence of river, tidal, and storm currents, the clay is characteristically uniform in composition and texture and in the attitude of its bedding. Therefore the clay must have been deposited in quiet water—namely, in this instance, water whose surface was considerably above the levels up to which the clay plains were built and in consequence probably deep enough to submerge the moraine.

POSITION OF THE MORAINE WITH RESPECT TO DIRECTION OF ICE MOVEMENT.

The general direction of ice movement in this region was south-southeastward, as is indicated by numerous striae and also by a few drumlins. In the neighborhood of Biddeford, Maine, the striae trend S. 10°–15° E., and from Biddeford southwestward the easting increases with seeming regularity to S. 40° ± 5° E. in the neighborhood of Portsmouth, although there are local exceptions. The ice flow was in accord with the general southeasterly land slope and approximately parallel to the trend of the major drainage lines. The moraine segments in Biddeford, Kennebunkport, Wells, South Berwick, Rye, the Hamptons, Seabrook, and Salisbury are then approximately athwart the general course of ice movement, and such departures of the moraines from that trend as are indicated by the map are accounted for by the influence of the local topography of the rock floor.

On the other hand, the Dover Neck, Newington and Portsmouth, and Newburyport segments are in part oblique to and in part even nearly parallel to the general direction of ice movement. The explanation of this seeming

[1] The writer's observations offer no support for subdivision of the clay on the basis of "distinct topographic types," as postulated by F. G. Clapp (Complexity of the glacial period in northeastern New England: Geol. Soc. America Bull., vol. 18, pp. 505–556, 1907).

discordance is found in the fact that the moraine is predominantly the product of accumulation of the load of effluent glacial waters and is not pushed material. It might therefore lie at any site on the margin of the ice which permitted the discharge of glacial streams, regardless of the normal form of the front with respect to the direction of ice advance. The factor that in all probability chiefly determined the form of the ice edge in the vicinities of Portsmouth and Newburyport was the destruction of the glacier by calving of bergs and melting in the deep waters of the Piscataqua and Merrimack estuaries. Thus reentrants were made in the ice front. Probably also subglacial drainage in large volumes was discharged at these low points and assisted in cutting back the front.

RECESSIONAL NATURE OF THE MORAINE.

A large number of exposures of drift deposits have been observed in the course of five seasons' field work on the general geology of southwestern Maine and the adjacent part of New Hampshire, particularly in the regions of Portland, Maine, and Portsmouth, N. H., which have been closely examined. In none of these exposures is there any evidence of more than one ice advance over that region. There is no superposition of later till on earlier till; there are no differences in the degree of weathering or extent of erosion of till which could safely be ascribed to any other cause than accident of situation or exposure; and there are no "interglacial" deposits. There is, therefore, no basis for assuming that the Newington moraine marks the termination of an epochal advance or readvance of the ice, nor even of a very short readvance. It can only be concluded that this is a recessional moraine that marks a stand of the ice front conditioned by a balance between the rates of ice movement and of ablation. In accord with this conclusion is the evident lack of angular till and of materials heaped up by glacial shove, a fact which suggests that the ice was not moving vigorously. The regular stratification of the washed material also indicates that the ice front made no advance during the deposition of the moraine. On the contrary, the great width of parts of the moraine and the thickness of the "backset" beds indicate slow retreat of the ice front during the accumulation of the moraine.

DISCONTINUITY OF THE MORAINE.

The major intervals between the segments of the Newington moraine which require explanation are of two kinds. Those in Biddeford and Kennebunkport and in Wells and South Berwick are occupied by rock hills of greater height than the moraine. These rock hills are, in fact, links rather than gaps between the moraine segments. They obstructed the advance of the ice and were the anchors that held the ice and in a measure determined the position of the Newington halt. No effort was made to find on these hills morainal deposits marking the position of the ice front; perhaps careful search will disclose them. However, the absence of push material and the preponderance of stream-borne materials along other parts of the ice border lead to the inference that little morainic drift was piled up against or on these hills, for they could not have been the sites of glaciofluvial discharge. Such materials as were dropped here from the melting ice were perhaps too small in amount to make a noticeable accumulation and would otherwise be indistinguishable from ground moraine.

On the other hand, the Kennebunk, Mousam, and Salmon Falls valleys make real breaks in the continuity of the moraine so wide (7 and 8 miles) as to demand special consideration. A brief search in these valleys for morainal deposits or for evidence of either absence or obliteration of the moraine was without conclusive result. On account of the deep filling by later marine sediments there seems to be little chance of establishing either the presence or the absence of the moraine across these valleys, but the manner in which the clay and sand plains surround exposed ends of moraine segments suggests strongly that the continuations of the segments lie buried under clay in the deeper parts of these valleys, just as the Biddeford and Saco segments are partly buried in the Saco Valley.

AGE OF THE MORAINE.

The age of the Newington moraine can not be decisively stated until the general problems of Pleistocene correlation in northern New England have been settled. It is established that the Newington moraine is the youngest strictly glacial deposit in the immediate vicinity of the coast of New Hampshire and southwestern Maine. The only younger deposits are the later beds of marine clay ("Leda") and sand which overlie parts of the Newington moraine, and, as has been indicated, these are sea-laid outwash materials of a somewhat later stage during which the ice front stood not far back from the Newington moraine. Clapp's statement[1] that there is a till formation younger than and overlying marine ("Leda") clays finds no support in any exposed sections of the clay and its associated deposits which the authors have been able to find. But it is not merely for that reason that Clapp's conclusion is held to be inapplicable to the coastal region here considered. The critical fact is that the surface of the clay deposit is not glaciated but is a plain of deposition which, except for slight or moderate trenching by stream erosion, has been entirely unaltered since its formation. It is not denied that Pleistocene marine clays older than the Newington substage may have been covered by till, but if such clays are present in this region they are not to be seen because they are buried. It is also granted that elsewhere marine clays equivalent to the Newington or later substages may have been glaciated but not that such relations have yet been established.

It seems reasonable and safe to assume that when ice of the Wisconsin stage occupied Long Island, Marthas Vineyard, Nantucket, and the Cape Cod Peninsula[2] there must have been ice over the coastal counties of New Hampshire and southwestern Maine. Therefore, it must be concluded that the Newington moraine is of Wisconsin age, probably late Wisconsin, and, as a corollary, that so also is the marine ("Leda") clay of that region.

[1] Clapp, F. G., Complexity of the glacial period in northeastern New England: Geol. Soc. America Bull., vol. 18, pp. 505-556, 1907.

[2] The correlations of moraines in these regions with the early Wisconsin moraine of New Jersey is accepted. See Fuller, M. L., The geology of Long Island, N. Y.: U. S. Geol. Survey Prof. Paper 82, table opposite p. 220, 1914.

SUMMARY.

A recessional moraine consisting of several separate segments disposed along a sinuous course lies near the Atlantic coast and has been traced through 60 miles from Saco, Maine, to Newbury, Mass. It is for the most part about or less than 100 feet above sea level but rises to 180 feet in Biddeford, Maine, 150 feet in Dover, N. H., and Newburyport, Mass., and is between 200 and 250 feet above the sea in Wells and South Berwick, Maine. Although not more than 40 to 100 feet higher than surrounding Pleistocene formations, nevertheless it is topographically prominent because it is in a region of slight relief. The moraine rests upon and is surrounded by a floor of ice-smoothed rock and of till. The region was submerged during the building of the moraine, and the ice front stood in the sea. The moraine is the result of the accumulation of glaciofluvial detritus discharged directly into the sea; consequently in some places it is built up as broad, flat, deltalike plains of sand and gravel. Clay ("Leda clay") was continuously deposited in the sea, both while the moraine was accumulating and after the ice retreated from the moraine, so that the younger clay beds in some places overlie the moraine. This clay is the fine glacial outwash. The moraine and the marine clay probably belong to a late Wisconsin substage of the Pleistocene epoch.

O

Crania aff. C. missouriensis.
Schizophoria aff. S. swallowi.
Productus aff. P. burlingtonensis.
Productus aff. P. arcuatus.
Productus aff. P. sampsoni.
Pustula n. sp.
Pustula sp.
Rhynchopora occiden talis.
Camarotoechiaaff.C.metallica.
Spirifer aff. S. grimesi.
Spirifer aff. S. vernonensis.
Brachythyris aff. B. suborbicularis.
Delthyris novamexicana.
Reticularia aff. R. cooperensis.
Pseudosyrinx aff. P. gigas.
Athyris lamellosa.
Cliothyridina temeraria.
Cliothyridina aff. C. obmaxima.
Cliothyridina aff. C. incrassata?
Eumetria? tuta.
Platyceras aff. P. equilatera.
Goniatites sp.
Orthoceras? sp.
Phillipsia aff. P. peroccidens.
Proetus sp.
Griffithides? sp.

The crinoids were not as abundant in bed 8 as in bed 7. Beds 5 and 6 contain corals and crinoids, but nothing was determined. According to Keyes bed 5 is Devonian,[1] consisting of three members, the lowest of which carries a typical late Devonian fauna.

In the exposure of Lake Valley limestone, 2 miles east of Hillsboro, Gordon[2] found beds 5 and 6 absent and beds 7 and 8 lying on fossiliferous Devonian shales. The following fossils were obtained:

Cyathaxonia? sp.
Zaphrentis sp.
Amplexus aff. A. fragilis.
Periechocrinus whitei.
Rhodocrinus wortheni var. urceolatus.
Cactocrinus multibrachiatus.
Leptaena analoga.
Cactocrinus proboscidialis.
Steganocrinus pentagonus.
Platycrinus subspinosa.
Platycrinus sp.
Physetocrinus lobatus.
Physetocrinus copei.
Fistulipora americana.
Schizophoria aff. S. swallowi.
Rhipidomella dalyana.
Leptaena analoga.
Productus aff. P. burlingtonensis.
Pustula n. sp.
Spirifer aff. S. vernonensis.
Spirifer aff. S. grimesi.
Delthyris novamexicana.
Brachythyris aff. B. suborbicularis.

Spiriferina sp.
Athyris lamellosa.
Cliothyridina aff. C. glenparkensis.
Platyceras aff. P. equilatera.
Platyceras sp.
Orthonychia sp.
Phillipsia aff. P. peroccidens.
Proetus aff. P. loganensis.

At Kingston, 9 miles west of Hillsboro, the following fossils were found by Gordon:[3]

Zaphrentis sp.
Amplexus aff. A. fragilis.
Platycrinus sp.
Fenestella sp.
Rhombopora sp.
Leptaena analoga.
Schizophoria aff. S. swallowi.
Pustula n. sp.
Spirifer aff. S. vernonensis.
Brachythyris aff. B. suborbicularis.
Pseudosyrinx aff. P. gigas.
Athyris lamellosa.
Cleiothyridina aff. C. incrassata.

From limestone overlying the Percha shale a short distance east of Kingston the writer collected the following forms, identified by G. H. Girty:

Fenestella, several sp.
Polypora sp.
Rhombopora sp.
Cheilotrypa? sp.
Cystodictya aff. C. pustulosa.

In another bed were found the following:

Cladochonus sp.
Cyathaxonia arcuata?
Fenestella sp.
Polypora sp.
Rhombopora sp.
Rhipidomella? sp.
Productus aff. P. mesialis.
Delthyris? sp.
Spiriferina sp.
Cliothyridina aff. C. glenparkensis.

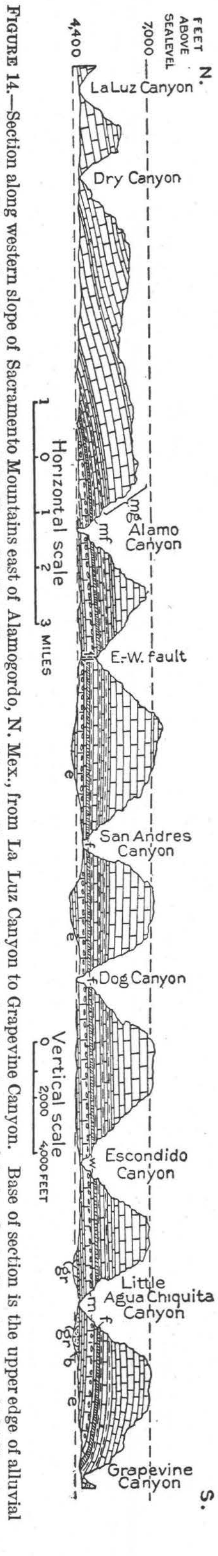


FIGURE 14.—Section along western slope of Sacramento Mountains east of Alamogordo, N. Mex., from La Luz Canyon to Grapevine Canyon. Base of section is the upper edge of alluvial fans and valley fill. gr, Granite; b, sandstone (Bliss?); e, El Paso limestone; m, Montoya limestone (dark massive limestone overlain by cherty limestone); w, light limestone (Fusselman?); f, Fusselman limestone; mf, shaly limestone, with Mississippian fossils; mg, Magdalena group.

[1] Am. Inst. Min. Eng. Trans., vol. 39, p. 147, 1909.
[2] Am. Jour. Sci., 4th ser., vol. 24, p. 61, 1907.
[3] Idem, p. 62.

The fossils collected by Lee in the canyon of Rio Salado, on the south side of the Sierra Ladrones, were determined by G. H. Girty,[1] as follows. All of them are lower Mississippian forms:

Zaphrentis 2 sp.
Granatocrinus? sp.
Platycranus? sp.
Rhipidomella aff. R. dubia.
Spirifer aff. S. logani.
Spirifer aff. S. tenuicostatus.
Spiriferella aff. S. neglecta.
Athyris lamellosa.
Cliothyridina aff. C. obmaxima.
Phillipsia sp.

There are abundant fossils in the Lake Valley limestone in the Cooks Peak region. The following were determined by G. H. Girty:

Rhombopora sp.
Cystodictya aff. C. pustulosa.
Paraparchites sp.
Leptaena analoga.
Rhipidomella pulchella?
Productus semireticulatus.
Productus ovatus.
Productus aff. P. burlingtonensis.
Productus aff. P. wortheni.
Brachythyris suborbicularis?
Spirifer centronatus.
Composita humilis.

From the lower division of the Fierro limestone of the Silver City region Paige obtained the following distinctive Mississippian forms identified by G. H. Girty:

Actinocrinus copei?
Dorycrinus lineatus.
Leptaena analoga.
Rhipidomella aff. R. oweni.
Productus mesialis.
Spirifer aff. S. imbrex.
Reticularia cooperensis.

Girty[2] regards the Lake Valley fauna at Silver City as closely related to that found at Fern Glen, Mo., and at other points in that general region.

From the Kelly limestone in the Magdalena Range, Keyes[3] reports *Batocrinus subaequalis* Hall.

From the Mississippian beds in the section east of Alamagordo, Girty[3] obtained the following species:

Triplophyllum sp.
Leptaena analoga.
Schuchertella aff.
S. chemungensis.
Rhipidomella diminutiva?
Schizophoria postsriatula?
Productus gallatinensis.
Productella n. sp. aff. P. pyxidata.
Shumardella? aff. S. missouriensis.
Brachythyris suborbicularis.
Ambocoelia levicula.
Reticularia cooperensis.
Proetus peroccidens.
Spirifer sp. undet.
Platyceras sp. undet.

In 1915 the writer collected from shales about 50 feet above the Fusselman ledge on the north side of Alamo Canyon the following forms identified by G. H. Girty:

Zaphrentis sp.
Rhipidomella dalyana.
Schizoporia? sp.
Spirifer rowleyi.
Spirifer centronatus?
Delthyris novamexicana.
Composita humilis?
Cliothyridina prouti?
Cliothyridina sp.

At the same horizon in the slope near Dog Canyon were collected the following:

Schizoblastus aff. S. roemeri.
Dielasma sp.
Spirifer aff. S. grimesi.
Platyceras aff. P. fissurella.
Platyceras aff. P. paralius.
Platyceras aff. P. equilatera.

Lower Mississippian (Lake Valley) fossils were collected at several localities in the San Andres Mountains. The following forms were identified by G. H. Girty:

San Andres Canyon, in heavy ledge above Percha shale:
Triplophyllum sp.
Schizopophoria aff. S. swallowi.
Productus aff. P. arcuatus.
Spirifer aff. S. grimesi.
Spirifer centronatus.
Brachythyris suborbicularis.

In cherty beds at top of this heavy ledge, in a canyon 3 miles south of San Andres Peak:
Triplophyllum sp.
Spirifer aff. S. pellensis.
Eumetria vera.

In the basal part of the first heavy ledge above the Percha shale on the ridge west of the San Nicolas Spring:
Cystodectya sp.
Chonetes aff. C. logani.
Spirifer sp.

[1] Personal communication.
[2] U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), p. 5, 1916.
[3] Am. Inst. Min. Eng. Trans., vol. 39, p. 169, 1909.

MAGDALENA GROUP.

The representatives of the Pennsylvanian series have been studied in detail in many parts of New Mexico, but the following statements refer only to the beds associated with the older formations in southern New Mexico and adjacent parts of Texas.

Cooks Range.—About 40 feet of dark-gray shale lying on the white chert of the Lake Valley limestone high on the slopes on the northwest side of Cooks Peak yielded fossils that appear to indicate the presence of a representative of the Magdalena group, the lowest subdivision of the Pennsylvanian series in New Mexico. Possibly it occurs elsewhere in Cooks Range, but at all other places visited the Gym and Lake Valley limestones are in immediate succession. The fossils in the limy layers in the shale include the following, all determined by G. H. Girty:

Derbya crassa.
Chonetes mesolobus.
Productus semireticulatus.
Pustula nebraskensis?
Marginifera muricata.
Pugnax sp.
Spirifer cameratus.
Spirifer rockymontanus.
Ambocoelia planiconvexa.
Aviculipecten, 2 sp.
Acanthopecten carbonifer.
Lima retifera.
Astartella vera.
Edmondia subtruncata.
Phillipsia scitula.

Silver City region.—As remarked on page 48, the upper part of the Fierro limestone of the Silver City region. as defined by Paige in the Silver City folio, includes beds representing more or less of the Magdalena group. The fossils found in this upper division were determined by Girty as follows:

Fusulina secalica.
Campophyllum torquium?
Zaphrentis sp.
Chaetetes milleporaceus.
Fenestella tenax.
Stenopora sp.
Meekopora? sp.
Prismopora triangulata.
Productus cora.
P. semireticulatus.
Pustula nebraskensis.
Spirifer cameratus.
S. rockymontanus.
Squamularia perplexa.
Composita subtilita.
Cliothyridina orbicularis.

These forms are comprised in the Magdalena fauna in Sierra and Socorro counties.

Mimbres Mountains.—At Kingston, on the east slope of the Mimbres Mountains, according to Gordon,[1] the basal Magdalena strata consist of about 300 feet of dark-blue and gray limestone in thick beds with thin shale partings. The upper part of the group has about the same thickness and consists chiefly of blue and drab shales interstratified with several beds of limestone from 15 to 20 feet thick. Unconformably overlying these beds are red sandstones and shales (Abo sandstone) of the Manzano group. At the Palomas mining camp, 20 miles north of Kingston and 2 miles east of Hermosa, the Palomas Creek canyon has nearly vertical walls, the lower half of limestone and shale in about equal amounts and the upper half of hard, massive gray limestone. About halfway up the cliff a few thin beds of quartzite are interstratified with the other rocks. There is no evidence on which to separate the group into Sandia formation and Madera limestone, as in the region farther east.

Magdalena Mountains.—In the Magdalena Mountains, according to Gordon,[1] the basal member of the Magdalena group is 10 to 15 feet of moderately coarse conglomerate interstratified with dark shale, whose bedding is apparently parallel to that of the underlying Kelly limestone. This conglomerate is overlain by 115 feet of limestone capped by coarse white quartzite or conglomerate in massive ledges separated by thin beds of shale. Next above is a member 80 to 90 feet thick, consisting mostly of limestone, in which are some thin beds of shale and quartzite. The basal part of this member is 6 feet of thick-bedded drab-blue subcrystalline limestone; next above are 25 feet of shale and thin limestone, 2 feet of quartzite, 50 feet of compact bluish earthy limestone, and 410 feet of shale and conglomeratic sandstone or quartzite. The total thickness of these beds (Sandia formation) is about 600 feet. They are overlain by 300 to 500 feet of limestone (Madera), more or less of whose surface has been removed by erosion.

GYM LIMESTONE.

The Manzano group is represented in central and northern New Mexico by the Gym limestone, which crops out extensively in the Flor-

[1] U. S. Geol. Survey Prof. Paper 68, pp. 232, 269, 1910.

ida Mountains, type locality,[1] and also in the Victorio Mountains. In both places it lies unconformably on formations from the El Paso to the Fusselman, for the Percha shale and Lake Valley and Magdalena limestones are absent. In Cooks Range a thin body of the Gym limestone lies on the Lake Valley limestone at most places, but on the northwest slope of Cooks Peak these two limestones are separated by an outlier of shale of Magdalena age. The Gym limestone also appears extensively in the Tres Hermanas Mountains, where it is uplifted and cut by porphyry, and it also crops out in a few small hills rising out of the desert in the south-central part of the county. The formation has not been recognized outside of Luna County, although doubtless it is represented in the Manzano and Hueco sections in other areas.

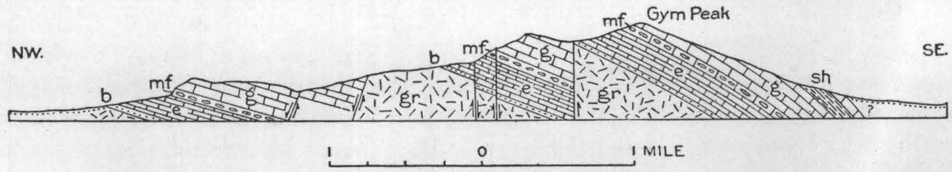


FIGURE 15.—Section across the southern part of the Florida Mountains, Luna County, N. Mex. gr, Granite; b, Bliss sandstone; e, El Paso limestone; mf, Montoya and Fusselman limestones; g, Gym limestone with dark-gray shale member (sh).

In the Florida Mountains the Gym limestone is about 1,000 feet thick, but, as shown in figure 15, it is greatly faulted and the uppermost beds have been more or less deeply removed by erosion. In Cooks Range its thickness is less than 50 feet.

The formation consists almost entirely of light-gray limestone, mostly massive and in part brecciated. An 80-foot member of dark-gray shale is apparently included on the southeast slope of the Florida Mountains, but this may be the Percha shale overlapped, or faulted into its present position. In the Tres Hermanas Mountains part of the Gym limestone is metamorphosed to white marble and there is included a member of 50 to 60 feet of gray to reddish quartzite.

Fossils were collected at several horizons in the Gym limestone at numerous localities. They were determined as follows by G. H. Girty:

Echinocrinus ornatus.
Meekella mexicana?
Productus semireticulatus.
Productus occidentalis.
Productus cora.
Marginifera splendens?
Pugnax utah.
Squamularia perplexa.
Composita perplexa.
Composita subtilita.
Composita mexicana?
Nucula levatiformis.
Nucula levatiformis var. obliqua.
Manzanella elliptica.
Parallelodon politum?
Pinna peracuta.
Monopteria marian?
Plagioglypta canna?
Bellerophon crassus.
Bellerophon majusculus?
Bucanopsis modesta.
Pleurotomaria texana.
Rhynchomphalus obtusispira.
Euomphalus aff. E. pernodosus.
Chonetes playtnotus?
Orthonema socorroense?
Sphaerodoma aff. S. humilis.
Sphaerodoma aff. S. primigenia.
Bulimorpha inornata.

In the San Andres and Sacramento mountains and farther north in New Mexico the supposed equivalent of the Gym limestone is separated from the Magdalena group by a thick series of red beds (Abo sandstone), but these beds are lacking in the southwest corner of the State and also in the region near and east of El Paso.

Most of the fossils in the Gym limestone are doubtless of the Manzano group, but they do not afford a basis for correlation with the rocks of other regions, nor do they indicate how much of the group is represented here. Mr. Girty has called the writer's attention to the fact that *Productus occidentalis* is characteristic of the limestone capping the Sacramento Mountains at Cloudscroft, a bed which is high in the Carboniferous. Some of the gastropods strongly suggest the Hueco fauna, and therefore the formation is believed to represent part of the Hueco limestone.

[1] Darton, N. H., Geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, p. 35, 1916.

HUECO LIMESTONE.

According to Richardson [1] the Carboniferous rocks are represented in the Franklin and Hueco mountains by a massive gray limestone of which 3,000 feet appears, but the total thickness is greater, as more or less of the top has been covered or removed by erosion. Thin bedding is rare, and chert is practically absent. The magnesia content was found to be less than 1 per cent. Locally some beds are black; in the Hueco Mountains most of the limestone is light colored. The Hueco Mountains consist mainly of this formation, and it constitutes the northwestern flank of the Franklin Mountains. The Hueco limestone carries an abundant fauna regarded by Girty as of late Carboniferous age, on account of which at least the upper part of it has been tentatively correlated with the Kaibab limestone of northern Arizona.

GEOLOGIC HISTORY.

The sequence of events in southern New Mexico during the earlier part of the Paleozoic era can be known only in a most general way, for many long intervals of the time are not represented by deposits. It is probable that many beds were laid down that were subsequently removed. Doubtless some of the beds now remaining have been thinned by erosion, and possibly, also, they were formerly much more extensive. Some or all of the pre-Pennsylvanian formations may have covered all of New Mexico. Apparently the uplifts were widespread and not attended by folding, for the attitude of all the Paleozoic formations is the same with a few slight local exceptions.

The first Paleozoic event of which there is evidence was the deposition of sand on beaches of granite and other old rocks in the later part of Cambrian time. There may have been accumulations of earlier Cambrian sediments, but if so they were completely removed. Possibly sedimentation was continuous into early Ordovician time, when the materials of the El Paso limestone accumulated to a thickness of 900 feet or more. The hiatus between the El Paso limestone and the Montoya is a long one, representing all of the Middle Ordovician and the early part of the Upper Ordovician. The hiatus between the Montoya and Fusselman is from late Richmond to probable early Niagara time. Only a small part of later Devonian time is represented by the Percha shale, so during that epoch there was either long emergence of the land or extensive removal of earlier Devonian sediments. During part of early Carboniferous time the region was submerged and the Lake Valley sediments were laid down, but there is only a long hiatus to represent later Mississippian time. Pennsylvanian and Permian time is represented in the main by deposits of the Magdalena and Manzano groups and the Hueco and Gym limestones. The Hueco and Gym are contemporaneous, at least in part, with the Manzano group, which includes 500 to 1,000 feet of red beds (Abo sandstone) that thin out to the south.

[1] U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

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GEORGE OTIS SMITH, Director

Professional Paper 108—C

A COMPARISON OF PALEOZOIC SECTIONS IN SOUTHERN NEW MEXICO

BY

N. H. DARTON

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A COMPARISON OF PALEOZOIC SECTIONS IN SOUTHERN NEW MEXICO.

By N. H. Darton.

INTRODUCTION.

In studying the geology of different parts of southern New Mexico the writer has obtained many new data on the distribution and relations of the sedimentary rocks. The stratigraphy of the Pennsylvanian series was investigated in detail, and in Luna County all the formations were studied.[1] A recently published folio[2] gives many new facts for the stratigraphy of the Silver City region, some of which are utilized in the present paper. Richardson's work in the El Paso region[3] established the succession in the southeastern part of New Mexico. There are also many details in publications by Gordon and Graton, Lee, Herrick, and others.

It has been known for some time that in southern New Mexico there are representatives of portions of later Cambrian, Ordovician, Silurian, Devonian, earlier Mississippian, and Pennsylvanian time, and that the lower formations thin out to the north, so that in central New Mexico the strata of the Pennsylvanian series lie directly on the pre-Cambrian crystalline rocks, as shown in Plate XIV, *B*. There are also numerous irregularities in the overlap relations of the formations. The broader features of the stratigraphy of this region are here presented. The principal Paleozoic formations in southern New Mexico are shown in the columnar sections (fig. 2), and some conditions of the distribution of the formations are indicated on the map (Pl. XIII).

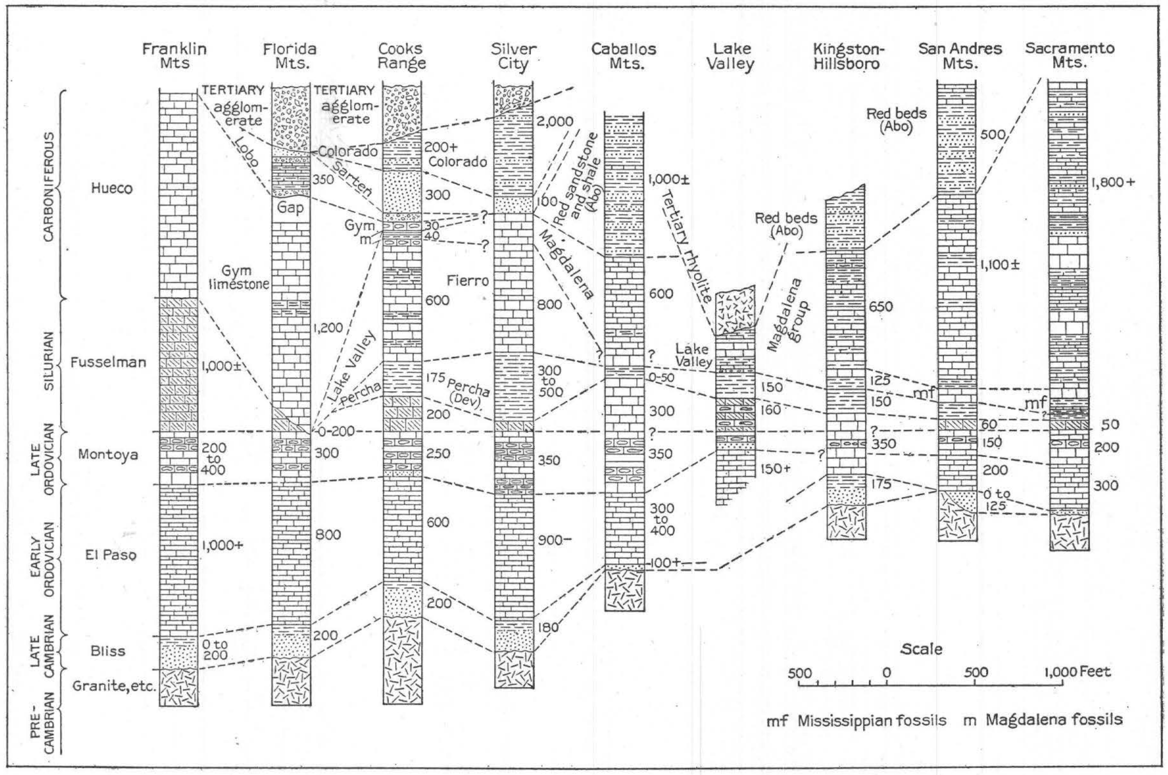


FIGURE 2.—Columnar sections showing stratigraphic relations of Paleozoic rocks in southern New Mexico.

[1] Darton, N. H., Geology and underground waters of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, 188 pp., 13 pl., 1916.

[2] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916.

[3] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

CAMBRIAN SYSTEM.

GENERAL FEATURES.

The presence of Cambrian strata in New Mexico was announced by Gordon and Graton [1] in 1906, on the evidence afforded by the discovery of *Obolus stoneanus* in sandstones on the west side of the Caballos Mountains near Shandon. In 1910 the name "Shandon quartzite" [2] was given to the beds at this place, and they were tentatively correlated with the Bliss sandstone of the Franklin Mountains, near El Paso, Tex., defined by Richardson [3] in 1904. Sandstones and other rocks of Cambrian age occur at many places in Arizona, where apparently they underlie wide areas. The name Bliss sandstone has been adopted for southern New Mexico because of its priority in the El Paso region. It replaces the name "Shandon quartzite."

BLISS SANDSTONE.

Franklin Mountains.—In its type locality, at the east base of the Franklin Mountains, the Bliss sandstone consists of small grains of quartz embedded in a matrix of sericite and kaolin. The basal beds are mostly quartzitic and locally conglomeratic, and the higher beds are softer and finer grained. The prevailing color is brown, but some portions have lighter tints. A thickness of 300 feet is attained in places, but locally the formation thins out and overlying limestones rest on the pre-Cambrian rocks. It appears to grade upward into the El Paso limestone. Annelid borings are abundant, and a few brachiopods in the lower beds comprise *Lingulepis acuminata, Obolus matinalis?*, and fragments of *Lingulella*. Some relations of the Bliss sandstone in the Franklin Mountains are shown in figure 3.

Florida Mountains and Cooks Range.—In Luna County the Bliss sandstone is similar in character, thickness, and relations to the formation in its type locality. It crops out in the Florida Mountains and Cooks Range, as well as in several outliers, everywhere lying with strong unconformity on granite, as shown in Plate XVI, *B* (p. 34), and grading upward into the El Paso limestone. Gray to brown sandstone prevails; part of it is quartzitic, but the upper beds are slabby and have intercalations of sandy and limy shale. The formation contains much glauconite. Its average thickness is 150 feet, but locally it is much thinner. No fossils were found in these areas.

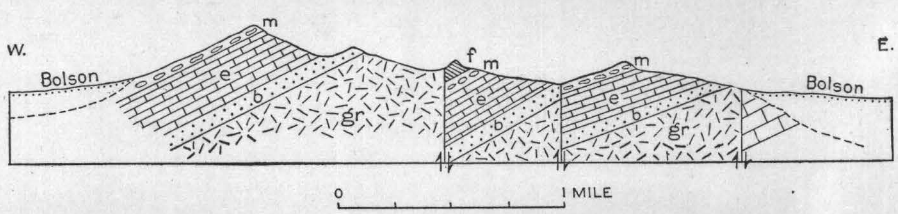


FIGURE 3.—Section across the Franklin Mountains 3 miles north of El Paso, Tex. (After Richardson.) gr, Granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone.

Silver City region.—In the Silver City region the Bliss sandstone consists of quartzite and limy sandstone containing some glauconite throughout. The thickness averages 180 feet, but varies somewhat. At most places the basal member is quartzite, which grades upward as a rule into fine-grained greenish sandstone but locally into soft ferruginous sandstone, and here and there the greater part of the formation is quartzite. At the top there is generally a thin quartzite or glauconitic sandstone, grading upward into limy sandstone that appears to merge with the overlying El Paso limestone. A typical section given by Paige [4] is as follows:

Section of Bliss sandstone 7 miles northwest of Silver City, N. Mex.

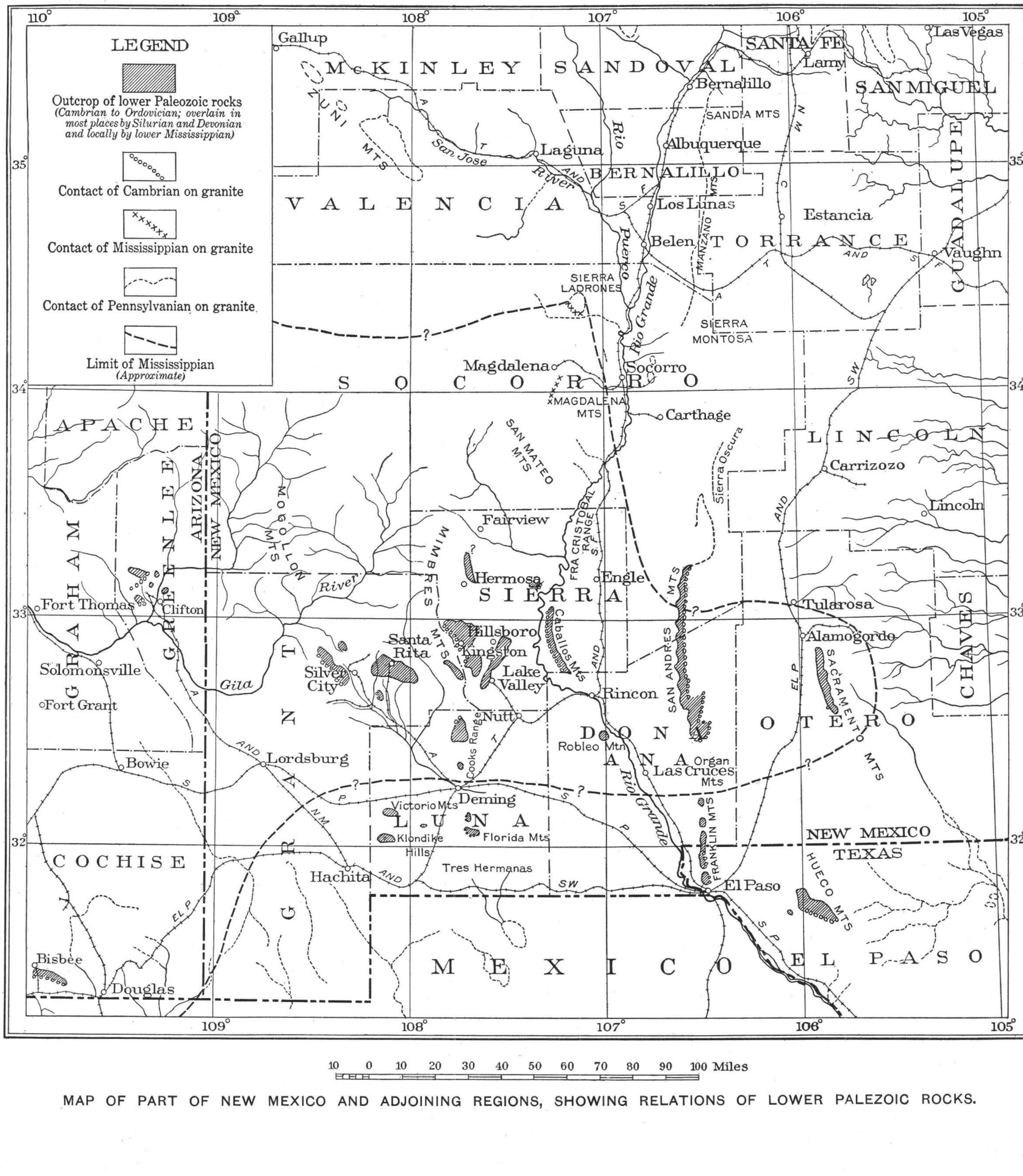
	Feet.
Sandstone, coarse, glauconitic	12
Limestone, sandy; thin, wavy bedding; fucoid markings	47
Quartzite, coarse, slightly cross-bedded	17
Sandstone, limy; thin, wavy bedding; fucoids?	57

[1] Gordon, C. H., and Graton, L. C., Lower Paleozoic formations in New Mexico: Am. Jour. Sci., 4th ser., vol. 21, p. 392, 1906. See also Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 225, 1910.

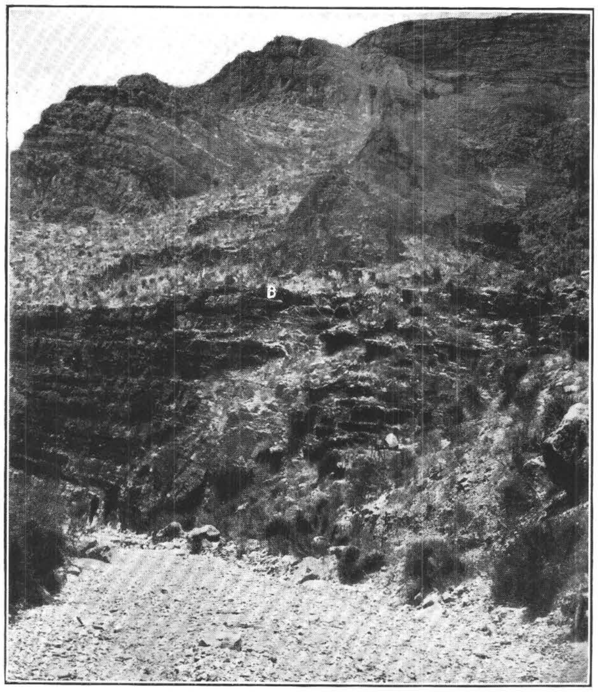
[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., op cit., p. 225.

[3] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas & Pacific Railway: Texas Univ. Mineral Survey Bull. 9, p. 27, 1904.

[4] Paige, Sidney, Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916.

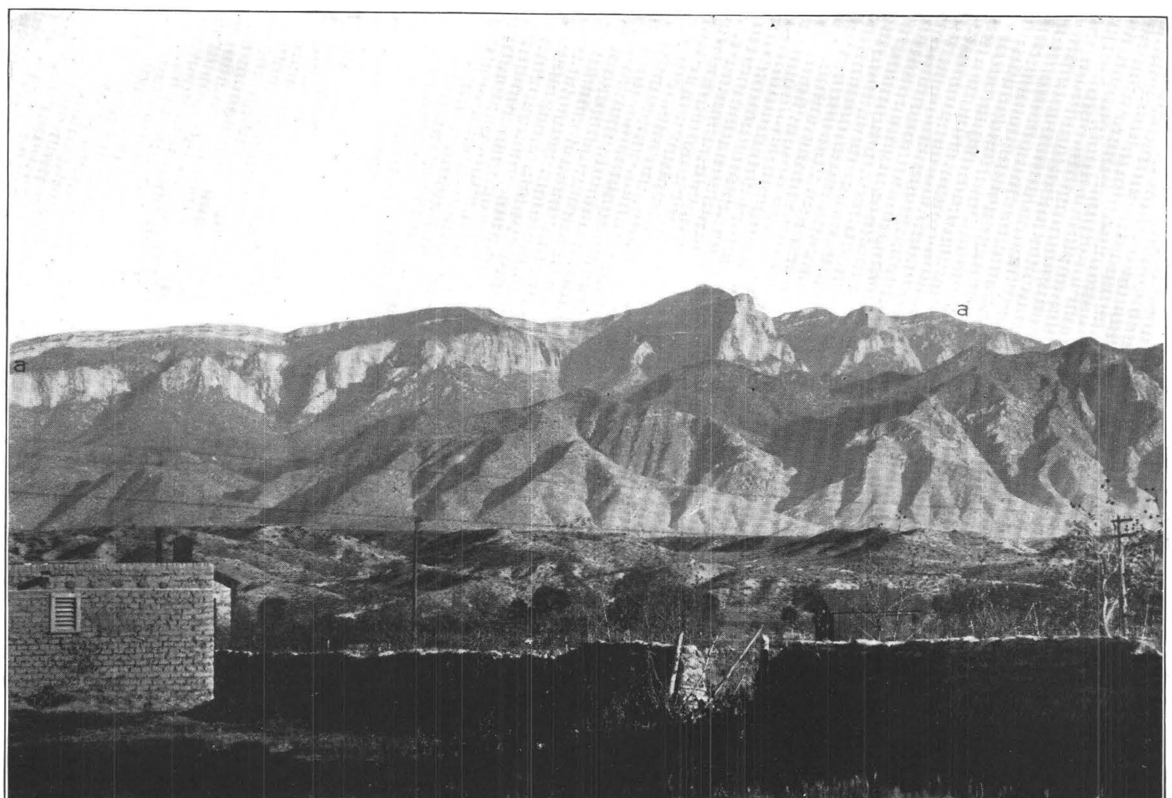


MAP OF PART OF NEW MEXICO AND ADJOINING REGIONS, SHOWING RELATIONS OF LOWER PALEOZOIC ROCKS.



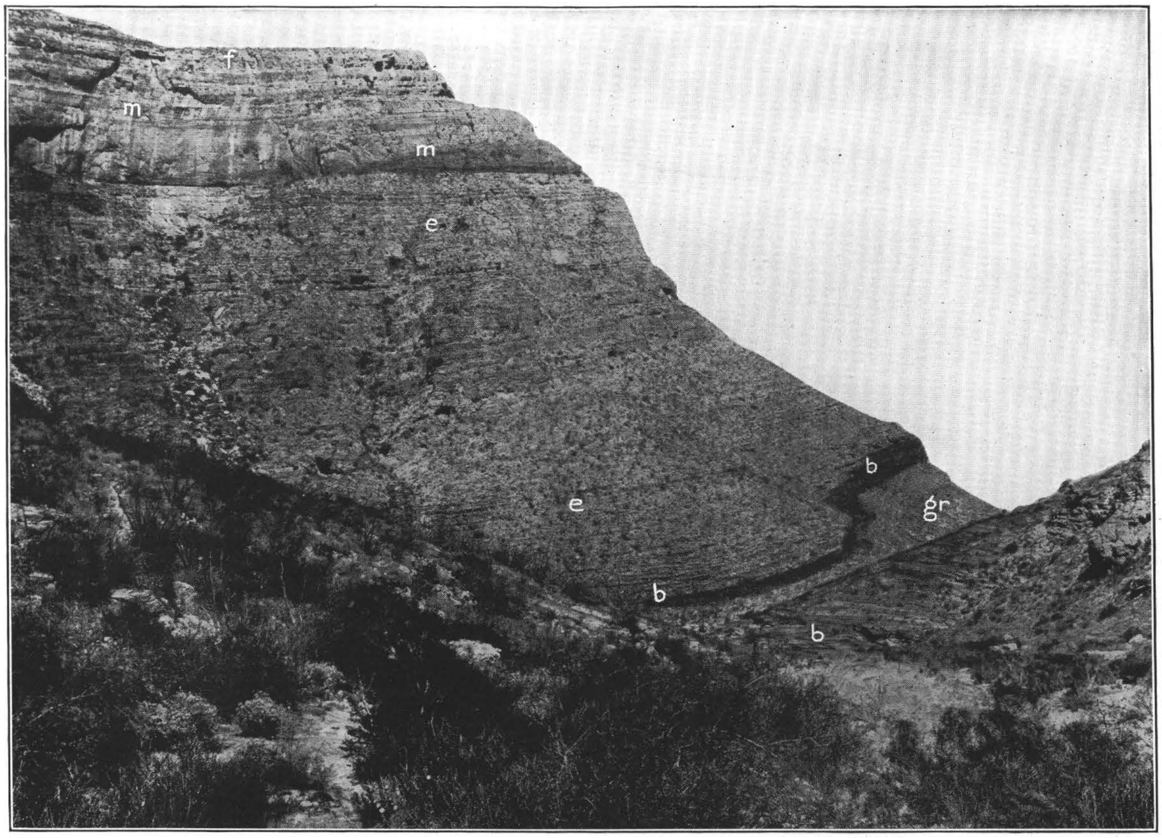
A. BLISS SANDSTONE IN BENNETT CANYON, 18 MILES NORTHEAST OF LAS CRUCES, N. MEX.

B, Contact of Bliss sandstone and El Paso limestone.



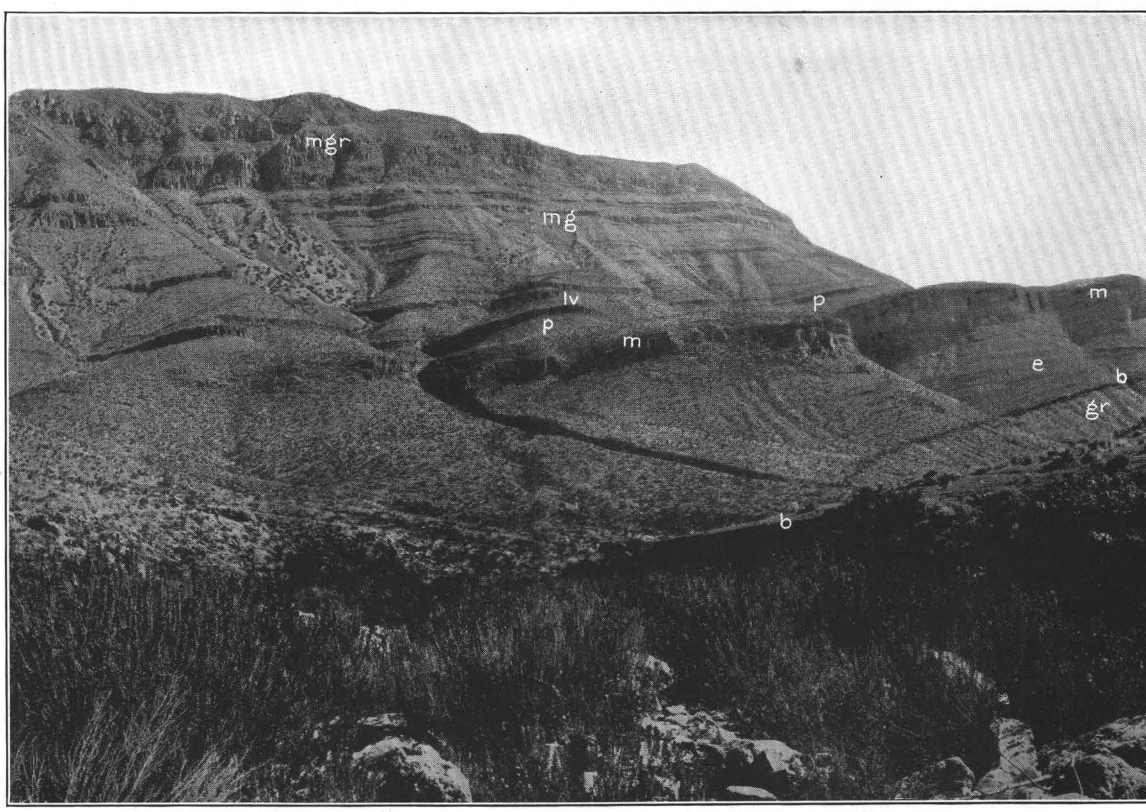
B. WEST FACE OF SANDIA MOUNTAINS AT BERNALILLO, N. MEX.

a, Sandia formation on granite, etc.



A. VIEW LOOKING EAST OUT OF MOUTH OF HEMBRILLO CANYON.

f, Fusselman limestone; m, Montoya limestone; e, El Paso limestone; b, Bliss sandstone; gr, granite.



B. VIEW LOOKING NORTHEAST IN GOODFORTUNE CANYON.

mgr, Microgranite; mg, limestone of Magdalena group; lv, Lake Valley limestone; p, Percha shale; m, Montoya limestone; e, El Paso limestone; b, Bliss limestone; gr, granite.

VIEWS ON EAST SIDE OF SAN ANDRES MOUNTAINS, WEST OF ALAMOGORDO, N. MEX.

	Feet.
Quartzite, massive, cross-bedded, ferruginous, glauconitic; pebbly streaks	17
Sandstone, soft, glauconitic	13
Quartzite, massive, coarse (on granite)	15
	178

The area of outcrop of the formation is small. It appears along the west slope of the ridge northwest of Silver City and on some outlying ridges and in a small exposure at the west end of Lone Mountain, 6 miles southeast of Silver City. The beds near the base yielded abundant specimens of *Billingsella coloradoensis*, an Upper Cambrian fossil.

Caballos Mountains.—The Bliss sandstone in the Caballos Mountains has been described by Gordon and Graton[1] and by Lee.[2] As explained above, the beds at this place were called "Shandon quartzite." They lie on a smooth plane on granite, which is exposed to a height of about 1,000 feet above the Rio Grande on the west slope of the range, as shown in figure 8 (p. 39) and Plate XVI, *A* (p. 34). Gordon and Graton described a thin basal member of dark quartzite, absent in places; white quartzite 4 to 5 feet thick; and an upper member, 40 feet thick, of dark-brown and green sandy shales and thin-bedded quartzite carrying *Obolus*. The beds recorded by Lee in a section 3 miles north of Shandon consist of a basal quartzite 10 feet thick, in places conglomeratic, grading upward into 90 feet of dark-green shale. The shale yielded *Obolus* (*Westonia*) *stoneanus*, *Obolus sinoe?*, *Eoorthis desmopleura*, and *Lingulella acutangulata?*, determined by C. D. Walcott and regarded as Upper Cambrian. A similar section was observed by Lee in Cerro Cuchillo, near Palomas Spring. (See Pl. XVII, *A*, p. 35.) In both places the overlying limestone is the El Paso. Lee states that the basal quartzite thickens to 300 feet 8 miles south of Shandon.

San Andres Mountains.—The Bliss sandstone crops out continuously along the east slope of the San Andres Mountains, but it becomes very thin in the north end of the range. (See figs. 9, p. 42, and 11, p. 45.) The formation is a conspicuous feature in Bennett Canyon, 18 miles northeast of Las Cruces, where it is 125 feet thick and lies between granite and the El Paso limestone. This exposure is shown in Plate XIV, *A*. The Bliss is 60 feet thick 2 miles northeast of Organ, where it is cut off by igneous rocks. At this locality the rocks are sandstone, mostly hard, and many layers contain considerable glauconite. In San Andres Canyon the formation comprises 110 feet of beds, consisting of a lower member of gray quartzite, mostly massive; a medial member of brown sandstone, partly slabby; and an upper slabby member that apparently merges with the base of the El Paso limestone. In the central part of the range, at Deadman and Hembrillo canyons, the thickness is from 30 to 40 feet. (See Pl. XV.) In Sulphur Canyon it consists of 25 feet of brown sandstone, conglomeratic at the base, grading upward into 30 feet of thin, slabby softer sandstone, in part glauconitic, which appears to grade into slabby, finer sandstone, and this in turn into an impure buff slabby limestone that is certainly the El Paso. In Rhodes Canyon the sandstone that separates the El Paso beds from the granite is 6 feet thick, and this thin deposit extends northward, as shown in Plates XV, *B*, and XVIII, *A* (p. 36).

Sacramento Mountains.—In the small exposure of the base of the sedimentary rocks just south of the mouth of Agua Chiquita Canyon, in the Sacramento Mountains, the El Paso limestone is separated from a dark granite by a few feet of hard sandstone, which is presumably Bliss. It is not especially characteristic, however, and yielded no fossils, so that the correlation can be only tentative.

Mimbres Mountains.—According to Gordon,[3] the limestone in the east slope of Mimbres Mountains is separated from the granite by quartzite, which undoubtedly represents the Bliss sandstone. (See fig. 10, p. 44.) Exposures on Carbonate Creek show 75 feet of dark-red quartzite, which includes a 3-foot bed of shale near the middle and rests on an irregular surface of red granite. In most of the slopes of these mountains the basal formations of the sedimentary series are hidden by younger igneous rocks, which cap the range.

[1] Am. Jour. Sci., 4th ser., vol. 21, pp. 391-392, 1906; U. S. Geol. Survey Prof. Paper 68, pp. 225-226, 1910.

[2] Lee, W. T., Notes on the lower Paleozoic rocks of central New Mexico: Am. Jour. Sci., 4th ser., vol. 26, pp. 180-181, 1908.

[3] U. S. Geol. Survey Prof. Paper 68, pp. 268, 269, 1910.

ORDOVICIAN SYSTEM.

GENERAL FEATURES.

Ordovician rocks were first discovered in the Southwest by G. G. Shumard in 1856,[1] who found fossils now known to be characteristic of the Ordovician in the Franklin Range at El Paso. Some years later the geologists of the Wheeler Survey [2] found similar fossils at several localities, including the vicinity of Silver City, N. Mex.

Gordon and Graton [3] found other fossiliferous localities in southern New Mexico in 1905. The beds of Ordovician age which they describe are about 750 feet thick, and in 1910 these beds, together with a Silurian limestone that overlies them in places, were designated the "Mimbres limestone."[4] All these limestones are well represented in the Franklin Mountains north of El Paso, where Richardson [5] subdivided them into the El Paso and Montoya limestones, of Ordovician age, and the Fusselman limestone, of Silurian age. As these formations are separable throughout southern New Mexico, the name "Mimbres limestone" is no longer useful. Throughout the region the middle part of the Ordovician and the lower part of the Silurian appear to be absent.

The Ordovician succession in southern New Mexico shows everywhere uniform and very marked characteristic features. They are wonderfully distinct at the many widely scattered exposures examined by the writer, from the Franklin Mountains west to Silver City, and to the north in Cooks Range, Lake Valley, and the San Andres, Caballos, and Sacramento mountains. The El Paso limestone, at the base of the section, is in most places of unmistakable character, its conspicuous features being thin bedding, a light color on weathering, and brownish-buff reticulations on the bedding planes, caused by irregular layers of an iron-silica deposit probably due to a seaweed. This formation is overlain by dark massive limestone at the base of the Montoya; locally a thin sandstone separates the two limestones, and everywhere there is a sharp break. The upper member of the Montoya invariably consists of alternating layers of limestone and chert carrying abundant Richmond fossils.

[1] Shumard, G. G., A partial report on the geology of western Texas, p. 103, Austin, 1886.

[2] U. S. Geog. and Geol. Expl. W. 100th Mer. Rept., vol. 3, pp. 515–517, 1875.

[3] Am. Jour. Sci., 4th ser., vol. 21, pp. 392–393, 1906.

[4] U. S. Geol. Survey Prof. Paper 68, p. 226, 1910.

[5] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

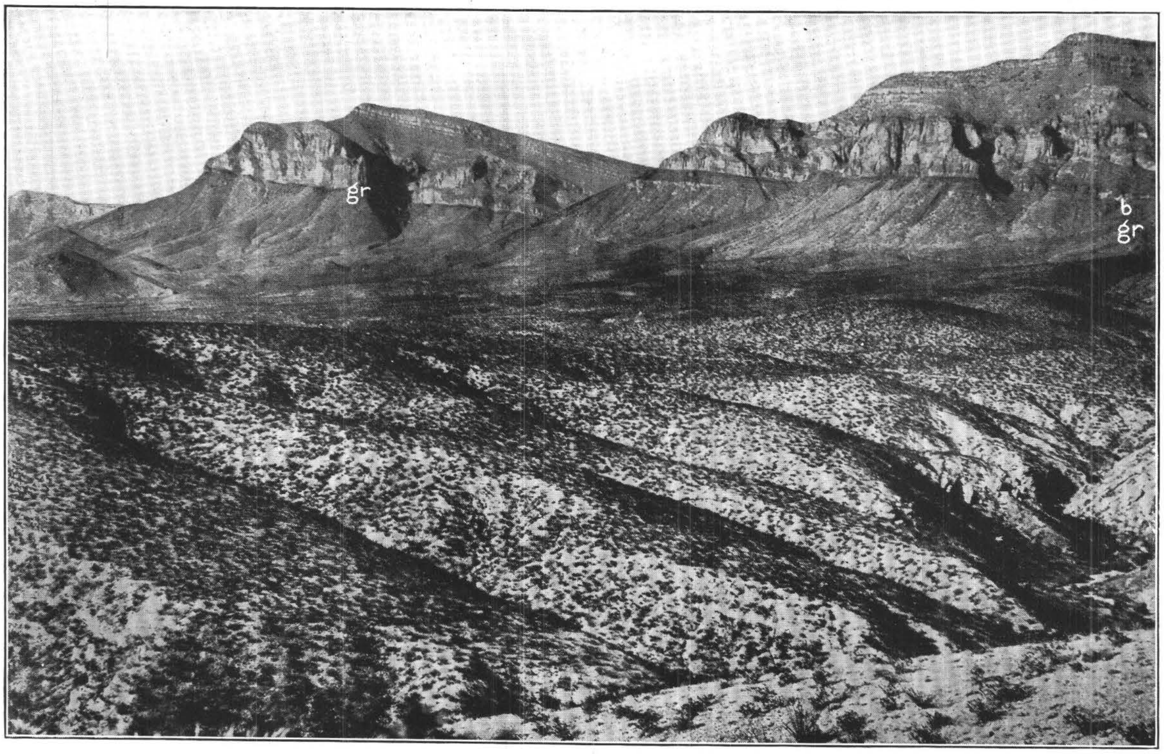
EL PASO LIMESTONE.

Franklin Mountains.—The El Paso limestone was separated from other Ordovician strata in the Franklin Mountains north of El Paso by Richardson.[6] In the type locality the formation consists of about 1,000 feet of gray limestone mostly massive but in part slabby. The lower 100 feet contains some sand and weathers brown. Where it is in contact with pre-Cambrian rocks the basal member 20 feet thick consists of round pebbles of porphyry in a limy matrix. In the middle of the formation occur thin connected nodules of brown chert in streaks parallel to the bedding, but this feature, characteristic here, was not observed in other regions. Magnesia is a general constituent in variable amount. The principal outcrop is along the eastern flank of the Franklin Mountains, where the relations are those shown in figure 3 (p. 32). Distinctive Lower Ordovician fossils were found in the formation at many places.

Florida Mountains.—The El Paso limestone is extensively exposed in the south-central part of the Florida Mountains and also on the northwestern slope of that range a short distance southwest of Deming. (See Pl. XVI, *B.*) At the latter place the thickness is about 800 feet and the lower 140 feet is darker and more massive than in other outcrops. The greater part of the formation consists of light-gray slabby dolomitic limestone with pale reddish-brown blotches over the bedding planes. There is very little chert. The upward gradation from the Bliss sandstone is well marked, and the change to the overlying Montoya limestone is abrupt. The structural relations in the southern part of the range are shown in figure 15 (p. 54).

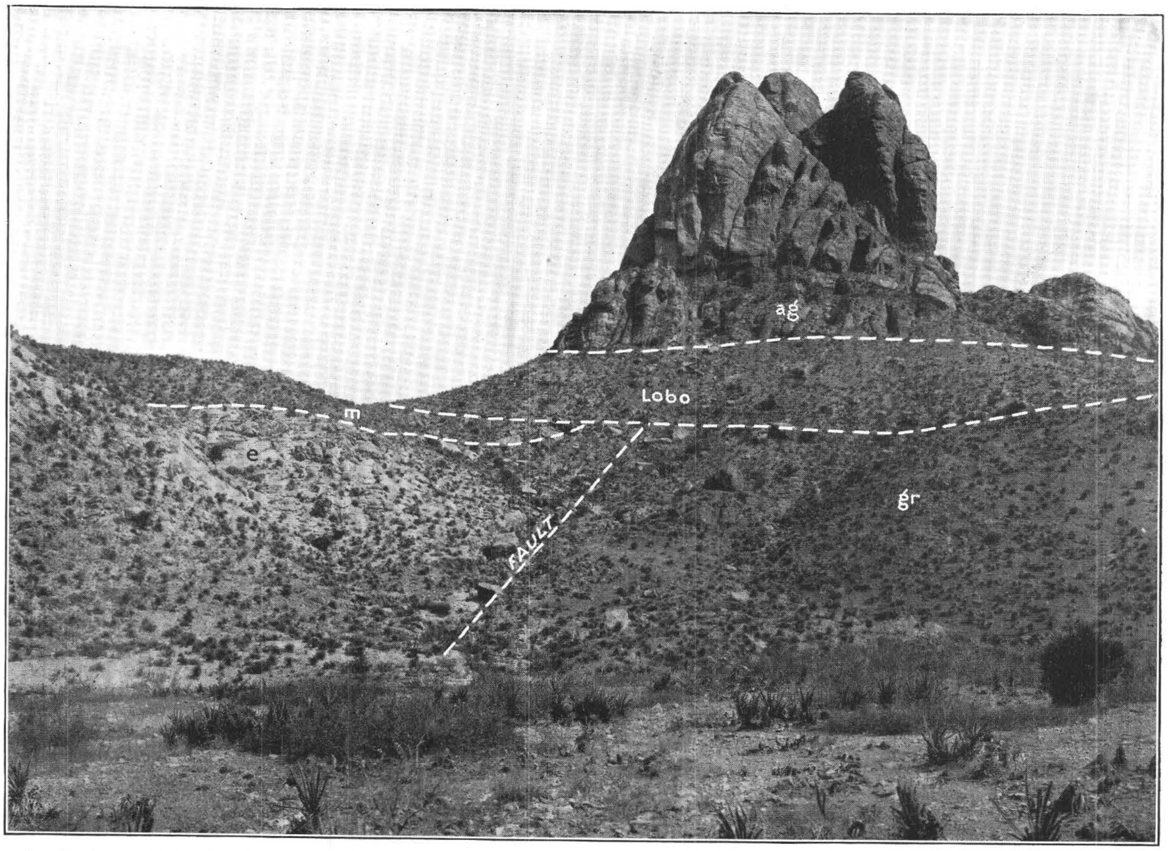
Cooks Range.—At the north end of Cooks Range and in Fluorite Ridge, at its south end, the El Paso is well exhibited. The northern exposures show 600 feet of beds between the Bliss sandstone and the sandstone member at the base of the Montoya. The relations near

[6] U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.



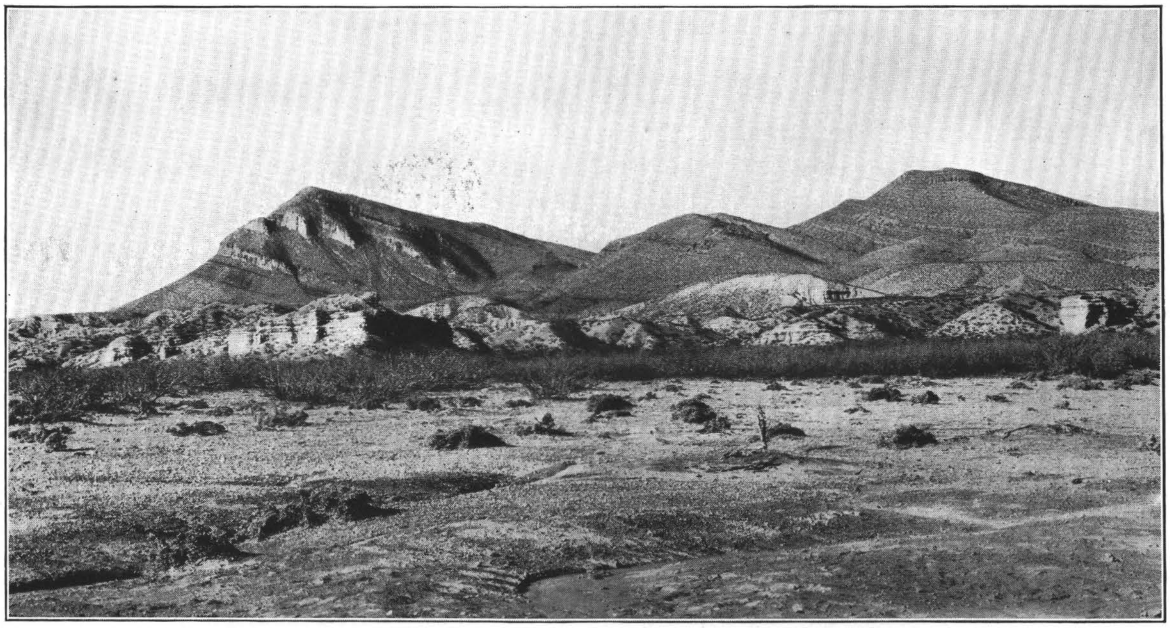
A. WEST FACE OF CABALLOS MOUNTAINS NEAR APACHE CANYON, SIERRA COUNTY, N. MEX.

Looking northeast. gr, Granite; b, Bliss sandstone.



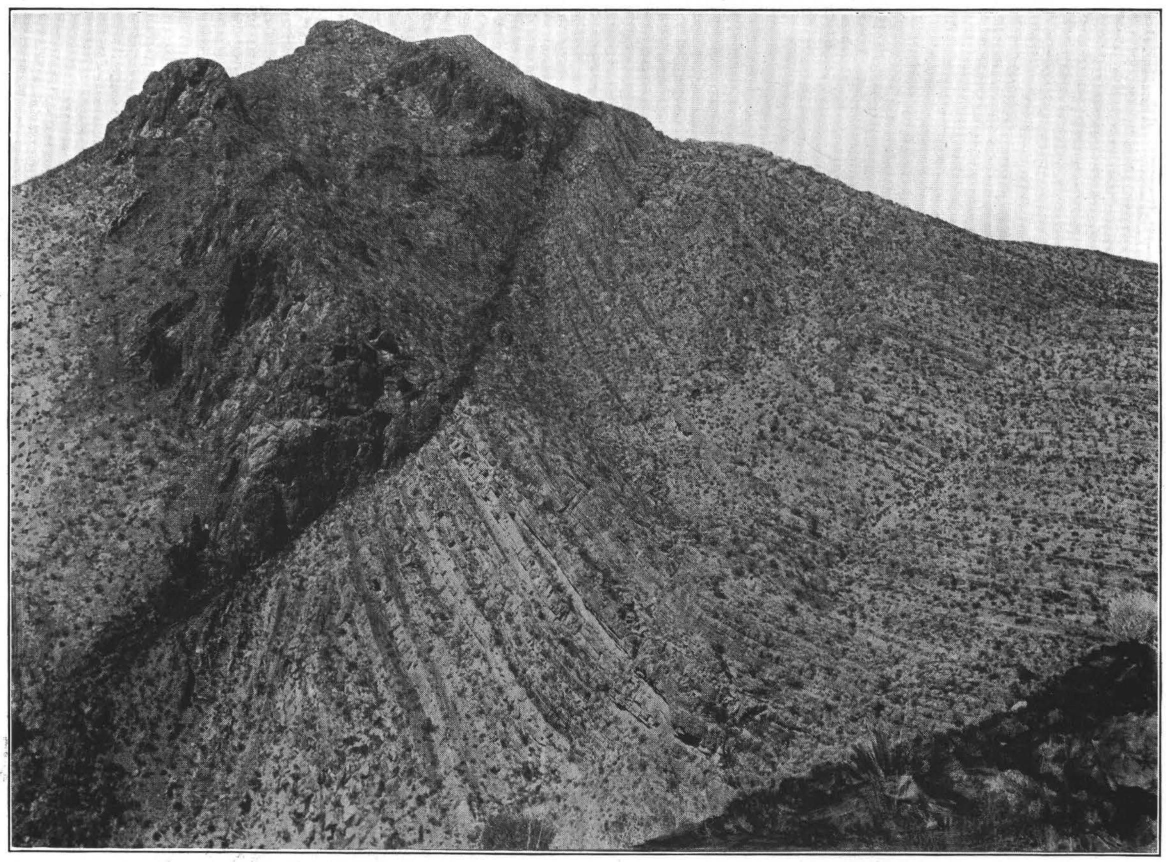
B. PALEOZOIC ROCKS ON GRANITE AT CAPITOL DOME, FLORIDA MOUNTAINS, LUNA COUNTY, N. MEX.

Looking northeast. ag, Agglomerate; m, Montoya limestone; e, El Paso limestone; gr, granite.



A. SIERRA CUCHILLO WEST OF PALOMAS SPRINGS, N. MEX.

Looking northwest. Granite, Bliss sandstone, Ordovician and Pennsylvanian limestones.



B. FAULT IN LIMESTONE AT PALOMAS GAP, CABALLOS MOUNTAINS, SIERRA COUNTY, N. MEX.

Looking north.

Cooks are shown in figure 4. In Fluorite Ridge, 12 miles north of Deming, the beds are so crushed and faulted that only about 400 feet of the El Paso limestone appears.

Snake Hills.—The east end of the Snake Hills, a small range rising out of the desert a few miles southwest of Deming, consists of El Paso limestone showing distinctive features and fossils. The base of the formation is not exposed, but to the west, as shown in figure 6 (p. 37), its top passes under the Montoya limestone with marked unconformity.

Victorio Mountains.—The knob constituting the northeastern member of the Victorio Mountains presents extensive exposures of El Paso limestone, 600 to 700 feet thick at least, dipping south toward a mass of Montoya limestone which constitutes much of Mine Hill. The El Paso beds present the usual slabby character, weather to a light color, and show abundant pale-brown reticulations on the bedding planes.

Klondike Hills.—The Klondike Hills, 12 miles south of the Victorio Mountains, consist mainly of the El Paso and Montoya limestones, the former mostly in the western part of the ridge as shown in figure 5. At one place the underlying Bliss sandstone is exposed. The thickness is about 650 feet and all the usual features are presented. At the top there is an unconformable overlap of sandy beds at the base of the Montoya limestone, but the attitude of both formations is practically the same.

Silver City region.—In the vicinity of Silver City the El Paso limestone is mostly gray or grayish blue and in part magnesian. It appears to grade upward from the Bliss sandstone, the lowermost 100 feet becoming progressively less sandy. The lower and middle parts are slabby, and the slabs have the characteristic mottled surface seen in other areas. In the upper part the formation is more massive and contains considerable chert. The total thickness is about 900 feet. The formation has nearly the same distribution as the Bliss sandstone in Lone Mountain in the Silver City Range, northwest of Silver City, and in an area north of Bear Mountain.

Caballos Mountains.—The El Paso limestone is a prominent feature in the great section along the west front of Caballos Mountains, where it has the relations shown in figure 8 (p. 39) and Plate XVI, *A*. The Bliss sandstone grades upward into the El Paso, and above it are typical cherty beds of the Montoya limestone. It constitutes 300 or 400 feet of the lower part of the limestone cliffs, and the rocks present the same characteristics that are seen in the Franklin Mountains and Luna County. However, Lee [1] notes a section 8 miles south of Shandon in which it consists of 200 feet of cherty limestone, overlain unconformably by 500 feet of cherty limestone (Montoya and later). Characteristic fossils were found by Lee in both formations.

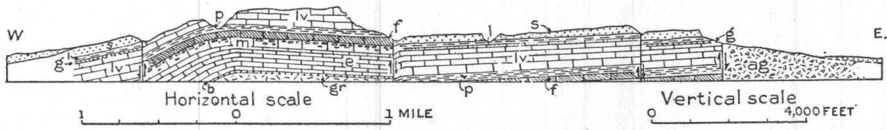


FIGURE 4.—Section across Cooks Range at Cooks, N. Mex. gr, Granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone; p, Percha shale; lv, Lake Valley limestone; g, Gym limestone; l, Lobo formation; s, Sarten sandstone (Cretaceous); ag, agglomerate.

Lake Valley district.—The lower 150 feet of the limestone in Quartzite Ridge, on the west side of the Lake Valley mining district, is made up of El Paso beds. On the east these beds are overlain by 20 feet of hard sandstone at the base of the Montoya limestone, and on the west they are cut off by igneous rocks. The relations are shown in figure 10 (p. 44). The rocks are the highly characteristic slabby limestone, weathering to a light color and having most of the bedding planes stained with brownish reticulations.

Mimbres Mountains.—Gordon and Graton [2] report an extensive section of Ordovician rocks in the Mimbres Mountains near Kingston. At this place the lower division doubtless represents the El Paso limestone, but it is mostly a blue and white marble, and the distinctive fossils were not found. On Carbonate Creek the basal limestone is exposed in contact with sandstone of Cambrian age (Bliss).

[1] Am. Jour. Sci., 4th ser., vol. 26, p. 180, 1908.
[2] Idem, vol. 21, p. 392, 1906.

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San Andres Mountains.—The El Paso limestone extends continuously along the east face of the San Andres Mountains, from the igneous contact near Organ to the north end of the range. Its relations are shown in figures 9 (p. 42) and 11 (p. 45). (See also Pls. XV and XVIII, *B*.) Its thickness is about 300 feet at the south but gradually diminishes northward from San Andres Canyon to 160 feet on Lostman Canyon, 125 feet at Rhodes Canyon, and 80 feet in Lava Gap. In Sulphur Canyon, which is nearly due west of Tularosa, it is 160 feet. The limestone lies on or grades upward from the Bliss sandstone and has characteristic slabby structure with the slabs weathering light gray and having surfaces mottled with reticulations of brownish-buff markings, probably due to a seaweed. Locally the medial beds are massive and less distinctive in appearance. Fossils were found at many places. The relations 18 miles northeast of Las Cruces and in Lava Gap are shown in figure 9 (p. 42).

The formation is conspicuous in Rhodes Canyon, a few miles south of Salinas Peak (see Pl. XVIII, *B*), in about latitude 33° 10′, where it is separated from the granite by only 6 feet of sandstone, and this relation continues to the north end of the range.

Sacramento Mountains.—The basal limestone in the west front of the Sacramento Mountains from Alamo Canyon to a point near Grapevine Canyon is typical El Paso, showing all the features distinctive in other areas, including fossils. The relations are shown in figures 13 (p. 50) and 14 (p. 51). The thickness is 250 feet, but except in a small area near the mouth of Agua Chiquita Canyon the basal beds are covered by talus. In Alamo Canyon 125 feet of the El Paso is well exposed in the cliff on the north side of the creek, capped by thin sandstone and dark massive limestone at the base of Montoya, as shown in Plate XIX, *A* (p. 37). At Dog Canyon 200 feet is exposed. The rocks are slabby limestones, weathering to a light tint, and in part the bedding planes show brownish-buff reticulations. The medial beds are more massive than at most other localities.

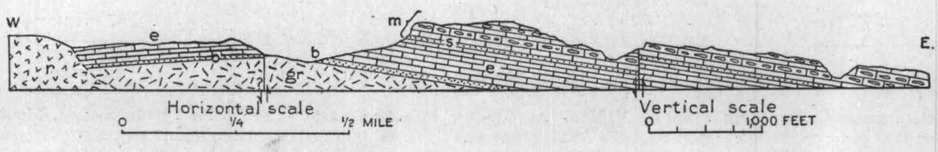
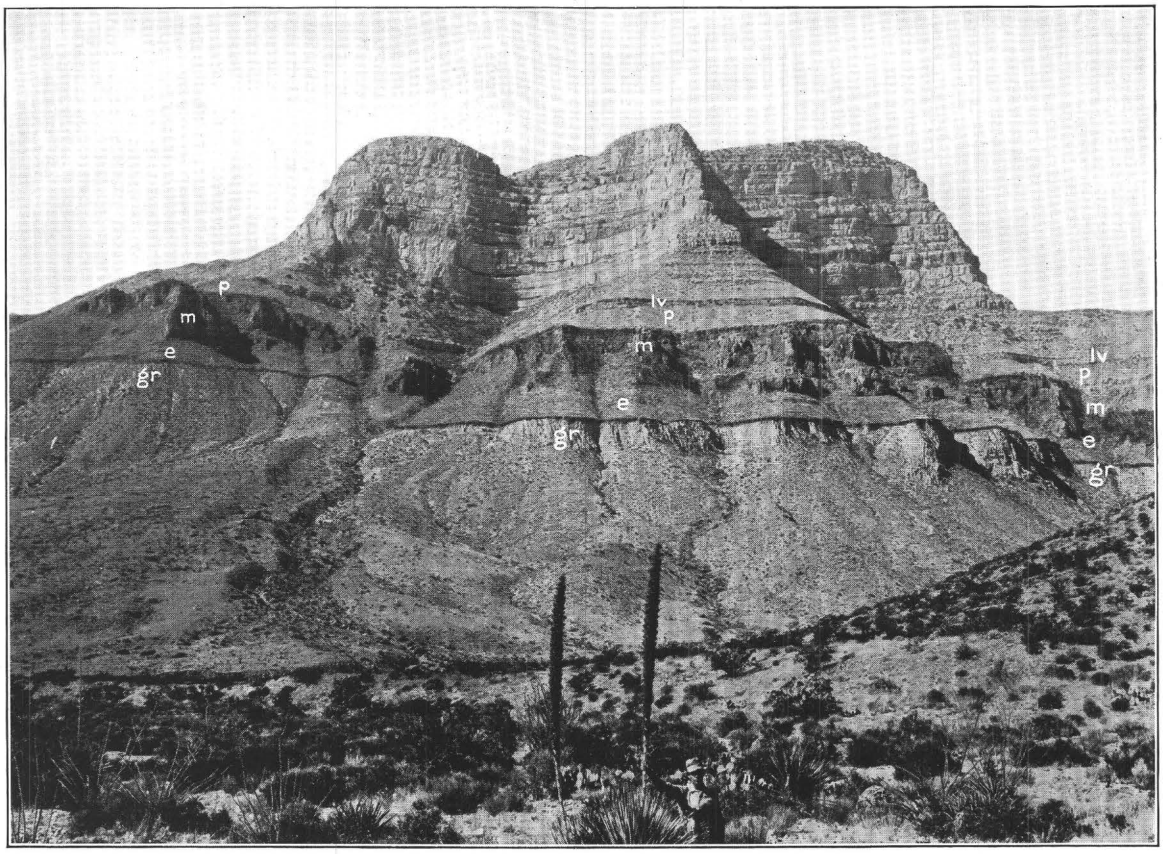


FIGURE 5.—Section through the Klondike Hills, Luna County, N. Mex. gr, Granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone with sandstone (s) at base; r, rhyolite.

Fossils.—Fossils occur in the medial and upper beds of the El Paso limestone at all localities, but they are not numerous either individually or in species. A small coiled shell, *Ophileta*, is by far the most common form. Richardson[1] found the fauna very meager in the Franklin Mountains but collected *Ophileta* and other gastropods, and also cephalopods related to *Piloceras* and *Cameroceras*. Higher beds near Deming have yielded a form resembling *Dalmanella pogonipensis*, *Strophomena* near *S. nemea*, *Hormotoma* sp., and *Trochonema*. In the Silver City region the fossils collected by Paige[2] were *Calathium anstedi*, *Dalmanella* cf. *D. wempeli*, *Protowarthia* cf. *P. rossi*, *Bucanella nana?*, *Lophospira* sp., *Raphistoma trohiscum?*, *Eccyliopterus* sp., *Maclurea* cf. *M. oceana*, *Holopea* sp., *Piloceras* cf. *P. wortheni*, *Cameroceras*, and the usual *Ophileta*. In the Caballos Mountain section Lee[3] collected *Ophileta* cf. *O. complanata* and *Hormotoma* cf. *H. artemesia*. In the exposure in Bennett Canyon in the San Andres Mountains, 15 miles northeast of Las Cruces, were obtained *Polygyrata rotuliformis?* and an indeterminable cystid. In the canyon 3 miles south of San Andres Peak were collected *Calathium* cf. *C. anstedi*, *Polygyrata trohiscus*, and *Piloceras* sp. In San Andres Canyon *Calathium* cf. *C. anstedi* was found and this distinctive fossil was observed throughout the exposures in the San Andres Range. From the cliff in Alamo Canyon, in the Sacramento Mountains, were collected *Calathium* cf. *C. anstedi* and *Dalmanella pogonipensis*.

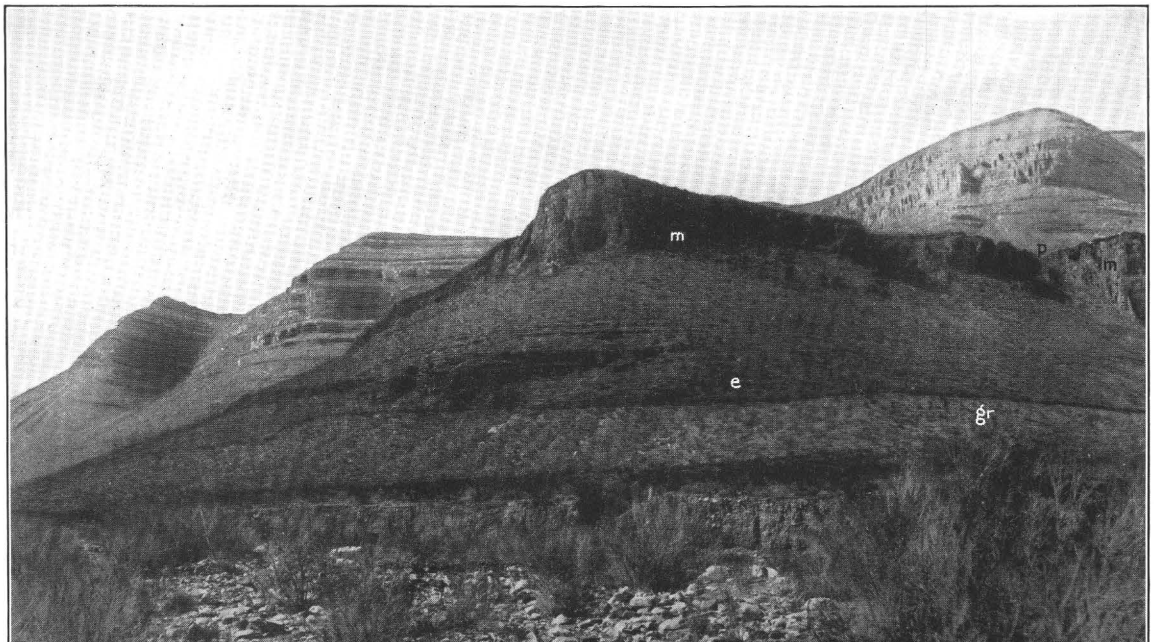
Age and correlation.—The fossils in the El Paso limestone are regarded by Ulrich and Kirk as Lower Ordovician, representing late Beekmantown time. It is possible that in some areas strata of early Chazy age have been included with the El Paso. On this basis the

[1] U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), p. 4, 1909.
[2] Idem, Silver City folio (No. 199), p. 4, 1916.
[3] Am. Jour. Sci., 4th ser., vol. 26, p. 180, 1908.



A. LIMESTONES FROM ORDOVICIAN TO PENNSYLVANIAN ON GRANITE, SHEEP MOUNTAIN, SAN ANDRES MOUNTAINS, SOCORRO COUNTY, N. MEX.

Looking south. lv, Lake Valley limestone; p, Percha shale; m, Montoya limestone; e, El Paso limestone; gr, granite.



B. EAST FACE OF SAN ANDRES MOUNTAINS AT RHODES CANYON, SOCORRO COUNTY, N. MEX.

p, Percha shale; m, Montoya limestone; e, El Paso limestone on Bliss sandstone; gr, granite.

highly cherty rock at the crest of the ridge. In the Klondike Hills (see fig. 5, p. 36) the basal member is a dark-gray sandstone, 6 to 8 feet thick, lying on the slightly irregular surface of the El Paso limestone. It is overlain by 30 to 40 feet of dark massive sandy limestone, capped as in other areas by a succession including two or three thick cherty members with limestone layers that contain many fossils, listed on page 40.

Silver City region.—The first observers of the Montoya limestone in southwestern New Mexico were Howell and Gilbert,[1] who in 1873 collected "Cincinnati" fossils from limestones near Silver City and in the Santa Rita Range.

In the Silver City area the Montoya limestone shows its characteristic features and has a thickness of about 300 feet. Its relations in the ridge west of Silver City are shown in

cliff yielded distinctive fossils. Between this cherty member and the limestone containing Pennsylvanian fossils is 500 feet of limestone whose age was not determined. Lee[2] also reports outcrops of the cherty limestone in the Sierra Cuchillo, near Palomas Springs, west of the Rio Grande (see Pl. XVII, *A*), and in the north slopes of Robledo Mountain, 15 miles south of Rincon, but the fossils collected at the latter locality appear more probably to be Fusselman.

Lee[2] reports that the cherty limestone carrying distinctive Montoya fossils is exposed in the south end of the Caballos Mountains, 8 miles south of Shandon, but the rocks are so faulted and crushed that it is difficult to make a section. Below these cherty beds is limestone containing El Paso fossils. In exposures along the same line of outcrop, about 6 miles west of Rincon, 300 feet of cherty limestone exposed at

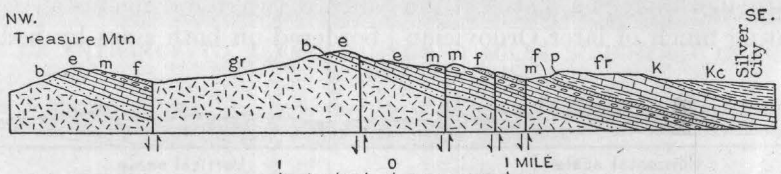


FIGURE 7.—Cross section showing relations of Paleozoic rocks in the Silver City region, N. Mex. (After Paige.) gr, Granite, etc.; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone; p, Percha shale; fr, Fierro limestone; K and Kc, sandstone and shales of Cretaceous age.

figure 7. Although most of the formation is limestone, it contains a large amount of chert, mainly in thin beds interlaminated with the limestone. One member of this character, 80 feet thick, begins about 40 feet above the top of the El Paso limestone, from which it is separated by magnesian limestone. The base is not distinct. Above the thick chert members are alternating thin beds of smooth whitish limestone and massive beds of blue limestone with cherty layers at intervals. Fossils of the Richmond fauna are abundant, especially in two layers, one near the base and the other near the top of the formation.

Caballos Mountains and adjoining regions.—In the Caballos Mountains, southwest of Engle, the Montoya limestone is extensively exposed. Lee[2] has given many details of its features, with a list of fossils determined by Ulrich. In a section 3 miles north of Shandon, shown in figure 8 and Plate XVI, *A*, the cherty limestone near the top of the first great limestone

the foot of the cliffs yielded a number of Montoya fossils. Apparently here, as elsewhere, the Montoya lies directly on the El Paso limestone, no intermediate Ordovician rocks being present.

Lake Valley.—Lying on the El Paso limestone in the west front of Quartzite Ridge, west of Lake Valley, is 20 feet of gray hard sandstone, above which is 25 feet or more of cherty and brecciated limestone that doubtless represents the Montoya. No fossils were found here. The relations are shown in figure 10 (p. 44). Next above is 80 feet of compact limestone that weathers to a very light color and is similar to beds which are tentatively included in the Fusselman in other uplifts. Apparently it does not contain fossils.

Mimbres Mountains.—According to Gordon and Graton,[3] the Ordovician limestones outcrop at intervals along the east slopes of the Mimbres Mountains from the vicinity of Kingston to and beyond Hermosa. From Hillsboro southward the upper siliceous beds,

[1] U. S. Geog. and Geol. Expl. 100th Mer. Rept., vol. 3, pp. 515-517, 1875.
[2] Am. Jour. Sci., 4th ser., vol. 26, pp. 181-182, 1908.
[3] Am. Jour. Sci., 4th ser., vol. 21, p. 392, 1906.

including the silicified portions of the overlying shale, appear at many places in irregular reefs projecting above the surface of the ground or as ledges capping escarpments. In the canyon of the Rio Percha, about a mile east of Hillsboro, the "upper limestone" is overlaid unconformably by a bed of red and white conglomeratic quartzite 6 to 10 feet thick, containing nodules that are possibly phosphatic. This stratum is overlain by a reddish-brown compact siliceous rock which may be a secondary deposit. Some of the strata carry Richmond fossils, but the limit of beds that should be classed as Montoya is not indicated.

San Andres Mountains.—The Montoya limestone is a prominent feature in the great eastward-facing escarpment of the San Andres Mountains. It appears on the north side of the igneous mass of the Organ Mountains and extends continuously northward to the north end of the range, where it thins out. It lies on the El Paso limestone throughout this area, and it is overlain by the Fusselman limestone to the south, as in the Franklin Mountains, and by the Percha shale north of the latitude of Tularosa. The principal features of thickness, stratigraphy, and relations to other formations are shown in figure 11 (p. 45). Some features are also shown in figure 9 (p. 42).

Two members are everywhere present—an upper member of alternating thin beds of chert and limestone, averaging about 75 feet in thickness but thinning to 30 feet at Hays Gap; and a lower member of very massive dark-colored limestone, about 100 feet thick, except north of Rhodes Canyon, where it thins gradually. The lower member includes locally at its base a sandstone that lies on the slightly uneven surface of the El Paso beds. This bed is 9 feet thick in the slopes 3 miles south of San Andres Peak and 15 feet thick in San Andres Canyon. At all places there is a sharp break at the base of the Montoya. The Montoya limestone ledge forms a high cliff of dark color and in places makes a shelf or bench along the mountain front, as shown in Plates XV and XVIII, *B*.

Sacramento Mountains.—The dark ledges of Montoya limestone are a prominent feature in the great series of limestones exposed in the higher part of the Sacramento uplift from the vicinity of Alamo Canyon to a point near Grapevine Canyon. The relations are shown in figures 14 (p. 51) and 15 (p. 54).

The two members that occur in the San Andres and Franklin mountains and other uplifts present characteristic features. The upper one, 60 feet thick, consists largely of alternating thin beds of chert and limestone with abundant Richmond fossils. The lower member is a dark-colored very massive limestone which crops out as a high cliff; its thickness is 75 feet at Dog Canyon and 120 feet at Alamo Canyon. At the latter place (see Pl. XIX, *A*) its base is gray sandstone and it is separated from the underlying El Paso beds by an abrupt change in character of material and apparently there is a slight channeling of the surface of the older formation.

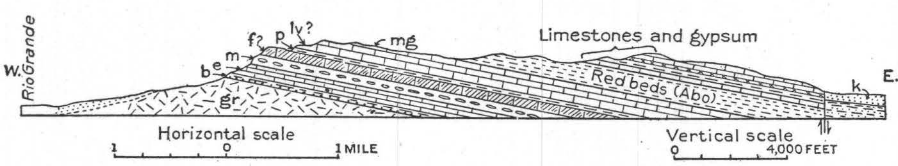


FIGURE 8.—Section across the Caballos Mountains, southwest of Engle, N. Mex. gr, Granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone (?); p, Percha shale (?); lv, Lake Valley limestone (?); mg, limestone of Magdalena group; c, Cretaceous sandstone.

Fossils.—The fossils found in the Montoya limestone in the Franklin Mountains, north of El Paso, were identified by E. O. Ulrich. The fossils in the lower part comprised *Receptaculites* near *R. oweni*, *Maclurina manitobensis*, and *Hormotoma major* (?). The fossils in the upper part are as follows:

Streptelasma rusticum.
Hemiphragma imperfectum.
Monotryprella quadrata.
Strophomena flexuosa.
Leptaena unicostata.
Dinorthis subquadrata.
Platystrophia acutilirata.
Rhynchotrema capax.
Orthis near O. davidsoni.
Plectorthis whitfieldi.
Parastrophia divergens.

These fossils are all of Richmond age. The fossils from outcrops in Luna County, as identified by Mr. Ulrich, comprise the following:

Eurydictya cf. E. montifera.
Dinorthis subquadrata.
Plectorthis whitfieldi.
Herbertella occidentalis.
Dalmanella cf. D. meeki.
Dalmanella near D. jugosa.
Platystrophia acutilirata var.
Strophomena cf. S. subtenta.
Rafinesquina loxorhytes.
Leptaena unicostata.
Plectambonites saxea.
Rhynchonella anticostiensis.
Rhynchotrema capax
Rhynchotrema perlamellosa.
Zygospira recurvirostris.
Streptelasma rusticum.
Cyrtodonta sp.
Vanuxemia sp.
Bumastus sp.

These forms are characteristic of the Richmond fauna that occurs in many parts of the Rocky Mountain region. No fossils were found in the basal dark massive member.

In the Caballos Mountains Lee [1] collected *Rafinesquina* cf. *R. kingi*, *Plectambonites saxea*, *Plectambonites* n. sp., *Favosites asper*, *Zygospira recurvirostris*, *Rhynchotrema capax*, *Calapoecia canadense*, and *Platystrophia dentata* var.

Many fossils were collected by Paige [2] in the Silver City area near the base and near the top of the formation. The following were determined by E. O. Ulrich:

Streptelasma.
Columnaria alveolata var.
Columnaria vicina.
Tetradium sp. nov.
Favosites asper.
Favosites cf. F. asper.
Stromatocerium huronense.
Dicranopora cf. D. fragilis.
Plectorthis kankakeensis.
Dalmanella tersa (?).
Dinorthis sp.
Dinorthis subquadrata.
Hebertella sinuata.
Platystrophia n. sp., near P. acutilirata
Strophomena sp.
Rhynchotrema capax.
Rhynchotrema anticostiensis.
Rhynchonella neenah.
Ctenodonta cf. C. coata.
Conradella sp.
Lophospira cf. L. perangulata.
L. medialis.

[1] Am. Jour. Sci., 4th ser., vol. 26, p. 181, 1908.
[2] U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), p. 4, 1916.

From the basal beds were collected *Eridotrypa mutabilis* (?), *Batostoma* cf. *B. varium*, *Dalmanella testudinaria* var., and *Zygospira recurvirostra* var.

In the vicinity of Hillsboro Gordon [3] obtained some corals identified by Ulrich as *Columnaria alveolata*, *Favosites asper* (late Ordovician variety), and *Stromatocerium* cf. *S. pustulosum*, regarded as Richmond.

In the San Andres Range fossils were collected at several localities. One ledge of cherty limestone in Sulphur Canyon yielded the following, determined by Edwin Kirk:

Bythopora gracilis.
Bythopora cf. B. meeki.
Bythopora striata.
Monotrypella quadrata.
Eridotrypa sp.
Dalmanella sp.
Zygospira recurvirostris (Richmond variety).
Calymene.

In the canyon 3 miles south of San Andres Peak *Dinorthis subquadrata* was found, and in Cottonwood and Rhodes canyons were collected numerous specimens of *Dalmanella testudinaria* var.

Along the west front of the Sacramento Mountains fossils are abundant in the cherty layers of the upper member and many corals are scattered through the lower massive dark limestone. From the lower member near Dog Canyon were obtained *Halysites gracilis*, *Streptelasma* sp., *Receptaculites* sp., and *Rhynchotrema capax*. The cherty member at this locality yielded abundant *Dalmanella* cf. *D. corpulenta*.

Age and correlation.—Most of the fossils collected in the Montoya limestones are species common in the Richmond of the Mississippi Valley and indicate that the formation comprises two, or possibly three, representatives of the Richmond epoch. The lowest may be correlated with the Fernvale of the Mississippi Valley, the lower part of the Bighorn dolomite of Wyoming, the Whitewood limestone of the Black Hills, and the middle of the Fremont limestone of eastern Colorado. The upper part of the Montoya may be correlated with some portion of the upper Bighorn and probably with the upper part of the Fremont and with the Stony Mountain limestone of Manitoba. It is not represented in the Black Hills and apparently not in the Mississippi Valley. The

[3] U. S. Geol. Survey Prof. Paper 68, p. 227, 1910.

Montoya is equivalent to part of the Lone Mountain limestone of Nevada. Apparently the formation is absent in Arizona.

SILURIAN SYSTEM.

FUSSELMAN LIMESTONE.

Franklin Mountains and eastward.—The existence of rocks of Silurian age in New Mexico was discovered by Gordon and Graton,[1] who found fossils at Silver City in 1905.[1] Their presence in the Franklin Mountains north of El Paso was announced by Richardson [2] in 1904, in a formation which he later designated the Fusselman limestone.[3] It is found that this limestone is separable in many parts of southern New Mexico.

In its type locality the Fusselman limestone is estimated to be about 1,000 feet thick and is of considerable topographic prominence, capping the range for several miles and appearing in a number of detached knobs. It also crops out in the Hueco Mountains, 3 miles east of El Paso. The rock is mostly a massive light-colored magnesian limestone. Fossils are scarce on the whole, but they abound at a few horizons, especially a characteristic *Pentamerus* that indicates upper Niagara age.

The upper limit of the Fusselman is indistinct, and a thin representative of the Devonian or Mississippian may possibly be present at the top. In an exposure 5½ miles west of south from Hueco Tanks, 30 miles northeast of El Paso, white limestone containing Silurian fossils is overlain by 100 feet of thin-bedded gray limestone in which no fossils were found. This formation dips much more steeply than the one below it. Overlying it with the same steep dip are beds that carry Pennsylvanian fossils. In the Hueco Mountains a similar thin-bedded gray to purplish limestone that contains some chert and weathers buff separates the beds containing Silurian and Pennsylvanian fossils and dips at a less angle than the Silurian. On the northwest flank of the Franklin Mountains, however, thin-bedded cherty limestone containing Pennsylvanian fossils overlies the Fusselman without discordance of dip. In the Van Horn area, farther east in Texas, Silurian, Devonian, and Mississippian representatives are absent.

[1] Am. Jour. Sci., 4th ser., vol. 21, p. 394, 1906.
[2] Texas Univ. Mineral Survey Bull. 9, p. 31, 1904.
[3] Am. Jour. Sci., 4th ser., vol. 25, pp. 479-480, 1908.

The Fusselman limestone lies on the Montoya limestone without conspicuous unconformity; at one locality 2 miles north of El Paso its lower layers carry small pebbles of black limestone similar to some that occurs in certain beds of the Montoya.

Cooks Range.—The Fusselman limestone is well developed in the Cooks Peak mining district, where it is the principal rock containing the ores of lead, silver, and zinc. It crops out extensively along the road from Cooks to the mountain top and along the slopes 2 miles to the north. It is a massive gray limestone of exceptionally hard, compact texture, but its upper part is cavernous in places, and in the cavities, a short distance below the Percha shale, most of the rich ore pockets have been found. In this region the thickness of the formation is about 200 feet. The distinctive *Pentamerus* occurs in places. The limestone appears in the south end of the range, near the fluorspar mines, but its relations are obscure owing to igneous intrusions and faults.

Florida Mountains.—In places in the southern half of the Florida Mountains the Fusselman limestone is absent in the varied overlaps. The Percha shale apparently is also absent, and the Fusselman limestone where present is overlain by the Gym limestone.

Victorio Mountains.—The Montoya limestone in Mine Hill is overlain by the Fusselman limestone, which constitutes the summit and west side of the hill. The silver ore deposits occur in this limestone, as in the Cooks Peak district. Its thickness appears to be somewhat more than 100 feet, but the top may be eroded. In other ridges to the west it is cut off by faults and also hidden by overlapping Gym limestone.

Silver City region.—In the Silver City region the Fusselman limestone consists of 30 to 40 feet of gray limestone and dolomitic beds, not plainly separated from the underlying Montoya. In its upper part there are abundant casts of the characteristic *Pentamerus*.

Caballos Mountains.—Above the massive cherty limestone with Montoya fossils in the Caballos Mountains Lee [4] found 500 feet of white to brown limestone, cherty in places, from which no fossils were obtained. These beds extend to the base of the limestone that carries Pennsylvanian fossils, and doubtless they include the Fusselman and possibly also

[1] Idem, vol. 26, p. 181.

strata of Devonian and Mississippian age. In the slopes 8 miles south of Shandon 300 feet of black shale, probably the Percha, is present in the section, and very likely it is, as usual, underlain by the Fusselman.

Robledo Mountain.—In a small exposure of cherty limestone not far below Pennsylvanian limestone on the northern slope of Robledo Mountain, 5 miles south of Rincon, Lee[1] obtained *Lophospira, Trochus?, Bucania?, Trochonema, Eotomaria,* and a pentameroid shell, all suggestive of Silurian age and if so indicating the Fusselman limestone.

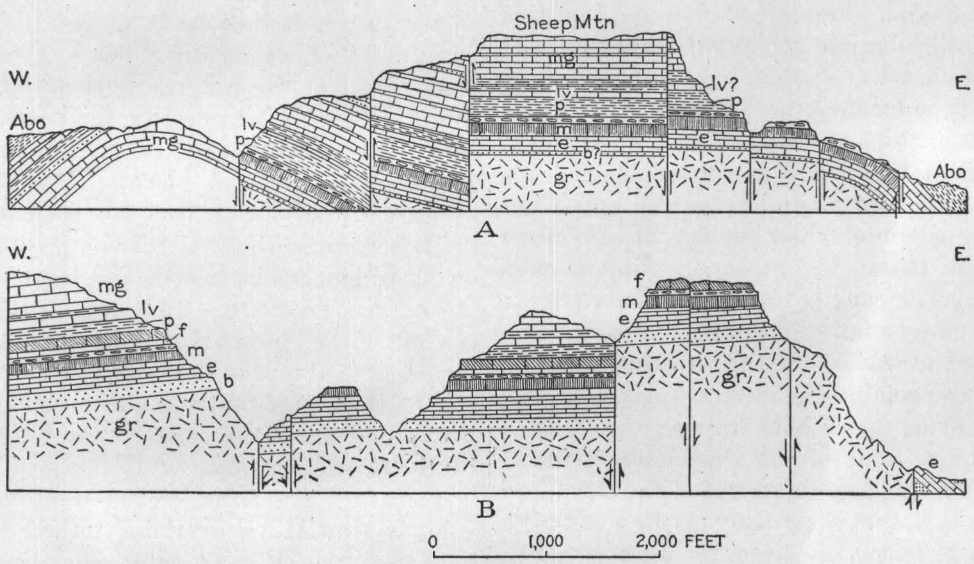


FIGURE 9.—Sections across the San Andres Mountains, Socorro and Dona Ana counties, N. Mex. A, Section across Sheep Mountain at Lava Gap; B, section southwest of San Nicolas Spring, in latitude 32° 35′ N.; gr, granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone; p, Percha shale; lv, Lake Valley limestone; mg, limestone of the Magdalena group.

Lake Valley.—It was found that the limestones underlying the Percha shale in the Lake Valley area (see fig. 10, p. 44) include 200 feet or more of the Fusselman limestone, which contains many distinctive fossils. At the base, overlying beds that are probably Montoya, there is an 80-foot bed of massive limestone which weathers to light tint, and which yielded no fossils but is tentatively regarded as the Fusselman, as in other regions. Next above are 40 feet of cherty beds, somewhat like the Montoya in character but carrying distinctive fossils. These beds grade upward into 80 feet or more of massive limestone of light color, constituting the summit of Quartzite Ridge for some distance and extending down its east slope to the Percha shale in the valley. In cherty layers on this slope distinctive fossils were collected. The upper member is probably the 12 feet of pink limestone referred to by Gordon,[2] who obtained from it some fragments of corals regarded as Silurian by Ulrich. According to Keyes[3] this limestone is dark colored and compact but contains crevices filled with red clay which give it a pink appearance.

Mimbres Mountains.—It appears probable from the statements of Gordon[4] that the Fusselman limestone is present, at least in places, in the Kingston-Hillsville region, but he reports no fossils. The statement that the "footwall lime" at Kingston and Tierra Blanca is similar to the ore-bearing sandstone in the Cooks mining district is highly suggestive in this connection.

San Andres Mountains.—The Fusselman limestone is a conspicuous feature in the limestone succession along the east front of the San Andres Mountains from a point near Organ, where it is cut off by igneous rocks, to a point 2 or 3 miles north of Sulphur Gap, where it thins out. Some of its relations are shown in figures 9 and 11. The thickness ranges from 220 feet in the southern part of the range to 120 feet in the middle part and at Sulphur Gap, and there is rapid thinning toward its north-

[1] Am. Jour. Sci., 4th ser., vol. 26, p. 185, 1908.

[2] U. S. Geol. Survey Prof. Paper 68, pp. 227, 277, 1910.

[3] Keyes, C. R., Genesis of the Lake Valley, New Mexico, silver deposits: Am. Inst. Min. Eng. Trans., vol. 39, p. 146, 1909.

[4] U. S. Geol. Survey Prof. Paper 68, p. 227, 1910.

ern termination. The formation comprises two members—an upper bed of hard dark-colored massive limestone, marked by a cliff at most places, and a lower member of fine-grained limestone, most of which weathers nearly white. The upper member contains distinctive fossils, but the lower one has yielded no fossils and is arbitrarily placed in the formation because of its distinctness from the underlying cherty beds, which are characteristic of the upper part of the Montoya. The massive bed gives rise to a shelf at the base of the slope of the overlying Percha shale. Its thickness is 80 feet in the southern part of the range, but it gradually thins northward to 40 feet in Lostman Canyon, 30 feet in Hembrillo Canyon (see Pl. XV, *A*), and 25 feet in Sulphur Gap. The lower limestone is 140 feet thick in the south end of the range, but it thins somewhat north of San Andres Peak. It is nearly 100 feet thick in Sulphur Gap but thins out and disappears in slopes north of the gap. In places some of its beds are soft and earthy, as in Lostman Canyon, but most of it is a fine-grained, compact dark-gray rock that weathers to very light gray or nearly white so that it is conspicuous in all outcrops.

Sacramento Mountains.—The Fusselman limestone makes a prominent ledge along the east front of the Sacramento Mountains from Alamo Canyon to a point near Agua Chiquita Canyon. Its disappearance to the north and south is due to the downward pitch of the anticline that brings it to the surface. (See fig. 14, p. 51.) The thickness ranges from 105 to 130 feet; the maximum is reached in Alamo Canyon. (See Pl. XIX, *A*, p. 37.) As in the San Andres Mountains and other uplifts, the formation comprises two members—an upper one, about 50 feet thick, of hard dark limestone carrying distinctive fossils, and a lower one of compact, fine-grained gray limestone that weathers nearly white, and is 60 feet thick in Dog Canyon and 85 feet thick in Alamo Canyon. The lower member yielded no fossils, but is arbitrarily included in the formation because of its unlikeness to underlying distinctively cherty beds at the top of the Montoya limestone. It constitutes a steep light-colored slope below the dark cliff of limestone of the upper member of the formation. This cliff is well shown in Plate XIX, *A*.

Fossils and correlation.—In general fossils are rare in the Fusselman limestone, but at some localities a few of the beds yield abundant remains. The most common and characteristic form is a *Pentamerus*, but many corals occur at some places.

The fossils found by Richardson [1] in the Franklin Mountains included *Amplexus*, *Favosites*, and numerous casts of *Pentamerus*, all indicative of Niagara age. The same *Pentamerus* is abundant in the upper beds near Cooks and Silver City. On the south side of Mine Hill, in the Victorio Mountains, numerous corals were collected, including *Heliolites megastoma*, *Favosites* cf. *F. venustus*, *Cyathophyllum* cf. *C. radicula*, *Halysites catenulatus* (large and small varieties), and *Syringopora* sp., also an orthoid suggesting *Rhipidomella hybrida*. These were determined by E. O. Ulrich, who regards them as probably late Niagara and similar to a coral fauna found by Kindle in the Laketown dolomite of northeastern Utah.

From the upper ledge of the limestone in the San Andres Mountains 1½ miles southwest of San Nicolas Spring, or about 22 miles northeast of Las Cruces, the writer collected the following forms, determined by Edwin Kirk: *Pentamerus* sp., *Cyathophyllum* sp., *Heliolites* sp., and *Hormotoma* sp.—a distinctive Fusselman fauna.

The *Pentamerus* was observed at many other localities in the San Andres Mountains as far north as Sulphur Gap and also in the east front of the Sacramento Mountains.

Fossils were collected at three horizons in the Fusselman limestone at Lake Valley, all from beds above the 80-foot member that weathers to a light color. Cherty layers not far above this member yielded *Monomerella* n. sp. and *Zaphrentis* sp. In cherty layers about 100 feet higher *Monomerella* was very abundant, and near the top, about 30 feet below the base of the Percha shale, were collected *Zaphrentis* sp., *Amplexus* sp., and a variety of *Pentamerus oblongus* that is characteristic of the upper beds in other regions.

[1] U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

DEVONIAN SYSTEM.

PERCHA SHALE.

General relations.—Only a small part of Devonian time is now represented in New Mexico. The deposits consist of the Percha shale, in which Gordon and Graton [1] found Devonian fossils in the Lake Valley and Kingston regions. The formation is named from Percha Creek, near Kingston. It overlies the Fusselman limestone, but in places it is absent and the Fusselman is overlain by beds of Carboniferous age. Notwithstanding the long interval between the Fusselman and Percha epochs, the beds show no noticeable difference in attitude, but there is an abrupt change from massive limestone to black shale.

Lake Valley and Hillsdale region.—In the Lake Valley mining region the Percha shale appears in a narrow outcrop that extends for about 3 miles along a valley just west of the ridge of Lake Valley limestone, as shown in figure 10. It is mentioned in several published reports regarding the relations of the ores of the district. Two members were recognized by Gordon [1]—an upper grayish-yellow to blue shale 60 feet thick (c in fig. 10) and a black fissile shale 100 feet thick (d in fig. 10). Neither of these is fossiliferous at Lake Valley, but beds near the top of the upper member yielded an extensive fauna at Hillsboro and Kingston. Keyes [2] stated that the overlying nodular limestone, 50 feet thick, at Lake Valley is also Devonian and proposed for it the name Barenda. He described it as consisting of three distinct members. The lowest one is a massive, compact gray limestone, like lithographic stone, 10 feet thick, weathering rusty brown and carrying a "typical late Devonian fauna." The medial member, 30 feet thick, is gray thin-bedded limestone, in part fine grained, with no fossils. The upper member consists of 10 feet of bluish thin-bedded limestone made up largely of chert in elongated nodules and containing no fossils. According to Keyes, "it contrasts strikingly with the massive compact blue limestone lying immediately above."

In the Kingston-Hillsboro region portions of the basal beds are altered to a fine-grained red to black siliceous rock of a jaspery character, somewhat brecciated and seamed with quartz. The quartz seams are believed to have been formed by heated siliceous water.

Cooks Range.—In Luna County the Percha shale appears in Cooks Range and Fluorite Ridge, where it has a thickness of 175 feet. The rock is a uniform black shale of moderate hardness separating into thin brittle layers. It crops out extensively along the limestone slopes on both sides of the range northwest of Cooks, where it immediately overlies the ore-bearing Fusselman limestone. It is absent in the Victorio Mountains.

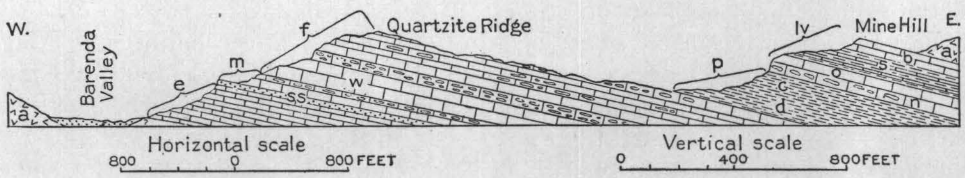


FIGURE 10.—Section through the Lake Valley mining district, Sierra County, N. Mex. e, El Paso limestone; m, Montoya limestone, with sandstone (ss) at base; f, Fusselman limestone, with white limestone (w) at base; p, Percha shale, including lower member (d) and upper member (c); n, nodular limestone; lv, Lake Valley limestone, including ore horizon, or "footwall lime" (o), shale and thin limestone (s); limestones, upper beds cherty (b), and andesite and rhyolite (a).

Florida Mountains.—In the southern part of the Florida Mountains there is a dark shale which closely resembles the Percha but which appears to be in the Gym limestone succession. though this apparent relation may be due to overlap or faulting.

Silver City.—The Percha shale crops out in several small areas about Silver City, and it also occurs in the vicinity of Georgetown and Hanover, a few miles to the east. The maximum thickness in this area is 500 feet, but in places the amount is much less.

Caballos Mountains.—Gordon [3] suggested that the black shale in the Caballos Mountains is the Percha, but he reported no fossils. In places, especially to the north, the shale is absent and the Pennsylvanian limestone lies on the Montoya or higher limestones. According

[1] Am. Jour. Sci., 4th ser., vol. 21, p. 394, 1904.
[2] Am. Inst. Min. Eng. Trans., vol. 39, p. 147, 1909.
[3] U. S. Geol. Survey Prof. Paper 68, p. 226, 1910.

to Lee,[1] in the section 8 miles south of Shandon 300 feet of black shale intervenes between "late Ordovician" cherty limestone and limestones of Carboniferous age.

Franklin Mountains.—As Richardson [2] found Carboniferous and Silurian fossils very near together in the Franklin Mountains, it appears that the Devonian is not represented in the succession of limestones in that range.

Sacramento Mountains.—The Devonian is probably represented in the section exposed along the west front of the Sacramento Mountains southeast of Alamogordo, in the lower part of the shale that lies on the Fusselman limestones, but the fossils found were not sufficiently well preserved to be determined specifically.

in blue shales near the upper part of the upper member at Kingston and at a locality 2 miles east of Hillsboro. The following were identified by Girty and Kindle:[4]

Zaphrentis sp.
Spirorbis sp.
Leptaena rhomboidalis.
Productella coloradensis var. plicatus.
Productella spinigera.
Productella hillsboroensis.
Schizophoria striatula var. australis.
Camarotoechia (Plethorhyncha) endlichi.
Camarotoechia contracta.
Eunella sp.
Athyris coloradensis.
Pugnax pugnus.
Spirifer whitneyi.
Spirifer whitneyi var. animasensis.
Spirifer notabilis.

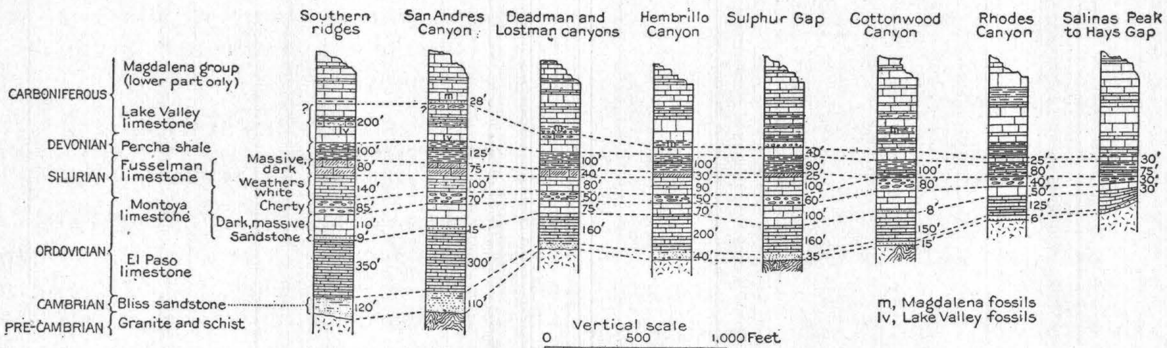


FIGURE 11.—Columnar sections showing stratigraphic variations in lower Paleozoic rocks in the San Andres Mountains, Dona Ana and Socorro counties, N. Mex.

San Andres Mountains.—Shale with Upper Devonian fossils extends along the San Andres Mountains from a point 2 miles northeast of Organ, where igneous intrusions cut off the succession, nearly to Mockingbird Gap. Its thickness is 50 feet or more, and it crops out in a slope between the prominent ledge of massive limestone above and a shelf or cliff of Fusselman or Montoya limestone below. The basal beds are black shale, above which are layers of slabby and nodular limestone separated by gray shale. Possibly in places the uppermost layers of shale are Carboniferous. The fossils found were mostly in the medial beds. Some of the relations are shown in figures 9 and 11 and Plates XV (p. 33) and XVIII (p. 36).

Fossils.—The Devonian fossils reported by Gordon and Graton [3] were found in abundance

Syringospira prima.
Reticularia spinosa.
Meristella barrisi.

Fossils found by Paige in the Percha shale at Silver City are as follows:

Schizophoria striatula var. australis.
Productella coloradensis.
Productella spinigera.
Productella laminatus.
Camarotoechia contracta?
Camarotoechia (Plethorhyncha) endlichi.
Pugnax pugnus.
Spirifer notabilis.
Spirifer whitneyi.
Reticularia spinosa.
Athyris coloradensis.
Aviculipecten n. sp.
Bellerophon sp.
Euomphalus eurekensis?
Corals and bryozoans.

The following fossils were found in the Percha shale in 1915 a mile south of Capitol

[1] Am. Jour. Sci., 4th ser., vol. 26, p. 182, 1908.
[2] U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), p. 4, 1909.
[3] Am. Jour. Sci., 4th ser., vol. 21, p. 394, 1904.
[4] See Kindle, E. M., The Devonian fauna of the Ouray limestone: U. S. Geol. Survey Bull. 391, 1909.

Peak, in the northern part of the San Andres Mountains. They were identified by Edwin Kirk:

Tropidoleptus carinatus var.
Alveolites sp.
Spirifer n. sp.
Stropheodonta near S. arcuata Hall.
Productella hallanus.
Atrypa reticularis.
Atrypa hystrix.
Schizophoria striatula var. australis?
Diaphosostoma sp.

On the north slope of Sheep Mountain, in Lava Gap, a mile farther south, were obtained *Zaphrentis*, *Atrypa reticularis*, *Cyrtia* n. sp., *Productella hallanus*, and *Stropheodonta* near *S. arcuata*. In Sulphur Gap, which is not far north of the latitude of Alamagordo, the following forms were collected from medial beds:

Atrypa hystrix.
Atrypa reticularis.
Schizophoria striatula var. australis.
Pugnax pugnus.
Camarotoechia contracta?
Chonetes sp.
Stropheodonta n. sp.
Spirifer whitneyi var. animasensis.
Spirifer sp.

In a canyon 3 miles south of San Andres Peak were found *Rhipidomella* sp., *Spirifer* sp., and *Chonetes* sp. In Cottonwood Canyon the shale yielded *Spirifer whitneyi*.

In nodular beds in the middle of the formation in San Andres Canyon were found the following:

Zaphrentis sp.
Fenestella sp.
Productella cf. Productella coloradoensis var. plicata.
Ambocoelia sp.
Schizophoria striatula var. australis.
Leiorhynchus? sp.
Spirifer cf. Spirifer utahensis.
Reticularia undifera var.
Phacops sp.

At the same horizon in Hembrillo Canyon were obtained *Fenestella*, *Atrypa reticularis*, *Pugnax pugnus*, *Cyrtia* sp., *Stropheodonta* near *S. arcuata*, *Gypidula* sp., and *Productella* sp.

A few fragmentary fossils were collected from black shale a few feet above the Fusselman ledge near Dog Canyon, in the west front of the Sacramento Mountains, but they could not be determined. Mr. Kirk recognized one of the brachiopods as *Meristella* or some closely allied genus, almost certainly Devonian.

Age and correlation.—The fossils from the Percha shale are regarded by Mr. Kirk as indicating that the formation is late Devonian, equivalent to the lower part of the Ouray limestone and the upper part of the Martin limestone (Upper Devonian) of the Bisbee region, Ariz., and the upper 2,000 feet of Nevada limestone of the Eureka district, Nev. As the lower beds of the Percha shale in the type locality have not yielded fossils, the formation may represent a somewhat greater range than is indicated by the collections recorded. The beds in the San Andres Mountains appear to carry a smaller number of the typical lower Ouray forms than are present in Lake Valley, and more of the forms characteristic of the Martin limestone and Nevada limestone. However, all the New Mexico collections are too fragmentary to permit precise correlation.

CARBONIFEROUS SYSTEM.

GENERAL FEATURES.

In southern New Mexico rocks of Carboniferous age comprise representatives of the earlier part of Mississippian and of a large part of Pennsylvanian and Permian time, the later Mississippian being unrepresented there, as in most other portions of the West. In the Lake Valley region and to the south the formation of lower Mississippian age is the Lake Valley limestone, which appears in most of the uplifts between latitudes 32° 20′ and 34°. The rocks of supposed Mississippian age in the Magdalena region are known as the Kelly limestone. The beds of the Pennsylvanian and Permian series occur throughout the area and in the adjoining States. They comprise a great thickness of limestone, which to the northeast is accompanied by the red sandstone and shale of the Abo sandstone and many thick deposits of gypsum.

In Luna County the formations of the Pennsylvanian and Mississippian series are separated by a hiatus of considerable amount, and there is an overlap of the higher limestone toward the south. Thus, in the Florida, Victorio, and Franklin mountains the later Carboniferous rocks lie directly on the Silurian limestone, and the Mississippian and earlier Pennsylvanian (Magdalena group) appear to be absent. The Manzano group, or later Carboniferous, is represented by a thick limestone formation, the Gym limestone. A still younger formation, separated as the Lobo and tentatively assigned to the Triassic, may possibly represent the upper part of the Manzano.

A comparison of the Carboniferous rocks of southern New Mexico with those of Arizona shows close similarity. The Lake Valley limestone has the same fauna as the Modoc limestone at Clifton,[1] 180 feet thick, and the Escabrosa limestone of the Bisbee region,[2] 700 feet thick. The Magdalena group is represented in whole or part by the Tule Spring limestone of Clifton, 500 feet thick, and by part of the Naco limestone of the Bisbee region. The Naco, which is 3,000 feet or more thick, appears to include in its upper part a thick representative of the Hueco limestone of western Texas. Farther west and north in Arizona, especially in the Grand Canyon region, the Redwall limestone, 1,000 feet or more thick, comprises representatives of both the Pennsylvanian and the earlier Mississippian, the Pennsylvanian beds being equivalent to the Magdalena group. The overlying red beds of the Supai formation, 1,200 feet thick, probably correspond to the Abo sandstone (red sandstone), 700 to 1,000 feet thick, at the base of the Manzano group. The overlying Coconino sandstone and Kaibab limestone, the latter in places containing gypsum deposits, are probably equivalent to the great succession of sandstone, gypsum, and limestone that constitute the upper part of the Manzano group in New Mexico. G. H. Girty regards the fauna of the upper limestone of the Manzano group as closely similar to that of the Kaibab limestone. Representatives of the Supai and Abo red beds are lacking to the south, notably in southern New Mexico, in southwestern Texas, and in the Naco limestone succession of the Bisbee region.

LOWER MISSISSIPPIAN LIMESTONES.

Lake Valley region.—The Lake Valley limestone received its name from the Lake Valley mining district, where it crops out in an area about 3 miles long and half a mile wide. In that district it consists of about 200 feet of limestone underlain by the Percha shale and at the top eroded and in part overlain by Tertiary igneous rocks. (See fig. 10, p. 44.) Distinctive lower Carboniferous (Mississippian) fossils were found in these limestones by Cope[3] in 1881 and by others at intervals later, notably by Springer,[4] who published a detailed list of many forms, including an extensive crinoid fauna closely similar to the lower Burlington of Iowa. The section given by Springer is as follows:

Section of Lake Valley limestone at Lake Valley mining camp, N. Mex.

	Feet.
9. Cherty limestone, with irregular flinty masses, in places light colored and full of crinoids	30
8. Limestone, heavy bedded, pink to drab; marly partings; many crinoids, corals, and other fossils	40
7. Limestone, thin bedded, bluish, mostly shaly; many crinoids, corals, bryozoans, and other fossils	20
6. Limestone, hard, granular, sandy, pinkish to bluish	6
5. Shale, light yellow, with flinty nodules	15
4. Limestone, irony, coarse, irregularly bedded, with marly partings; corals and crinoid fragments	30
3. Sandstones, dark brown, heavy bedded and hard below, shaly above	12
2. Shale, light yellowish, with irregular flinty masses; no fossils	8
1. Slope covered by débris.	

Beds 7 and 8 yielded most of the fossils. The beds below No. 7 Springer referred to the Kinderhook group. No fossils were reported from bed 3. A section given by Gordon,[5] who visited the locality in 1905 is as follows:

Section of Lake Valley limestone at Lake Valley, N. Mex.

	Feet.
9. Capping of andesite.	
8. Limestone, coarse, subcrystalline, yellowish white; moderately thick beds, some cherty; many crinoids and other fossils; top eroded	60
7. Shale, blue; includes thin bluish limestone beds; many fossils but fewer crinoids than No. 8	75
6. Limestone, grayish blue, hard, more or less siliceous, called "blue limestone" in the mines. Local breccia of flint at top. At base 5-foot bed of coarse crystalline yellowish-white limestone	25
5. Limestone, compact, grayish, filled with nodular chert; partings mostly thick	50
Percha shale.	

[1] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Clifton folio (No. 129), 1905.

[2] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (No. 112), 1904.

[3] Cope, E. D., Geology of the Lake Valley mining district: Am. Naturalist, vol. 15, pp. 831-832, 1881.

[4] Springer, Frank, on the occurrence of the Lower Burlington limestone in New Mexico: Am. Jour. Sci., 3d ser., vol. 27, pp. 97-103, 1884.

[5] Gordon, C. H., Mississippian formations in the Rio Grande valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 24, pp. 58-64, 1907.

No. 5 (n, fig. 10) is the nodular limestone of Clark,[1] who described the region in considerable detail. Keyes,[2] however, placed this member in the Devonian and called it the Barenda limestone.

Cooks Range.—In Luna County the Lake Valley limestone occurs only in Cooks Range, where its thickness is between 600 and 700 feet. It consists mainly of light-gray, massive to slabby limestone, with several intercalated members of shale, partly limy. The limestone members crop out mostly as cliffs 80 to 100 feet high, separated by shaly slopes. The basal member consists of 150 feet of bluish-gray limestone, with some chert in its lower part. The upper member contains some thick bodies of white chert and cherty limestone. A small body of Lake Valley limestone lies on the Percha shale in Fluorite Ridge, at the south end of Cooks Range, near Cooks Peak. It is cut by the great porphyry intrusion and interrupted by several faults. Fossils are abundant in the limestone in this locality.

Silver City region.—In the Silver City region the two divisions of the Carboniferous are grouped together by Paige[3] as the Fierro limestone. The rocks are limestones, ranging in color from light gray to dark blue or purplish. West of Silver City the upper half is chiefly light gray or light blue and the lower part darker blue. All but the upper 100 feet is cherty, and near the base there is some red chert. Some thin, more or less shaly beds are included. The Fierro limestone varies in thickness because of the unconformity at its top, and doubtless also between its two divisions, but the maximum thickness is about 800 feet. It is widely distributed, constituting much of the range northwest of Silver City, part of Lone Mountain, and areas near Fort Bayard and north of Santa Rita. Fossils are abundant in some beds, and the lower ones yield many Mississippian forms.

Mimbres Mountains.—Gordon[4] states that the Lake Valley limestone crops out at many points along the east side of the Mimbres Mountains, and he gives the section reproduced here as figure 12, showing its relations in that region. At Kingston the formation consists of thick-bedded blue limestones with nodular cherty beds and shaly thin-bedded limestone, 100 to 125 feet in all. Many distinctive fossils occur in it.

Caballos Mountains.—It is not unlikely that some Lake Valley limestone is included in the great section on the west front of the Caballos Mountains, but no data are available on this point.

Magdalena Mountains.—The Kelly limestone, or so-called "Graphic Kelly" limestone, the ore-bearing formation in the silver-lead mines at Kelly, is supposed to be of Mississippian age, Herrick[5] and Keyes[6] having reported that crinoids were found in it. This limestone is white and crystalline, and occurs in thick beds, about 125 feet in all, lying on pre-Cambrian schist and granite. (See Pl. XIX, *B.*) Near the middle is a 5-foot layer of dark-blue noncrystalline rock, weathering yellowish drab, which the miners call "Silver Pipe limestone."

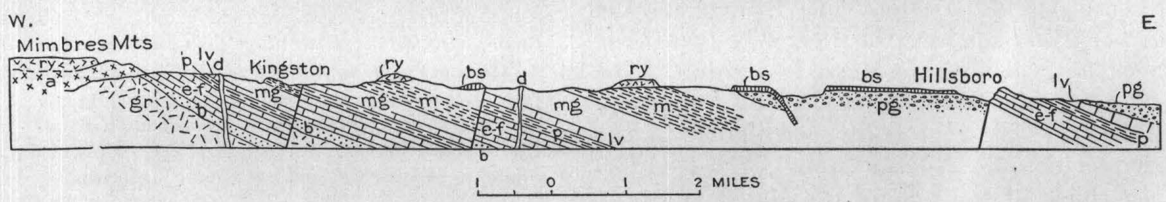


FIGURE 12.—Section from the Mimbres Mountains eastward through Kingston and Hillsboro, N. Mex. (After Gordon.) gr, Granite; b, Bliss sandstone; e-f, Mimbres limestone [El Paso, Montoya, and Fusselman]; p, Percha shale; lv, Lake Valley limestone; mg, Magdalena group; m, Manzano group; pg, Palomas gravel; bs, basalt sheet; a, andesite; ry, rhyolite; d, dike.

Keyes[6] gives the following section of the limestones in the Magdalena Mountains, including the Kelly limestone, in which Mississippian crinoids were obtained:

Section of limestone in Magdalena Mountains.

	Feet.
Limestone, blue, heavy bedded, with thick shale partings	300
Shale, sandy, greenish	200
Sandstone, greenish, micaceous, soft	50
Sandstone, quartzite, pebbly (base of Magdalena group)	60

[1] Clark, Ellis, The silver mines of Lake Valley, N. Mex.: Am. Inst. Min. Eng. Trans., vol. 24, pp. 138-169, pl., 1884.

[2] Am. Inst. Min. Eng. Trans., vol. 39, p. 147, 1909.

[3] U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), p. 5, 1916.

[4] U. S. Geol. Survey Prof. Paper 68, p. 229, 1910.

[5] Herrick, C. L., Laws of formation of New Mexico mountain ranges: Am. Geologist, vol. 33, p. 310, 1904.

[6] Keyes, C. R., Northward extension of the Lake Valley limestone: Iowa Acad. Sci. Proc., vol. 12, pp. 169-171, 1904.

	Feet.
Shale, dark, siliceous (Mississippian)	50
Limestone, gray, crinoidal (Mississippian)	45
Limestone, heavy bedded, crinoidal ("upper vein")	30
Limestone, blue, impure, fine grained, siliceous ("Silver Pipe lime")	8
Limestone, gray, subcrystalline (contact vein)	60
On schists, granite, greenstone, etc.	

San Andres Mountains.—The Lake Valley limestone occurs in an area of considerable extent in the San Andres Mountains, but it is not thick and may be discontinuous. In the central part of the range a heavy bed of limestone overlying the Percha shale yielded lower Mississippian (Lake Valley) fossils at several localities, notably in San Andres Canyon and on the slopes 3 miles south of San Andres Peak, and also at a locality, shown in figure 9 (p. 42), west of San Nicolas Spring, or about 16 miles northeast of Las Cruces. The greatest thickness observed was in San Andres Canyon and northward for 10 or 12 miles, where the amount may be 100 feet or more. The principal bed that yielded Lake Valley fossils is a massive limestone, cherty in its upper part; but some overlying softer beds and a higher massive bed may possibly be included in the formation. In San Andres Canyon the higher massive bed is capped by 28 feet of hard gray sandstone, immediately above which is shaly limestone containing Magdalena fossils. In Hembrillo Canyon the only member present is the first massive bed that caps the Percha shale, for the strata next above carry Pennsylvanian fossils. This bed extends northward past Salinas Peak to and beyond Hays Gap, where, however, no fossils were found in it. In Sulphur Canyon it is 60 feet thick and is capped by 30 feet of a peculiar sandstone, including considerable conglomerate of large pebbles and fragments of white chert. This material is presumably basal Magdalena. Some of it appears also in Lostman Canyon. In Deadman Canyon the massive limestone bed above the Percha shale is 80 feet thick and grades upward into 50 feet of limestone with cherty layers. In Rhodes Canyon the ledge is only 25 feet thick, and in Lava Gap it is 30 feet thick. The outcrop at the latter place is shown in Plate XVIII, *B*.

Sacramento Mountains.—In 1900 C. L. Herrick [1] announced the discovery of fossils of the Mississippian series in the west front of the Sacramento Mountains but gave but little information as to the conditions of occurrence. The bed was stated to be 560 feet above the base of the section in Dog Canyon (see Pl. XIX, *A*), and the thickness of the "Burlington limestone," as Herrick termed it, is 250 feet. In 1908, G. H. Girty examined a section east of Alamogordo, in which 1,500 feet of limestone and shale containing Pennsylvanian fossils, were found to be underlain by 150 feet of limestone containing Mississippian forms. Some of the same species were collected in Alamo Canyon, a few miles farther south, by G. B. Richardson, and also in 1915 by the writer. An unpublished section, kindly furnished by Mr. Girty, is as follows:

Section of Carboniferous racks in ridge N. 63° E. of Alamogordo, N. Mex.

	Feet.
43 Massive limestone	50±
42. Thinner beds and concealed	100±
41. Dark limestone	50±
40. Concealed	30
39. Dark limestone	3
38. Concealed	50
37. Soft greenish gritty sandstone	10
36. Concealed; débris, limestone and thin greenish sandstone	100
35. Dark massive limestone, weathering brown	25
34. Concealed	20
33. Dark limestone	5
32. Sandy shale, partly concealed	10
31. Earthy limestone (fossils)	4
30. Dark shale above (20 feet), concealed below	50
29. Argillaceous and calcareous shale (fossils)	10
28. Dark siliceous limestone	10
27. Greenish sandy shale	15
26. Greenish-brown gritty sandstone	10
25. Shaly material	5
24. Thin dark siliceous limestone	10
23. Concealed; probably thin impure limestone	15
22. Massive dark limestone	10
21. Concealed	15
20. Siliceous limestone below, concealed in middle, purer and fossiliferous limestone above	20
19. Greenish gritty sandstone, thin bedded below, massive in middle, thinner above	60
18. Partly concealed; upper part with thin black limestone, weathering bluish and yellowish	50
17. Lower 30 feet probably thin gritty sandstone; upper 20 feet massive; some layers calcareous, with quartz pebbles and fossils	50
16. Gritty sandstone, calcareous below and fossiliferous	10
15. Dark-brown limestone, somewhat shaly, many fossils	10
14. Poorly exposed; probably thin dark siliceous limestone, weathering brown, poor fossils	100±

[1] Herrick, C. L., Univ. New Mexico Bull., vol. 2, No. 3, p. 8. The geology of the white sands of New Mexico: Jour. Geology, vol. 8, pp. 112-128, 1900.

	Feet.
13. Black limestone, siliceous, weathering brown	3
12. Poorly exposed; probably thin impure limestone and a few ledges of dark cherty limestone; poor fossils	50
11. Light-colored sandstone and fine conglomerate; poorly exposed	100±
10. Shale with calcareous layers; fossils	30
9. Dark impure limestone	15
8. Unexposed; probably thin sandstone and then impure limestone; *Productus cora* and *P. semireticulatus* in débris	100
7. Whitish and rusty gritty sandstone, and fine conglomerate, not well exposed; perhaps as much as	300
6. Light-colored crinoidal limestone; some very soft and weathering to gravel	75
5. Dark siliceous limestone with chert in bands	30
4. Massive, rather soft calcareous shale; big crinoid stems and *Schizophoria*	5
3. Dark limestone and thin shale interbedded; limestone with "*Caudagalli*"	20
2. Same as No. 1 but more massive	15
1. Dark bluish-gray calcareous shale, thin bedded and rather massive; base not seen.	

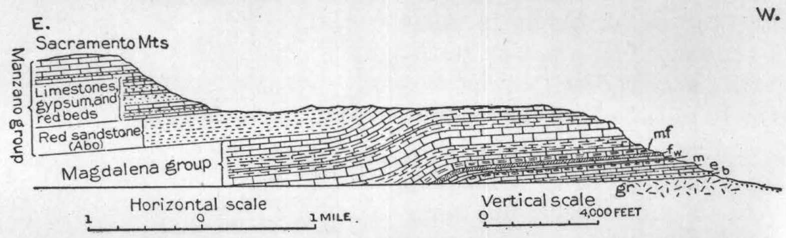


FIGURE 13.—Section of the west front of the Sacramento Mountains, 12 miles southeast of Alamogordo, N. Mex. gr, Granite; b, sandstone (Bliss?); є, El Paso limestone; m, Montoya limestone (dark massive limestone, overlain by cherty limestone); w, limestone, white when weathered (Fusselman?); f, Fusselman limestone; mf, shaly limestone, with Mississippian fossils.

Fossils of Mississippian age were obtained from bed 6 (see list on p. 52), as well as in the lower beds, and this member is tentatively regarded as the top of the Mississippian, although possibly bed 7 should also be included. Beds 1 and 2 extend down to the edge of the valley fill. The strata containing Mississippian fossils extend all along the west front of the range, from a point opposite Alamogordo nearly to Grapevine Canyon. The most abundantly fossiliferous beds are in the 100-foot member of shales and slabby limestone lying between a massive ledge of coarse-grained limestone and the top of the cliff of Fusselman limestone.

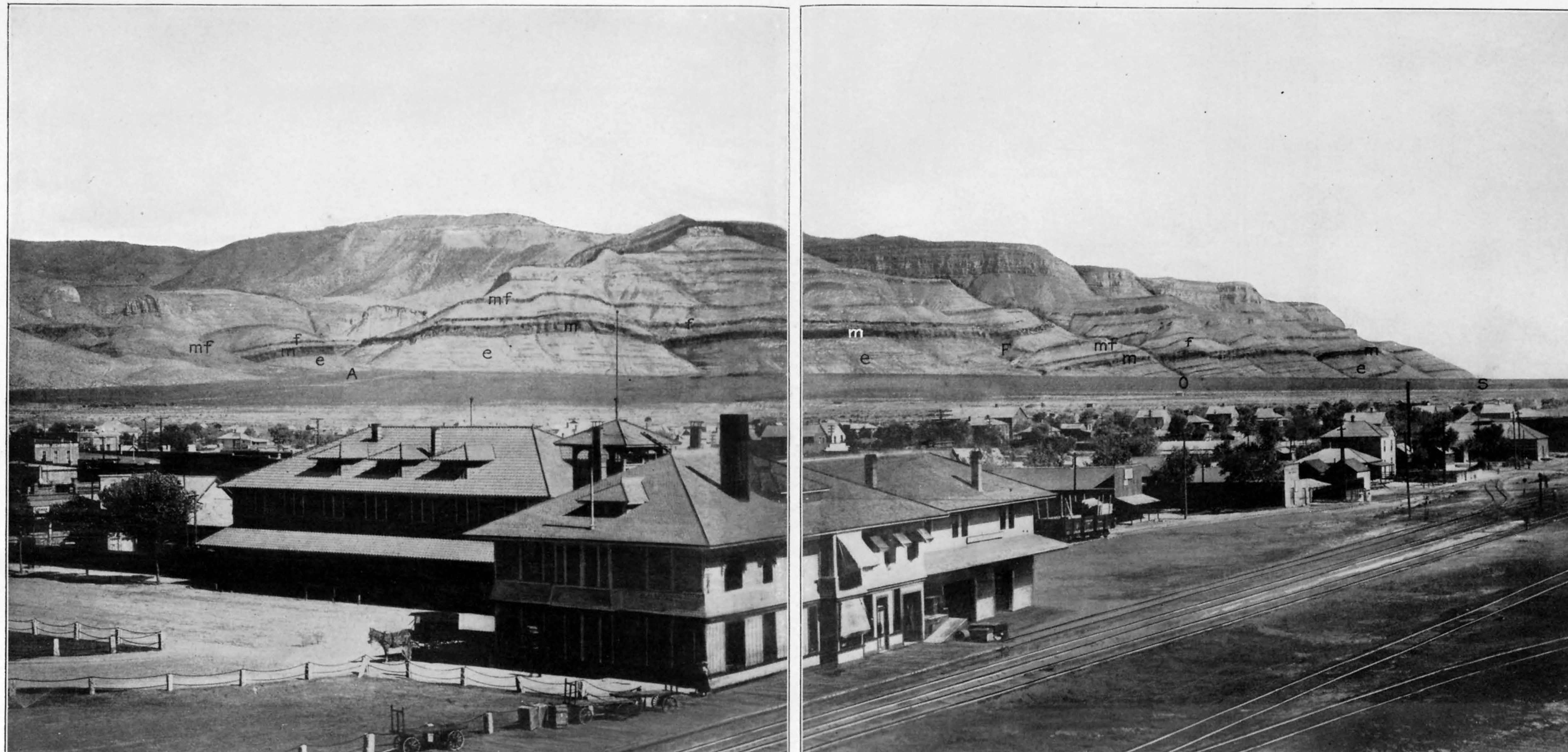
The relations of these Mississippian beds are shown in figures 13 and 14, the latter showing the long arch extending along the mountain front east-southeast of Alamogordo. (See also Pls. XX and XXI.)

Sierra Ladrones.—The northernmost known rocks of Mississippian age in New Mexico occur on the south side of the Sierra Ladrones, Socorro County, where in 1905 W. T. Lee [1] obtained distinctive Mississippian fossils. (See list on p. 52.) The locality was in the canyon of Rio Salado, about one-eighth of a mile from the granite ledges and therefore very near the base of the sedimentary succession. Not far above are limestones with fossils of Pennsylvanian age, and in 1913 the writer found Pennsylvanian fossils within 3 or 4 feet of the granite on the northwest side of the mountain. Evidently the Salado Canyon exposure is either an outlying lens of the Mississippian limestone or an extension northward from Magdalena Mountain. The Mississippian is not present east of Socorro and in the Manzano, Sandia, Zuni, Nacimiento, and Rocky mountains, where rocks of the Pennsylvanian series lie directly on pre-Cambrian granite.

Fossils.—In the type locality at Lake Valley, from beds 7 and 8 in the section given on page 47, were obtained the following fossils. The identifications were made by G. H. Girty, except those of the crinoids, which were made by Frank Springer:

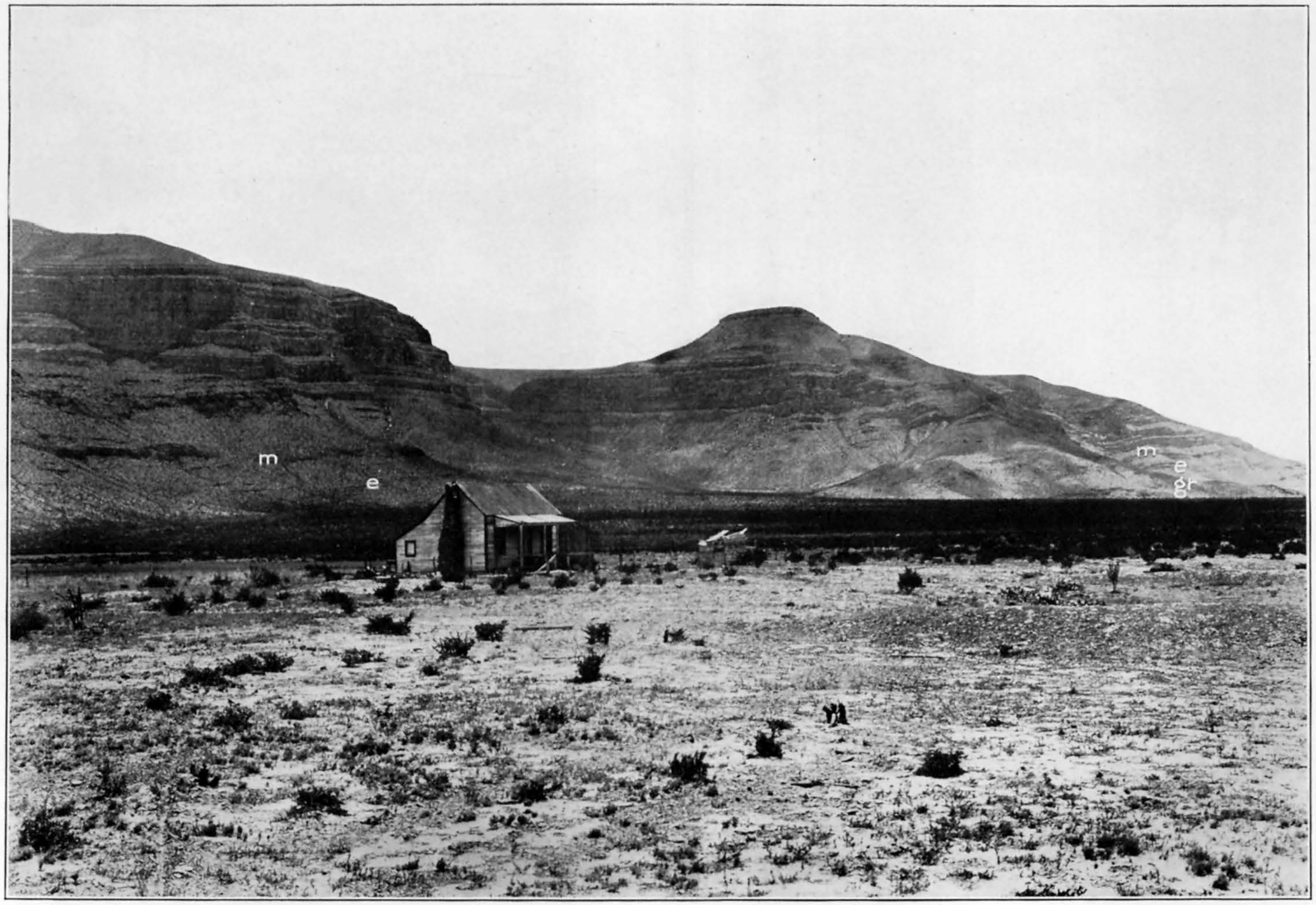
Cladochonus sp.
Favosites aff. F. valmeyerensis.
Zaphrentis sp.
Amplexus aff. A. fragilis.
Platycrinus peculiaris.
Platycrinus parvinodus.
Platycrinus pileiformis.
Periechocrinus whitei.
Megistocrinus evansi?
Dorycrinus unicornis.
Physetocrinus lobatus.
Physetocrinus planus.
Steganocrinus sculptus.
Fistulipora americana.
Cheilotrypa? sp.
Fenestella sp.
Pinnatopora sp.
Rhombopora sp.

[1] Gordon, C. H., Mississippian formations in the Rio Grande valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 24, p. 58, 1907.



VIEW LOOKING SOUTHEAST ALONG WEST FRONT OF SACRAMENTO MOUNTAINS FROM ALAMOGORDO, OTERO COUNTY, N. MEX.

A, Mouth of Alamo Canyon; O, canyon with small orchard at its mouth; F, northwest-southeast fault; S, San Andres Canyon; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone; mf, limestone with Mississippian fossils above which are Pennsylvanian limestones.



VIEW ALONG WEST FRONT OF SACRAMENTO MOUNTAINS AT AGUA CHIQUITA CANYON, OTERO COUNTY, N. MEX.

Looking southeast. m, Montoya limestone; e, El Paso limestone; gr, granite.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 108—D

WASATCH FOSSILS IN SO-CALLED FORT UNION BEDS OF THE POWDER RIVER BASIN, WYOMING

AND THEIR BEARING ON THE STRATIGRAPHY OF THE REGION

BY

CARROLL H. WEGEMANN

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ILLUSTRATIONS.

WASATCH FOSSILS IN SO-CALLED FORT UNION BEDS OF THE POWDER RIVER BASIN, WYOMING, AND THEIR BEARING ON THE STRATIGRAPHY OF THE REGION.

By Carroll H. Wegemann.

Northeastern Wyoming is occupied by a broad structural basin opening to the north and bounded on the east, south, and west by three mountain uplifts—the Black Hills, the Laramie Mountains, and the Big Horn Mountains. (See fig. 16.) Throughout much of this basin the surface rocks are of Tertiary age. They contain the principal coal beds of the region and have been classified in all the more recent Survey reports as Fort Union. The true age of these rocks and the general stratigraphy of the fresh-water beds that underlie them are the theme of this paper.

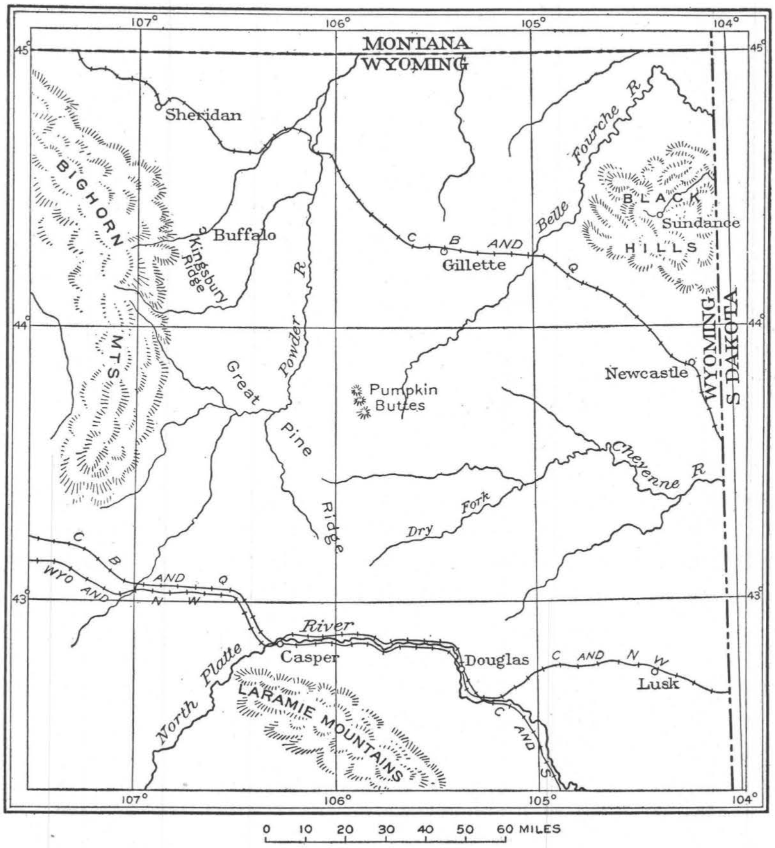

FIGURE 16.—Map of northeastern Wyoming.

The rocks above the Fox Hills sandstone on the southwest side of the basin may be separated, on lithologic grounds, into three divisions. The Lance formation, about 3,200 feet thick, consisting of gray shale and buff fine-grained slabby or concretionary sandstone, is at the base. It contains a few thin coal beds at various horizons in the formation, particularly near the base and top, but they are so thin and the coal is so poor as to be of no commercial value. One of the most characteristic features of the Lance consists of large round concretionary masses that weather from the sandstone beds. (See Pl. XXII, *A*.) These masses resemble great boulders, and some of them are as much as 10 or 15 feet in diameter.

At its top the Lance grades almost imperceptibly into the beds of the overlying formation, the transition being marked by thin beds of coal and carbonaceous shale. Neither at the base nor at the top has evidence of unconformity been observed in this region.

The Lance formation, as a whole, is a unit that is not susceptible of division on lithologic grounds. The vertebrate remains, however (for the most part *Triceratops* and *Trachodon*), are not distributed through the whole formation, but are found only in the lower 2,000 feet. The upper 1,200 feet of beds, although identical in appearance with those below, are apparently barren of vertebrate fossils.

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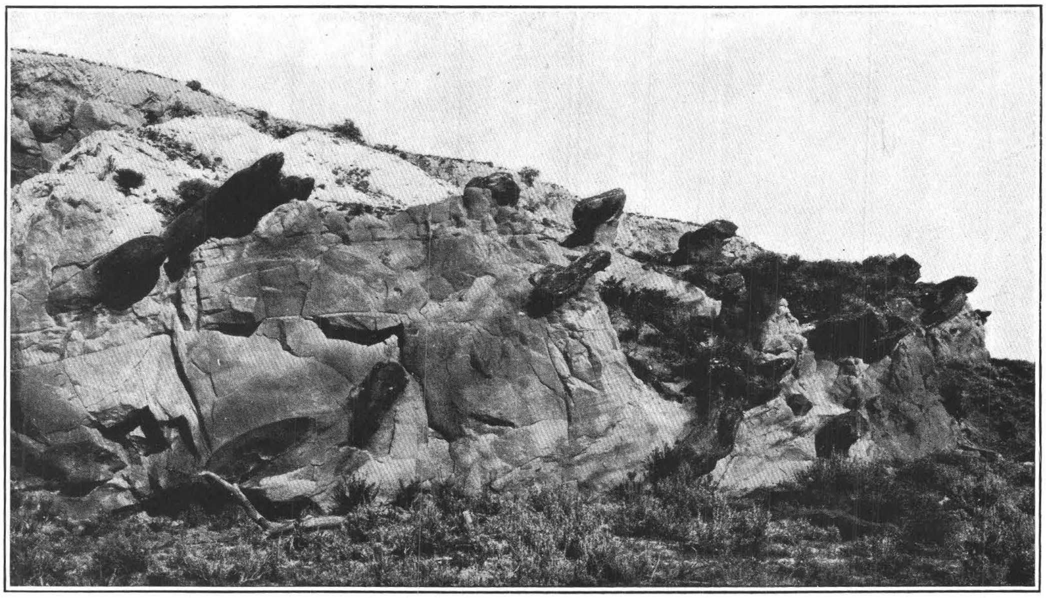
Above the Lance formation is about 2,000 feet of very fine grained bluish-white sandstone interbedded with gray shale and with a few beds of coarser sandstone, containing grains one-eighth of an inch in diameter. This formation is distinguished from the underlying Lance by its bluish-white color, the absence of large round concretionary masses, and the presence of beds of highly ferruginous sandstone only a few inches thick. The iron in many of these ferruginous beds appears to be of secondary origin, having probably been deposited from ground water. Some of it may represent swamp deposits, although this is difficult to demonstrate.

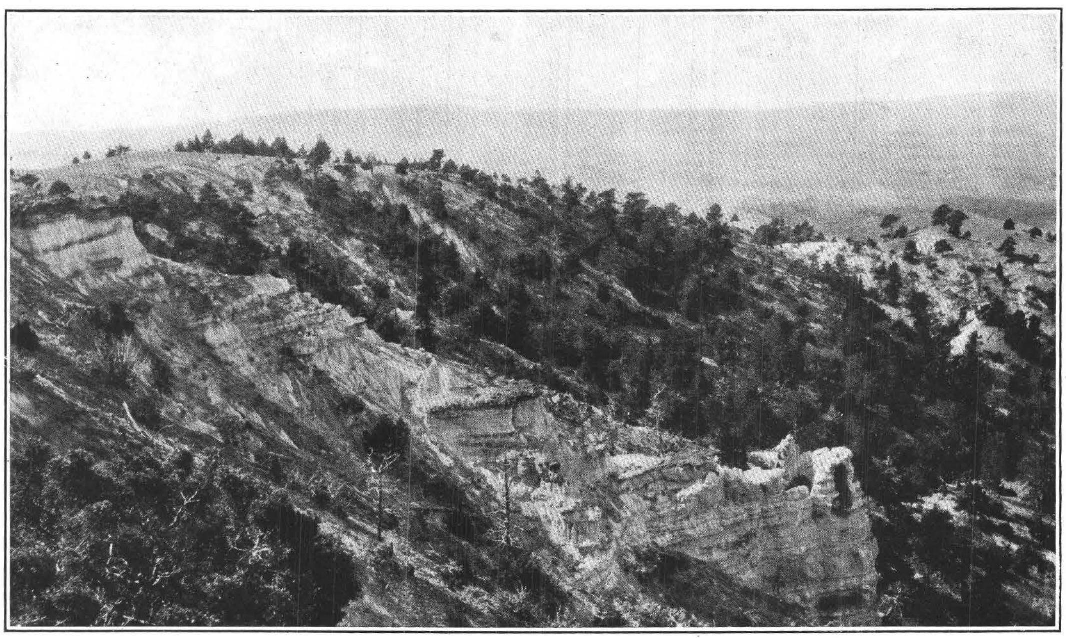
The formation as a whole is more resistant to erosion than the formations above and below it, so that its outcrop around the margin of the great basin already described forms a prominent escarpment, which is generally timber covered, and to which the writer has referred in several reports as the "Great Pine Ridge." (See Pl. XXII, *B*.) Fossil leaves, that are found in abundance in some of the ferruginous beds, have been determined by F. H. Knowlton as of Fort Union age, but the strata have heretofore been considered as comprising only the basal member of that formation.

The bluish-white shale and sandstone of the Great Pine Ridge are overlain by about 2,500 feet of beds that are the principal coal-bearing rocks of the upper Powder River valley and that have in the past been considered by most workers in the region, the writer included, as of Fort Union age, constituting the upper division of that formation. (See Pl. XXIII, *A*.) These beds consist mainly of gray shale and fine-grained dirty-white sandstone. They include some beds of coarser sandstone, especially in the upper part of the formation, and at the bases of these are found in many places thin layers of conglomerate. At certain horizons there are layers of pink shale and pink sandstone whose color—in the sandstone at least—is variable from place to place. Ferruginous layers, so abundant in the underlying formation, are here absent. Distributed through the formation at various horizons are beds of subbituminous coal, which range in thickness from a few inches to 50 feet. Some of the beds are apparently very lenticular and can be traced for only a few miles along their outcrop. Others are very persistent and underlie hundreds of square miles of territory.

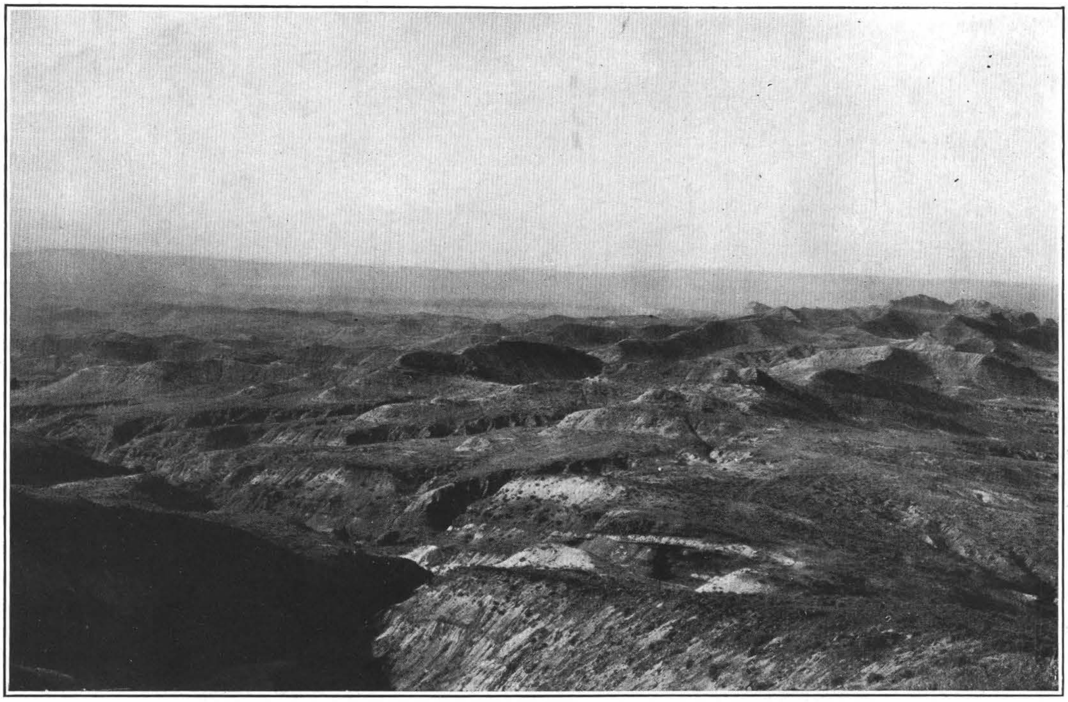
During the season of 1915 R. W. Howell and the writer examined an area of about 2,000 square miles, extending from northwest Converse County northward along the divide on which are situated the Pumpkin Buttes to the Powder River valley. In the Pumpkin Buttes are exposed the highest beds that are present in this general region. About 12 miles west of the buttes lies the Great Pine Ridge, and between this ridge and the buttes is the most advantageous locality at which to measure the thickness and study the characteristics of the overlying formation, the so-called upper division of the Fort Union. To Mr. Howell belongs the credit of finding the first tooth of *Coryphodon* discovered by the party. The specimen was found between the Middle and North buttes at about 950 feet below the top of the formation as there exposed. Mr. Howell and the writer afterward returned to the place and obtained several other teeth. All came from a blue shale underlying a thick sandstone bed; at the base of which is one of the small local unconformities characteristic of the formation. Later in the season we obtained from Mr. William Black, a rancher, other specimens of *Coryphodon* teeth, which he described as having been found at the top of Dome Butte, an outlier of North Pumpkin Butte. The sandstone that caps this butte is the same as the basal part of the thick sandstone bed that caps all the Pumpkin Buttes. Mr. Black gave the locality accurately, and Mr. Howell afterward visited it. He did not discover any more teeth but did find fragments of bone embedded in sandstone, that correspond in texture to that in which the specimens which we had received were embedded. J. W. Gidley states, with regard to this as well as the former collection, that the teeth belong to *Coryphodon molestus*, a genus known only from the Wasatch. It would seem, therefore, that these remains afford definite evidence for correlating the rocks that form the Pumpkin Buttes, or the upper 1,000 feet of the formation heretofore called Fort Union, with the Wasatch. The 1,400 feet of beds from the base of the Pumpkin Buttes down to the top of the Great Pine Ridge are lithologically similar to the rocks of the buttes themselves, and there is every reason, on lithologic grounds, to suppose that they belong to the same formation



A. SANDSTONE BED IN LANCE FORMATION, SHOWING LARGE "CONCRETIONS."

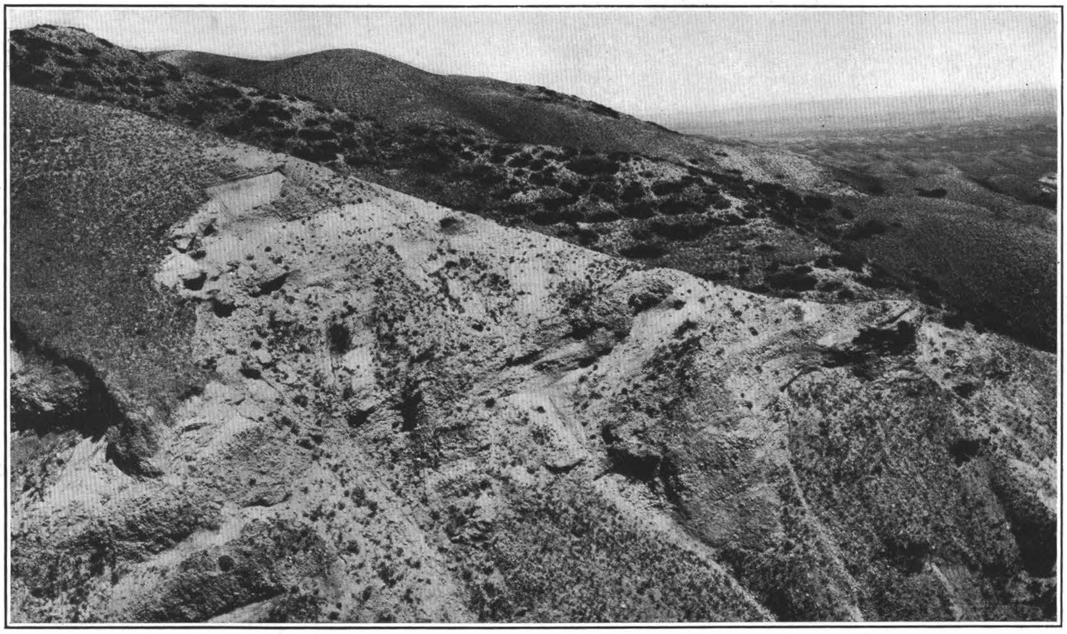


B. GREAT PINE RIDGE, WYO., FORMED BY OUTCROP OF FORT UNION FORMATION.



A. BADLANDS IN WASATCH FORMATION AT FOSSIL LOCALITY NEAR THE DAVIS RANCH, SUSSEX, WYO.

Photograph by T. W. Stanton.



B. KINGSBURY CONGLOMERATE ON KINGSBURY RIDGE, 8 MILES SOUTHWEST OF BUFFALO, WYO.

as the rocks from which *Coryphodon* has been obtained.

In 1910 T. W. Stanton, A. R. Schultz, and the writer made a collection of small mammal teeth from a horizon about 700 feet above the top of the beds forming the Great Pine Ridge, at a place 20 miles west of Pumpkin Buttes. (See Pl. XXIII, *A*.) Some shale beds in the vicinity are pink or red and resemble the Wasatch beds of southwestern Wyoming. The writer was directed to this locality by Mr. H. W. Davis, an old-time rancher of the region, who stated that some years before students from Amherst, Mass., had made a collection from the locality and found the jaw of a fossil horse. Concerning this statement Prof. F. B. Loomis, of Amherst, has informed the writer that a party under his direction made a collection near the Davis ranch in 1904 which included teeth regarded by him as belonging to *Eohippus* and *Coryphodon*. With regard to the 1910 collection near the Davis ranch, Mr. Gidley has very kindly prepared the following statement:

On a former preliminary examination of the material from the vicinity of the Davis ranch, Sussex, Wyo., I was led to believe that it indicated Fort Union deposits at that locality. My conclusion was based principally on the presence in the collection of a little insectivorous mammal represented by a portion of a lower jaw containing two teeth. This or a closely related species occurs also in the Fort Union beds of Sweet Grass County, Mont., and so far as I know has never been found elsewhere. Its presence, however, is by no means conclusive evidence of the Fort Union age of these beds. For, while this particular animal has not yet been found in other formations, there are several forms commonly found in the Fort Union (or the Torrejon) which are known to extend beyond the limits of this formation and occur in beds recognized as lower Wasatch.

Of the three mammal molars also included in the collection from the Davis ranch, I stated five years ago that they represented undescribed species but seemed to be generically identical with certain forms of the Torrejon. To this I can now add that one of these (catalogue No. 6734) is very close to if not identical with *Polycodus ralstoni*, recently described by Matthew [1] from beds in the Clark Fork basin, Wyo., designated by Granger [2] the Sand Coulee beds and regarded as transitional in age between the Fort Union (represented in northwestern New Mexico by the Puerco and Torrejon) and the Wasatch. This suggests that the other specimens may also prove to belong to this horizon, especially as it now seems very evident that many of the Fort Union forms have passed without much change into the basal Wasatch.

As the Clark Fork beds and Sand Coulee beds of Granger, which contain both Fort Union and Wasatch forms are regarded as a transitional phase, there appears to have been no great time break between the Fort Union and Wasatch formations. A series of beds near Ignacio, Colo., mapped by Gardner [3] as Wasatch, also appears to contain a fauna intermediate between Fort Union and Wasatch. The fossils from this locality are not numerous, but they show the presence of *Coryphodon* (species not determinable) in the upper levels. The lower levels contain a phenacodont, intermediate between *Phenacodus* of the Wasatch and *Euprotogonia* of the Torrejon; *Hemiacodon* (probably a new species), a Bridger genus; and *Nothodectes* sp., a genus from Granger's Clark Fork beds [2] (species may also be identical). A few other teeth in the collection appear to be species belonging to the Clark Fork beds.

Coryphodon and *Eohippus* are not known to occur lower than the beds designated by Granger Sand Coulee beds. Therefore, as *Coryphodon* has been found in the Pumpkin Buttes locality and as Loomis has reported *Coryphodon* and *Eohippus* from the Davis ranch locality it seems reasonable that these beds should be classed with the Wasatch formation and that those at the Davis ranch should be regarded as probably equivalent to one of the lower members of this group, either the Sand Coulee or the Clark Fork of Granger.

It is evident, then, that the fresh-water beds above the Fox Hills sandstone in this part of Wyoming comprise at the base a formation 3,200 feet in thickness which bears *Triceratops* in its lower 2,000 feet and which is unquestionably Lance, at the top a formation 2,400 feet in thickness which bears *Coryphodon* and is therefore Wasatch, and intermediate between these two a formation 2,000 feet in thickness which bears Fort Union leaves in abundance and which probably represents that formation. We may therefore refer to the rocks of the Great Pine Ridge as the Fort Union of this region, and to the formation overlying it as Wasatch.

That the Wasatch rests unconformably upon the Fort Union would seem to be indicated by the following observations: At Kingsbury Ridge, 8 miles southwest of Buffalo and about 50 miles northwest of the Pumpkin Buttes, is a thick conglomerate named by Darton [4] the Kingsbury, which appears to represent a great alluvial fan, its outcrop being some 40 miles in length from north to south and 2 to 5 miles in width from east to west. (See Pl. XXIII, *B*.) It was apparently deposited by streams which flowed from the highest part of the Big Horn Mountains and which had, prior to the deposi-

[1] Matthew, W. D., The Cretaceous-Tertiary problem: Geol. Soc. America Bull., vol. 25, pp. 387–402, 1914.

[2] Granger, Walter, On the names of lower Eocene faunal horizons of Wyoming and New Mexico: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 204–205, 1914.

[3] Unpublished material.

[4] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 61, 1906.

tion of the conglomerate, cut deep valleys in the underlying beds. The conglomerate thus rests unconformably on the rocks below it, transgressing at Kingsbury Ridge strata ranging in age from Tertiary to Carboniferous. Its greatest thickness is estimated by Darton [1] as 2,500 feet. In recent Survey reports it has been treated as a member of the Fort Union formation. It is certainly younger than the Fort Union beds on which it rests toward the south, and in that direction also the conglomerate as a member thins out within a few miles, although layers a few inches to several feet in thickness can be found at or near its horizon as far south as Powder River. To the east the Kingsbury conglomerate appears to become finer grained and to finger out into the shale and sandstone of the coal-bearing beds that are now believed to be of Wasatch age. In other words, it is the writer's opinion that the Kingsbury conglomerate is equivalent to part of the Wasatch, and that the unconformity at its base separates that formation, in the Kingsbury region at least, from all older rocks.

Along the Dry Fork of Cheyenne River 35 miles south of Pumpkin Buttes and 90 miles southeast of Kingsbury Ridge there is some evidence of an unconformity between the Wasatch and underlying Fort Union beds. The Dry Fork of the Cheyenne heads in the Great Pine Ridge, and along its valley there are exposed two beds of coal stratigraphically about 160 feet apart. The lower coal bed is only a few feet above the top of the Fort Union as exposed in the Great Pine Ridge. The upper coal bed may be traced eastward along the Cheyenne Valley for about 10 miles from the ridge to a point where both the lower and upper beds are exposed, together with about 50 feet of strata underlying the lower bed. There is no indication at this locality of the highly ferruginous layers characteristic of the Fort Union. Still farther east along the Cheyenne lower rocks are exposed, including a third coal bed that lies about 220 feet below the lower coal bed above described. The rocks associated with this third bed are in appearance Wasatch rather than Fort Union. A coal bed, therefore, which at the head of the Dry Fork of the Cheyenne rests almost directly on the Fort Union beds has below it in an area 15 miles farther east at least 275 feet of strata that appear to be Wasatch, and it seems probable that an unconformity is here present between the two formations. Inasmuch, however, as the coal beds in the lower part of the Wasatch do not extend for any great distance north and south in the region of the Fort Union outcrop, and as there are, besides the coal beds, no other key rocks that are easily recognizable in the lower part of the Wasatch, it is impossible to prove conclusively the amount of the unconformity.

In summary, we find in the region southeast of the Big Horn Mountains three fresh-water formations above the marine sandstone of the Fox Hills; the lowest of these is Lance, the highest Wasatch, and the intermediate formation may reasonably be considered to be Fort Union. A local unconformity is known to exist in the vicinity of Buffalo between the Wasatch and Fort Union, and there is evidence to indicate that this unconformity is present, although less evident in other parts of the Powder River basin.

[1] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 61, 1906.

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FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Professional Paper 108—E

GEOLOGIC HISTORY INDICATED BY THE FOSSILIFEROUS DEPOSITS OF THE WILCOX GROUP (EOCENE) AT MERIDIAN, MISSISSIPPI

BY

EDWARD WILBER BERRY

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Shorter contributions to general geology, 1917

(Pages 61–72)

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GEOLOGIC HISTORY INDICATED BY THE FOSSILIFEROUS DEPOSITS OF THE WILCOX GROUP (EOCENE) AT MERIDIAN, MISSISSIPPI.

By Edward Wilber Berry.

INTRODUCTION.

The presence of erosion intervals at several horizons in the Eocene of the Gulf States has been pointed out in a recent paper,[1] and the evidence of an erosion interval between the period of deposition of the sediments of the Wilcox group (lower Eocene) and that of the Claiborne group (middle Eocene) was reviewed in some detail in a general discussion of the extensive flora of the Wilcox group of that region.[2] This evidence was not entirely conclusive and was based on the littoral character of the basal Claiborne, the occurrence of autochthonous beds of lignite at the base of the Claiborne at certain localities in the northern part of the Mississippi embayment, the great change between the Wilcox and Claiborne floras and faunas, and the reported unconformities in western Georgia [3] and in southwestern Texas.[4] Recently E. N. Lowe,[5] State geologist of Mississippi, discovered a westward extension into that State of the glauconitic shell marl of the Bashi ("Woods Bluff") formation of southern Alabama. C. W. Cooke, of the United States Geological Survey, visited this region in the spring of 1916 and collected fossil plants at Meridian, Miss. This collection contained two new and important plants, and it is the purpose of the present paper to discuss briefly these additions to the flora of the Wilcox group and the new evidence of the unconformity between the Wilcox and the Claiborne groups afforded by this outcrop.

THE LOCALITY.

The outcrop from which the fossil plants were obtained is in the southeastern part of the town of Meridian, Miss., on a hillside immediately south of the Meridian & Memphis Railway, in an extensive excavation for the fill leading to the overhead crossing of the Mobile & Ohio Railroad, 200 yards east of that crossing. The section, for which I am indebted to Mr. Cooke, shows the following sequence:

Section at Meridian, Miss.

	Feet.
Fine yellow incoherent sand with flat, disklike pebbles of clay and thin beds of clay, some of which show apparent ripple marks	15–20±
Probable unconformity.	
Gray to brown and black hackly clay, very sandy in places, with much lignitic matter; impressions of leaves abundant near the top	30±
Greenish-yellow fine incoherent glauconitic sand with large spheroidal indurated masses crowded with fossil shells (*Venericardia planicosta, Pseudoliva petrosa tuomeyi, Solariella louisiana,* etc.), characteristic of the Bashi ("Woods Bluff") formation of the Wilcox group	12

The fossil plants were collected from the end of the cut nearest to the railroad crossing, and the base of the section is a little higher than the flood plain of Souwashee Creek. The basal member contains an abundant marine fauna, which Mr. Cooke states is characteristic of the Bashi formation of the Alabama section. The overlying member is packed with plant remains in its upper layers. The following table

[1] Berry, E. W., Erosion intervals in the Eocene of the Mississippi embayment: U. S. Geol. Survey Prof. Paper 95, pp. 73–82, 1916.

[2] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, pp. 36–38, 1916.

[3] Veatch, Otto, and Stephenson, L. W., Preliminary report on the geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26, p. 228, 1911.

[4] Dumble, E. T., Some events in the Eocene history of the coastal area of the Gulf of Mexico in Texas and Mexico: Jour. Geology, vol. 23, pp. 481–498, 1915.

[5] Lowe, E. N., Mississippi, its geology, geography, soils, and mineral resources: Mississippi Geol. Survey Bull. 12, p. 71, 1915.

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enumerates those that are determinable and gives their known range:

Species of fossil plants occurring at Meridian, Miss.

	Previously known range.		
	Lower Wilcox.	Middle Wilcox.	Upper Wilcox.
Lygodium binervatum (Lesquereux) Berry	×	....	(?)
Zamia mississippiensis Berry, n. sp.	....	....	....
Sabalites grayanus Lesquereux	....	×	×
Ficus puryearensis Berry	×	×	×
Nelumbo protolutea Berry, n. sp.	....	....	....
Gleditsiophyllum eocenicum Berry	....	×	×
Dalbergites ellipticifolius Berry	....	....	×
Sapindus formosus Berry	....	×	×
Sapindus mississippiensis Berry	....	×	×
Mespilodaphne eolignitica Berry	×	×	×
Mespilodaphne pseudoglauca Berry	....	×	×
Nectandra lowii Berry	....	×	×
Combretum obovalis Berry	....	....	×
Aralia acerifolia Lesquereux	....	....	×

It will be seen that of the 14 species identified from Meridian, three occur in the lower Wilcox or Ackerman formation, eight in the middle Wilcox or Holly Springs sand, and twelve, or all but the two new species, in the upper Wilcox or Grenada formation. In addition it should be noted that several recorded from the middle Wilcox are found only near the top of that division, so that the present assemblage would be referred unhesitatingly to the upper Wilcox or Grenada formation even were its stratigraphic position unknown.

GEOLOGIC INTERPRETATION.

The Bashi formation of the Alabama section is overlain by the Hatchetigbee formation, which contains an obviously shallow-water marine fauna. It would seem indisputable that the lignitic sands overlying the glauconitic marl at Meridian correspond to the Hatchetigbee formation as it occurs to the southeast in Alabama and also to the Grenada formation as it occurs to the northwest. The Hatchetigbee fauna indicates the shallowest-water assemblage of Mollusca represented in the Alabama section of the Wilcox group.

This rather obvious correlation is not, however, the feature of especial interest in the Meridian section. The significance of that section lies in the facts that at the base the material is a glauconitic sand with an abundant fauna—obviously a shallow-water marine deposit—and that these marine sands pass imperceptibly upward into sandy lignitic clays which must be interpreted, in part at least, as true continental deposits, thus clearly presaging the withdrawal of the sea during the interval between the Wilcox and the Claiborne.

The presence of land plants and scattered lignitic material (allocthonous) in the sediments argues for the nearness of a vegetation-covered shore. The legitimate evidence in the Meridian locality, however, justifies more than this inference, for the upper layers of the middle member are not only filled with the remains of land plants but contain in addition the rootstocks and abundant leaves of what appears to be the Eocene ancestor of the American Lotus. This species (*Nelumbo protolutea*) belongs to a genus whose known living representatives are large perennial herbs growing exclusively in shallow and still fresh water, or occasionally in water that is only very slightly brackish. Were the leaves the only traces of this plant present in the deposits they might be interpreted as having been drifted into an estuary, although their great abundance in all sizes and the fact that the leaves are not deciduous but would have to be torn away from their stout petioles are opposed to such an interpretation. But inasmuch as the clays contain rootstocks which during life creep in the mud at the bottoms of ponds, and as a great abundance of rootlets permeate the clays in every direction, many of them with the root hairs preserved, it is obvious that these remains were not transported but grew on the spot where they are now found.

They thus afford a record for this locality of a period of changing conditions during which greensands carrying a marine fauna became replaced by littoral sands and muds and these in turn were overlain by the sandy muds of what was probably a shallow pond containing a vigorous growth of innumerable nelumbos or lotuses and receiving the leaves that fell from the trees along its shores.

The section at Meridian, as interpreted by Mr. Cooke, appears to show an unconformity above the plant bed, and the uppermost member—a fine yellow sand—contains disklike pebbles of waterworn clay, of a type usually associated with rather quiet wave action on beaches, and thin beds of clay that appear to have been ripple marked. These clay beds and pebbles may be local in character or they may mark the beginning of the Claiborne transgression.

The conclusion seems justified that the upper Wilcox was a time during which the open sea became gradually smaller as the strand line moved southward, and that there was an interval of emergence between the deposition of the Wilcox and that of the Claiborne group, an interval whose considerable length is indicated by the great contrasts between the terrestrial floras and the marine faunas of the Wilcox and the Claiborne.

The locality at Meridian is the southernmost point in the Wilcox outcrop where fossil plants have been found, and if this locality, so far to the south, thus clearly indicates the succession of events between the last Wilcox marine fauna and the transgressing sands of the lower Claiborne sea, it is obvious that a similar succession and a longer erosion interval characterized that great area of the Mississippi embayment which lies to the north of Meridian.

TWO NEW SPECIES OF FOSSIL PLANTS.

The two new species described below are of especial interest in that the *Nelumbo* adds an entirely new type to the Wilcox flora, representing a family hitherto unknown in that remarkable assemblage of between 300 and 400 species, and the second adds a new cycad (*Zamia*), represented by fronds, the only known cycad from the American Tertiary except a single piece of a pinnule of another species of *Zamia* from the Wilcox, previously described.[1]

Class GYMNOSPERMAE.
Order CYCADALES.
Family CYCADACEAE.
Genus ZAMIA Linné.

Zamia mississippiensis Berry, n. sp.

Although *Zamia*-like foliage is very common and widespread in Mesozoic deposits the world over and more than 30 species of *Zamia* still exist in tropical and subtropical America, including two that occur in the Floridian region, only a few cycads have thus far been discovered in Tertiary deposits anywhere. Much interest therefore attaches to the present discovery of a small-leafed form of *Zamia*.

Leaves elongate, slender, and linear. Rachis stout. Pinnules small, crowded, opposite or subopposite, bluntly pointed, constricted proximad to a relatively broad inequilateral base, attached to the sides of the top of the rachis. Length 1.25 to 1.50 centimeters; maximum width about 2 millimeters. Margins entire. Texture coriaceous. Venation consisting of eight to ten longitudinally subparallel veins, a few of them dichotomous proximad.

This characteristic *Zamia* is represented in the present collections by three specimens, two of which are shown in the accompanying figures.

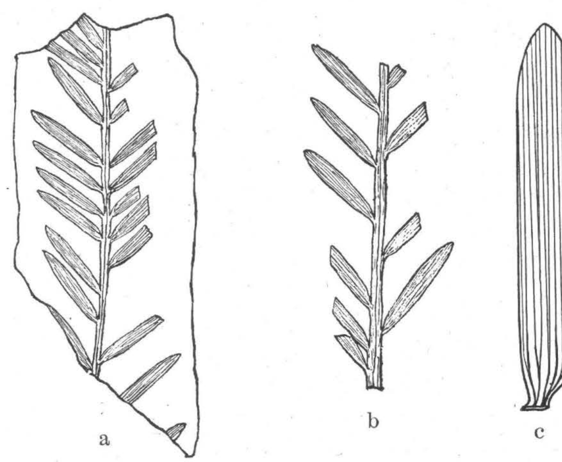


FIGURE 17.—*Zamia mississippiensis* Berry, n. sp. a, Specimen showing traces of 14 pairs of pinnules; b, specimen with slightly larger pinnules; c, pinnule enlarged 4 diameters to show form and venation.

In the specimen represented in figure 17, b, which shows a portion of the pinnule-bearing part of a rachis 4.4 centimeters long, the pinnules are slightly larger than in the other specimen figured and are more scattered, but this is due to the loss of the intervening pinnules. In the other specimen (fig. 17, a) a similar pinnule-bearing part of the rachis 4.7 centimeters long shows traces of 14 pairs of pinnules. The rachis is somewhat more slender than in the specimen shown in figure 17, b, and the pinnules are slightly smaller. The unfigured specimen shows 5 centimeters of pinnule-bearing rachis with traces of 12 pairs of pinnules.

These remains evidently represent a *Zamia* with slender, graceful leaves and much reduced pinnules, somewhat suggestive of the

[1] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 169, pl. 114, fig. 2, 1916.

existing *Zamia floridana* De Candolle, which inhabits the so-called flatwoods of the east coast of Florida south of New River.

In my account of the lower Eocene flora of southeastern North America[1] I described as *Zamia? wilcoxensis* a single broken pinnule of a cycad which I compared with the existing Floridian *Zamia pumila* Linné. It is interesting to find the remains of a second species somewhat resembling the only other living Florida species at a horizon as old as the lower Eocene. The two species, though based on a rather meager amount of material, are apparently distinct, for *Zamia? wilcoxensis* has pinnules with more than twice as many veins as the pinnules of *Zamia mississippiensis*. It is of course possible that the two occurrences represent the extremes of variation of a single lower Eocene species, but I do not regard this as probable.

Only five or six other Tertiary species of cycads are known, and most of these are based on poorly preserved or unrepresentative material. The only non-European form is an undoubted species of *Zamia* from the Eocene of Coronel, Chile, described by Engelhardt.[2] The oldest known Tertiary species is *Zamites palaeocenicus*, from the Thanetian of Gelinden, Belgium, described by Saporta and Marion.[3] Meschinelli [4] described a species from the Stampian of Venetia, Italy, which he referred to *Ceratozamites*, and two species have been recorded from the lower Miocene (Aquitanian) of Europe—a *Zamites* from southern France [5] and a well-marked *Encephalartos* from Kumi, in Greece.[6] Heer [7] recorded a species of *Zamites* from the Helvetian of Switzerland and a species of *Cycadites* from the Tortonian of that country, but both of these are rather doubtful determinations.

The small amount of material on which the present species is based is nevertheless sufficient to establish the undoubted relationship of the fossil, as the accompanying text figures show, and it is quite possible that future research will reveal other members of this interesting family in the later Tertiary deposits of this region, as the plants thus far collected from the upper Eocene and lower Oligocene are more tropical in character than those from the lower Eocene.

[1] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 169, pl. 114, fig. 2, 1916.

[2] Engelhardt, H., Ueber Tertiärpflanzen von Chile: Senckenberg. naturf. Gesell. Abh., Band 16, p. 646, pl. 2, fig. 16, 1891.

[3] Saporta, Gaston de, and Marion, A. F., Révision de la flore heersienne de Gelinden, p. 20, pl. 1, figs. 4, 5, 1878.

[4] Meschinelli, L., Studio sulla flora fossile di Monte Piano: Soc. veneto-trentina Sci. Nat. Atti, vol. 10, p. 276, pl. 6, Padua, 1889.

[5] Saporta, Gaston de, Sur la découverte d'une cycadée dans le terrain tertiaire moyen de Provence: Soc. géol. France Bull., 2d ser., tome 21, pp. 314–328, pl. 5, 1864.

[6] Saporta, Gaston de, Notice sur l' *Encephalartos gorceixianus*, cycadée fossile, du dépôt miocène de Koumi (Eubée): Soc. bot. et hort. Provence Bull., pp. 41–44, 1 pl., 1880.

[7] Heer, Oswald, Flora tertiaria Helvetiae, vol. 1, p. 46, pl. 15; pl. 16, fig. 1, 1855.

Class **ANGIOSPERMAE.**

Order **RANALES.**

Family **NYMPHAEACEAE.**

Genus **NELUMBO** Adanson.

Nelumbo protolutea Berry, n. sp.

Plates XXIV–XXVI.

Leaves of all sizes, orbicular or suborbicular in outline, peltate. Petioles stout, that of one of the smaller leaves being 5 millimeters in diameter. Margins slightly undulate. Texture coriaceous. Primaries numerous, radiating from the center of the leaf, about 25 in number (this is the number in the central fragment of the very large leaf figured in Pl. XXIV, fig. 2, as it is also in leaves not over half the size), stout, prominent on the under side of the leaves. Although all the primaries are approximately equal in size they appear to be more crowded in one-half of the leaf than in the other, as in the large leaf figured (Pl. XXIV, fig. 2), where the ratio in the one-half to the other is 10 to 15. They pursue rather uniformly straight courses but fork dichotomously three or four times; the first dichotomy is somewhat more than half the distance to the margin. The angles of the dichotomies are about 30°. In some specimens the primary remains straight and the secondaries are curved, as in the vertical primary shown in Plate XXIV, figure 2. The marginal dichotomy is tiny, and the ultimate parts of the forking of adjacent primaries are united by a broad loop or arch subparallel with the margin, as shown in Plate XXIV, figure 1, and Plate XXV, figure 2. The tertiaries are thin and percurrent, or they inosculate midway between adjacent primaries. Areolation very fine but well marked, forming isodiametric hexagonal meshes, well shown enlarged twice in Plate XXVI, figure 3.

The diameter of the larger leaf figured (Pl. XXIV, fig. 2) is estimated as 32 centimeters; that of the leaf shown in Plate XXV, figure 2, at 28 centimeters; that of the leaf shown in Plate XXV, figure 4, at 15 or 16 centimeters; and that of the small leaf shown in Plate XXV, figure 3, at 7 centimeters. The clays at this locality are packed with fragments of large leaves, so that the normal diameter seems to have been between 25 and 35 centimeters. The leaves were probably normally concave, as in the existing species, and several are preserved with the two halves of the upper surface in apposition. A fragment showing this method of preservation is shown in Plate XXV, figure 1.

Associated with the leaves are fragments of the rootstock, most of them poorly preserved but showing traces of nodes with leaf cushions and rootlet scars. In Plate XXVI, figure 2, are shown the flattened rootlets radiating from a node, and figure 1 on the same plate shows the rootlets and root hairs. Traces of rootlets are very common in the clays and serve to indicate that this species grew at the exact locality where it was preserved, as might also be inferred from its great abundance. Associated with these remains are a few rather poorly preserved oblate-spheroidal seeds, about 1.3 centimeters long and 0.8 centimeter in diameter, which I consider as representing the seeds of this species, although they are too poorly preserved for exact diagnosis. No traces of the characteristic large torus of this genus have yet been discovered at this locality.

This new species is wholly unlike any American Tertiary species heretofore known and is larger and much better preserved. Among the considerable number of European Tertiary forms it resembles somewhat *Nelumbo buchii*, from Monte Promina, in Dalmatia, as figured by Ettingshausen,[1] and *Nelumbo protospeciosum* from the Aquitanian of southern France, described by Saporta.[2] The latter is one of the most completely known fossil forms. It is represented by large and small leaves showing the details of areolation, by traces of flowers (stigmatic disks), and by seeds. Saporta considers it in the direct line of descent to the existing sacred lotus of India (*Nelumbo nelumbo*), which it certainly resembles very much. This French species is more like the Wilcox form than any other previously described, and if the two occurred at the same horizon it would be impossible to distinguish them by their foliage alone. *Nelumbo protospeciosum* is probably descended from *Nelumbo provinciale*, from the Upper Cretaceous lignites of Fuveau, in Provence, referred by Saporta to the Campanian stage but now usually considered as forming a part of the Aturian stage.

The existing species of Nelumbo are two in number, both magnificent plants. One, the Indian lotus, *Nelumbo nelumbo* (Linné) Karsten, is found in the southeastern Asiatic region from southern Japan to northern Australia and ranges westward as far as the Caspian Sea. The other, the American lotus or great water lily, *Nelumbo lutea* (Willdenow) Persoon, is found in eastern North America from Ontario and Michigan to Florida and Louisiana and southward in the West Indies and northern South America, extending as far as latitude 7° S. in Brazil.

Any genus of plants represented by but two closely related existing species, each with a comparable habitat and distribution and separated by the breadth of the Pacific Ocean, is sure to have had a long geologic history during which the ancestors of the existing species occupied the intervening land areas. That *Nelumbo* had such a history has long been known, and a considerable number of fossil species have already been described. The oldest are forms with small leaves for which I have proposed the generic term *Nelumbites*[3] and which are common in the Patapsco formation of the Potomac group in Maryland and Virginia (late Lower Cretaceous or Albian in age) and occur also in the earlier Upper Cretaceous of North America. Of about the same age or somewhat younger are *Nelumbium lusitanicum* and *Nelumbium choffati*, reported by Saporta[4] from the supposed Albian of Portugal, neither of which has been figured or adequately described.

A species of especial interest in the present connection is *Nelumbo kempii* Hollick,[5] which occurs in the Magothy formation of Long Island and New Jersey, for it appears to be

[1] Ettingshausen, Constantin von, Die eocene Flora des Monte Promina in Dalmatien: K. Akad. Wiss. Wien Denkschr., Band 8, p. 36, pl. 10, figs. 2, 3; pl. 11, fig. 1; pl. 12, 1855.

[2] Saporta, G. de, Recherches sur la végétation du niveau aquitanien de Manosque, p. 17, pl. 1, figs. 2, 3; pl. 4, figs. 1, 2, 1891.

[3] Berry, E. W., Maryland Geol. Survey, Lower Cretaceous, p. 462, 1911.

[4] Saporta, G. de, Nouveaux détails concernant les Nymphéinées: Compt. Rend., vol. 119, pp. 835–837, 1894.

[5] Hollick, Arthur, The Cretaceous flora of southern New York and New England: U. S. Geol. Survey Mon. 50, p. 61, pl. 13, figs. 1–4; pl. 14, figs. 1, 2; pl. 15; pl. 16, figs. 1–6, 1906.

the logical ancestor of *Nelumbo protolutea* of the Wilcox, thus paralleling *Nelumbium provinciale* Saporta,[1] of the Aturian of southern France, which seems to be the ancestor of *Nelumbo protospeciosum* Saporta, in turn leading to the existing Indian lotus. Other Upper Cretaceous species are *Nelumbium schweinfurthi* Couyat and Fritel,[2] from the Aturian of Assouan, Egypt; *Nelumbium arcticum* Heer,[3] from the Atane beds of western Greenland; *Nelumbo intermedia* Knowlton,[4] from the Montana group of the West; and *Nelumbo dawsoni* Hollick,[5] from the Belly River beds of Canada. The two latter are small-leafed forms, possibly referable to *Nelumbites*.

Besides several poorly characterized forms, the following more definite species may be mentioned from the Tertiary: *Nelumbo lakesianum* Lesquereux [6] and *N. tenuifolium* Lesquereux,[7] from the early Tertiary of Colorado; *N. palaeocenicum* Fritel,[8] from the Sparnacian, or lower Eocene, of the Paris Basin; *N. microcarpum* Ettingshausen,[9] from the Ypresian, or lower Eocene, of England; *N. buchii* Ettingshausen,[10] which is found at a number of localities in the Oligocene and Miocene of Europe; *N. nymphaeoides* Ettingshausen,[11] from the Oligocene of Europe; and *N. casparianum* Heer,[12] *N. ettingshauseni* Sieber,[13] and *N. hungarica* Tuzson,[14] from the Miocene of Europe. One species, *N. minima* Clement and E. M. Reid,[15] is recorded from the Pliocene of northern Europe, and the genus is also represented by rhizomes in the late Tertiary of Japan.

The remains referred to these several species comprise leaves, flower parts, rhizomes, rootlets, characteristic fruits, and seeds, and they clearly establish the once cosmopolitan range of the genus, at least in the Northern Hemisphere, and its former abundance in Europe and residence there as late as the upper Pliocene. The existing *Nelumbo nelumbo*, therefore, appears to be a species whose extinction in Europe was brought about by the unfavorable conditions that existed during the Pleistocene epoch but which survived in eastern and southern Asia, as did its only existing ally, *Nelumbo lutea*, in eastern North America, by the opportunities afforded it to withdraw southward beyond the reach of adverse conditions—opportunities which Europe, with its high east-west mountain ranges and interior seas, failed to furnish.

In order to visualize the facts set forth in the preceding discussion I have assembled them on the accompanying sketch map (fig. 18), which shows the approximate range of the two existing species of *Nelumbo* by the obliquely lined areas and such Cretaceous and Tertiary records as occur outside these areas by solid black circles.

1 Saporta, Gaston de, Le *Nelumbium provinciale:* Soc. géol. France Pal. mém. 5, 1890.

2 Couyat, J., and Fritel, P. H., Sur la présence d'empreintes végétales dans le grès nubien des environs d'Assouan: Compt. Rend., vol. 151, p. 963, 1910.

3 Heer, Oswald, Flora fossilis arctica, vol. 6, Abt. 2, p. 92, pl. 40, fig. 6, 1882.

4 Knowlton, F. H., Flora of the Montana formation: U. S. Geol. Survey Bull. 163, p. 53, pl. 13, figs. 3-5, 1900.

5 Hollick, Arthur, A new fossil *Nelumbo* from the Laramie group at Florence, Colo.: Torrey Bot. Club Bull., vol. 21, p. 309, 1894.

6 Lesquereux, Léo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 252, pl. 46, figs. 1, 2, 1878.

7 Idem, p. 253, pl. 46, fig. 3.

8 Fritel, P. H., Note sur trois nymphéacées nouvelles du Sparnacien des environs de Paris: Soc. géol. France Bull., 4th ser., vol. 8, p. 472, pl. 10, fig. 3, 1908.

9 Ettingshausen, Constantin von, Report on phyto-palaeontological investigations of the fossil flora of Sheppey: Roy. Soc. London Proc., vol. 29, p. 395, 1879.

10 Ettingshausen, Constantin von, Die eocene Flora des Monte Promina in Dalmatien: K. Akad. Wiss. Wien Denkschr., Band 8, p. 36, pl. 10, figs. 2, 3; pl. 11, fig. 1; pl. 12, 1855.

11 Idem, p. 37, pl. 10, fig. 1; pl. 11, fig. 2.

12 Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, p. 299, 1859.

13 Sieber, Johann, Zur Kenntniss der nordböhmischen Braunkohlenflora: Akad. Wiss. Wien Sitzungsber., Band 82, p. 83, pl. 2, figs. 15, 16, 1880.

14 Tuzson, Janos, A. Zsilvölgy egy új Harmadkori növénye: Magyar tud. Akad. Math. Természettud., Ert. 29, pp. 827-829, 1911; Beiträge zur fossilen Flora Ungarns: K. ung. geol. Reichsanstalt Jahrb., vol. 21, p. 257, pl. 17, fig. 3; pl. 19, figs. 2, 3; pl. 20; pl. 21, figs. 1, 2, 1914.

15 Reid, Clement and E. M., The Pliocene floras of the Dutch-Prussian border, p. 85, pl. 6, fig. 20 a, b, 1915.

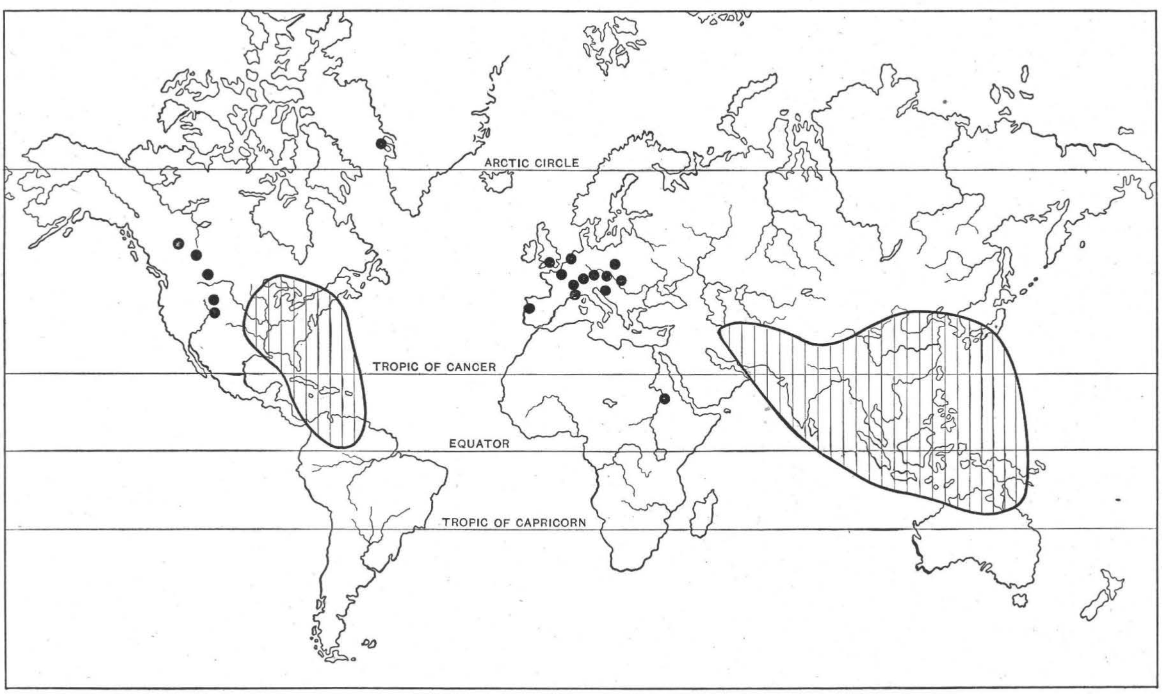
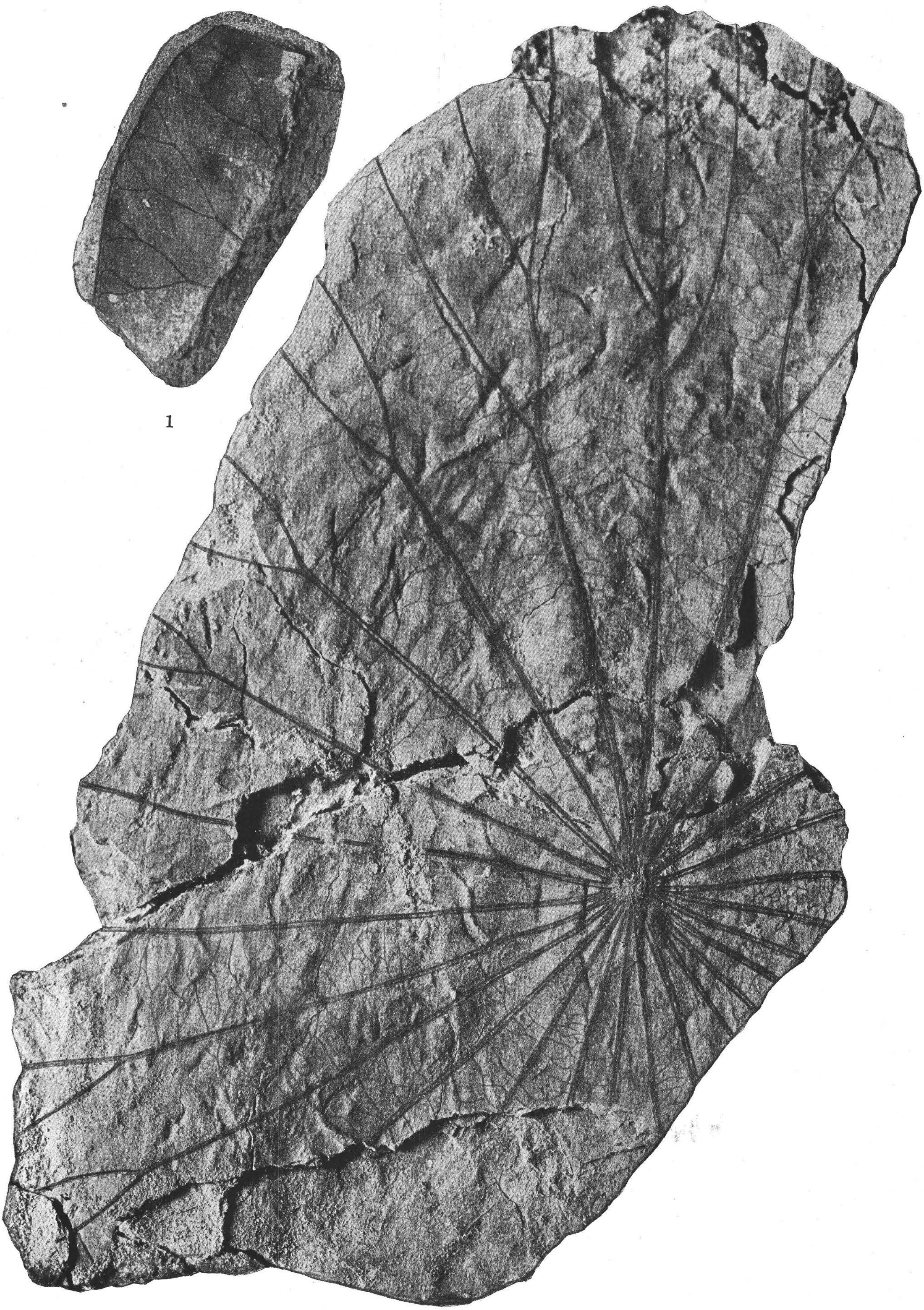


FIGURE 18.—Sketch map showing the existing and geologic distribution of *Nelumbo*.

PLATES XXIV-XXVI.

PLATE XXIV.

FIGURES 1, 2. *Nelumbo protolutea* Berry, n. sp., from the Grenada formation at Meridian, Miss.
1. Specimen showing margin and marginal venation of a small leaf.
2. Specimen showing the central part of a large leaf.



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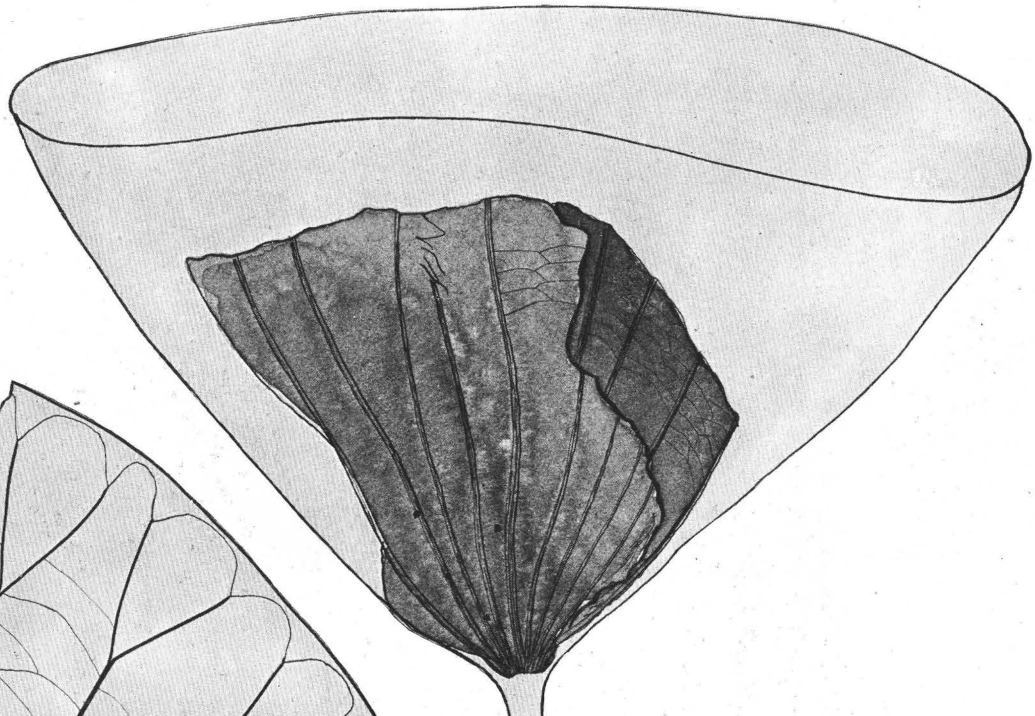
NELUMBO PROTOLUTEA BERRY.



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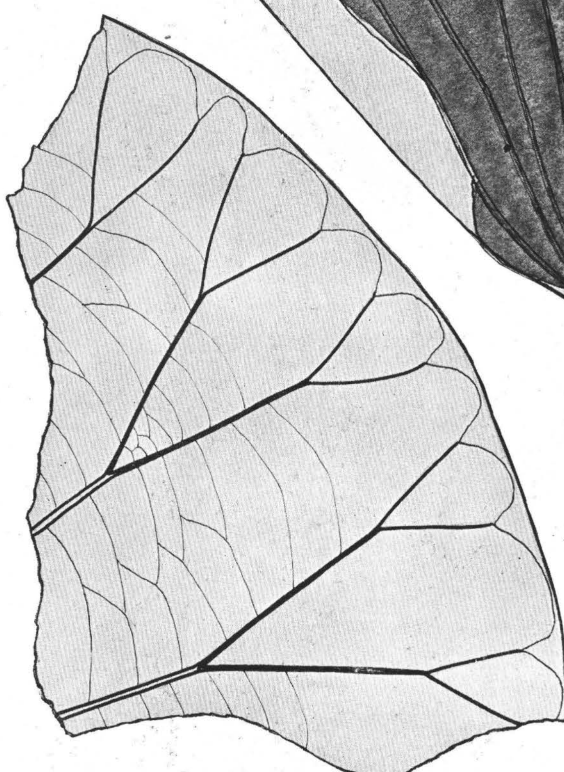

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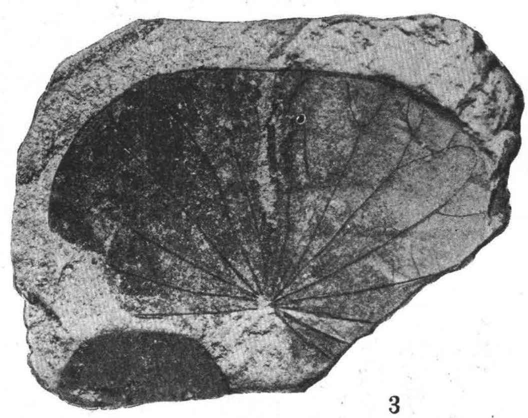

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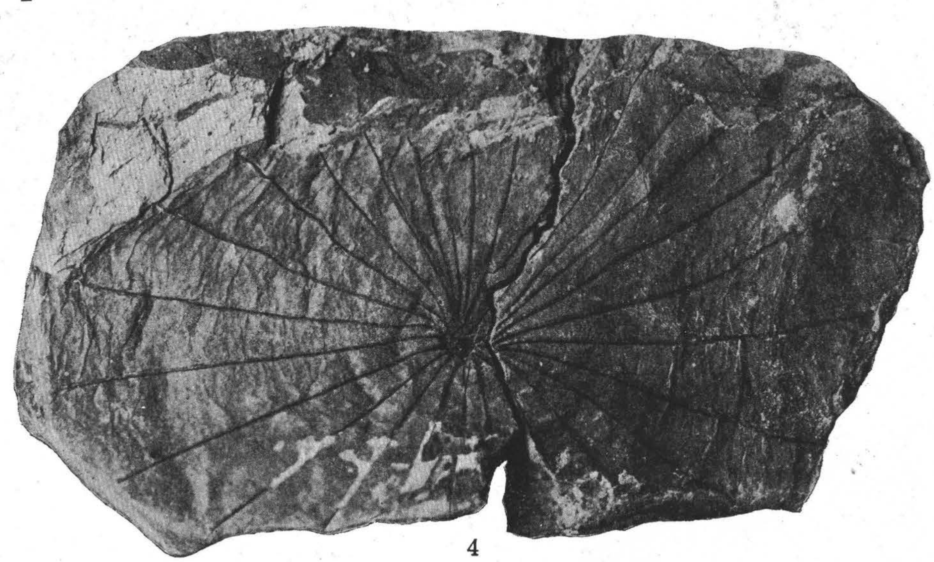

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NELUMBO PROTOLUTEA BERRY.

PLATE XXV.

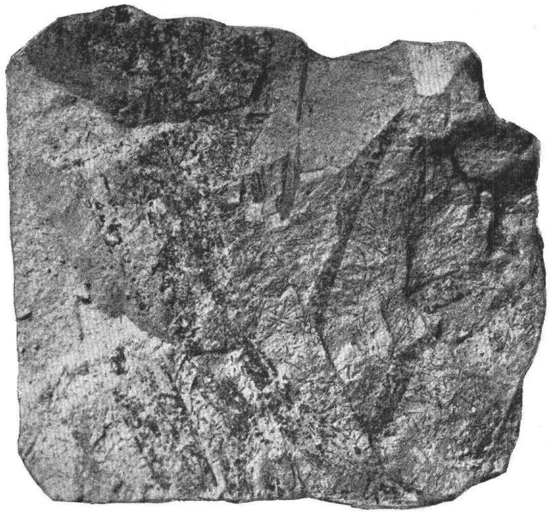
FIGURES 1–4. *Nelumbo protolutea* Berry, n. sp., from the Grenada formation at Meridian, Miss.

1. Specimen showing part of the under and upper surfaces of a small funnel-shaped leaf.
2. Specimen showing margin and marginal venation of a large leaf.
3. Specimen showing part of a very small leaf.
4. Specimen showing the central part of a medium-sized leaf.

PLATE XXVI.

FIGURES 1–3. *Nelumbo protolutea* Berry, n. sp., from the Grenada formation at Meridian, Miss.

1. Specimen showing rootlets and root hairs.
2. Specimen showing rootlets radiating from the node of a crushed rootstock.
3. Fragment of a large leaf, enlarged 2 diameters, to show the well-marked hexagonal areolation and other details of the venation.



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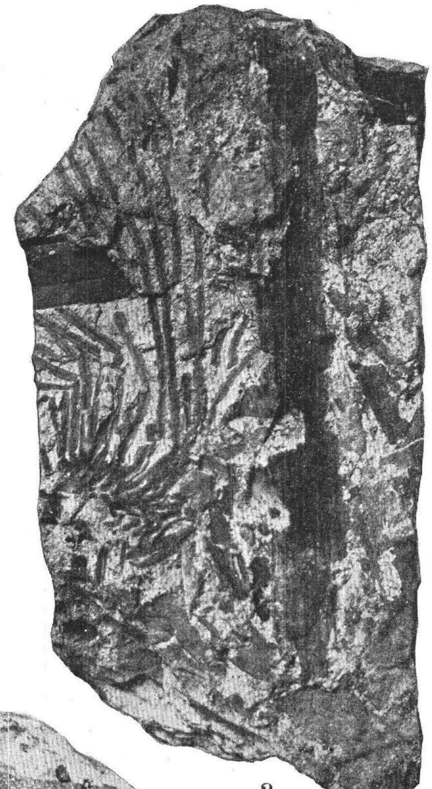

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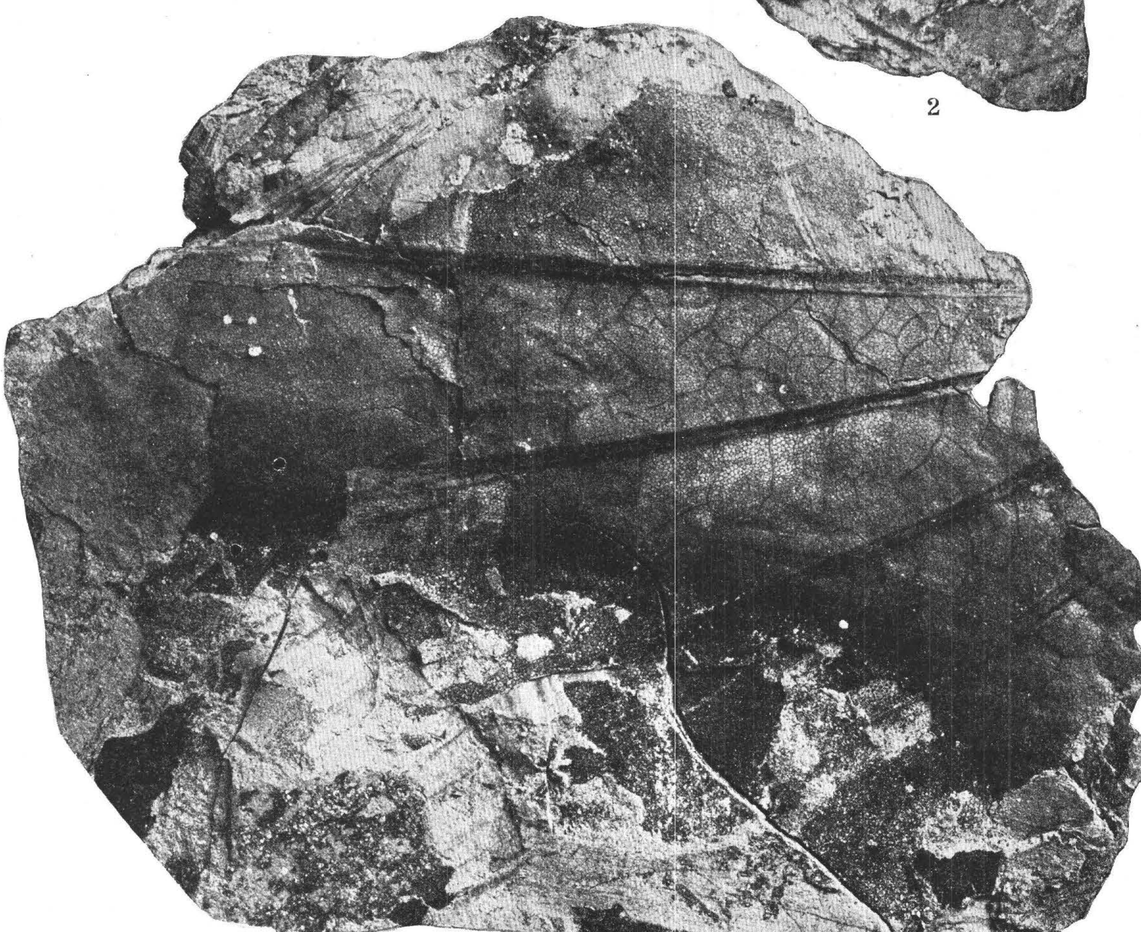

3 X2

NELUMBO PROTOLUTEA BERRY.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 108—F

A FOSSIL FLORA FROM THE FRONTIER FORMATION OF SOUTHWESTERN WYOMING

BY

F. H. KNOWLTON

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(Pages 73-107)

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CONTENTS.

ILLUSTRATIONS.

A FOSSIL FLORA FROM THE FRONTIER FORMATION OF SOUTHWESTERN WYOMING.

By F. H. Knowlton.

INTRODUCTION.

This paper deals with a small but important fossil flora, now known to be of Colorado age, from the vicinity of Cumberland, Lincoln County, Wyo. It was for many years thought to be of Jurassic age, and only within the last decade has its stratigraphic position been established. Although small in number of species, this flora offers information bearing on the physical and climatic conditions that prevailed during early Upper Cretaceous time in this region, and, moreover, it furnishes a series of stratigraphic marks that may be used in the recognition of this horizon elsewhere. It has also a possibly important biologic bearing, for it shows the presence of certain plant types that are now found living in Polynesia. The presence of certain types of insects that lived in and on the plants is shown by their characteristic markings. Finally, this study has a historical and sentimental interest because it is based on material collected on the celebrated Frémont exploring expedition more than 70 years ago and now rediscovered and redescribed.

The fossil plants to be described in this paper were discovered in 1843 by Capt. John C. Frémont, while engaged on an exploring expedition that had for its object the finding of a "new and better road" over the mountains and plains to Oregon and northern California. On August 19, 1843, the expedition turned north from Fort Bridger, on the old Oregon Emigrant Road, and soon passed over Muddy Creek, near the present site of Carter, Uinta County, Wyo. The fossil plants were found somewhat farther north, on Little Muddy Creek, near the present line between Uinta and Lincoln counties. Frémont's description [1] of the discovery of the fossil plants is as follows:

[1] Frémont, J. C., Report of the exploring expedition to the Rocky Mountains in the year 1842, and to Oregon and north California in the years 1843–44: Twenty-eighth Cong., 2d sess., House Ex. Doc. 166, p. 131, 1845.

> August 19: A few miles from our encampment [of August 18] the road entered a high ridge connecting the Utah with the Mud River chain; and in one of the hills near which we passed I remarked strata of a conglomerate formation. We crossed a ridge of this conglomerate and descended upon one of the heads of Hams Fork, called Muddy, where we made our midday halt. In the river hills at this place I discovered strata of fossiliferous rock having an oolite structure, which, in connection with the neighboring strata, authorize us to believe that here, on the west side of the Rocky Mountains, we find repeated the modern formations of Great Britain and Europe, which have hitherto been wanting to complete the system of North American geology. * * *
>
> In the afternoon we continued our road and, searching among the hills a few miles up the stream and on the same bank, I discovered among alternating beds of coal and clay a stratum of white indurated clay containing very clear and beautiful impressions of vegetable remains. This was the most interesting fossil locality I had met in the country, and I deeply regretted that time did not permit me to remain a day or two in the vicinity. * * * After remaining here only about an hour, I hurried off, loaded with as many specimens as I could conveniently carry.

These plants were referred to James Hall,[1] then paleontologist to the State of New York, who named, described, and figured most of them in an appendix to Frémont's report. Hall also gave the following additional information concerning the locality, evidently derived from Frémont's notes:

> Longitude 111°, latitude 41½°, Muddy River: These specimens are of a yellowish-gray oolitic limestone, containing turbo, cerithium, etc. The rock is a perfect oolite and, both in color and texture, can scarcely be distinguished from specimens of the Bath oolite. One of the specimens is quite crystalline, and the oolitic structure somewhat obscure. In this instance the few fossils observed seem hardly sufficient to draw a decisive conclusion regarding the age of the formation; but, when taken in connection with the oolitic structure of the mass, its correspondence with the English oolites, and the modern aspect of the whole, there remains less doubt of the propriety of referring it to the oolitic period. A further collection from this interesting locality would doubtless

[1] Hall, James, Descriptions of organic remains collected by Capt. J. C. Frémont in the geographical survey of Oregon and north California: Idem, Appendix B, pp. 304–307, pls. 1, 2, 1845.

develop a series of fossils which would forever settle the question of the relative age of the formation.

A few miles up this stream Capt. Frémont has collected a beautiful series of specimens of fossil ferns. The rock is an indurated clay, wholly destitute of carbonate of lime, and would be termed a "fire clay." These are probably, geologically as well as geographically, higher than the oolite specimens, as the rocks at this place were observed to dip in the direction of N. 65° W. at an angle of 20°. This would show conclusively that the vegetable remains occupy a higher position than the oolite. Associated with these vegetable remains were found several beds of coal differing in thickness.

The stratum containing the fossil ferns is about 20 feet thick, and above it are two beds of coal, each about 15 inches. These are succeeded by a bed of sandstone. Below the bed containing the ferns there are three distinct beds of coal, each separated by about 5 feet of clay. Before examining the oolitic specimens just mentioned I compared these fossil ferns with a large collection from the coal measures of Pennsylvania and Ohio, and it was quite evident that this formation could not be of the same age. There are several specimens which I can only refer to the *Glossopteris phillipsii* (see description), an oolitic fossil; and this alone, with the general character of the other species and the absence of the large stems so common in the coal period, had led me to refer them to the oolitic period. I conceive, however, that we have scarcely sufficient evidence to justify this reference; and though among the fossil shells there are none decidedly typical of the oolite, yet neither are they so of any other formation; and the lithological character of the mass is not reliable evidence. Still, viewed in whatever light we please, these fossil ferns must, I conceive, be regarded as mostly of new species and in this respect form a very important addition to the flora of the more modern geological periods.

From the foregoing statement it appears that, although Hall tentatively referred these plants to the Oolite—that is, to the Upper Jurassic—as perhaps the best disposition that could be made under the circumstances, he was by no means certain of their age.

For more than 40 years after these plants were described and figured by Hall they remained in obscurity and practically lost. In 1887 I found some of them, including five of the figured types, in the United States National Museum. They were without adequate labels and were thickly covered with dust and mingled with other material of miscellaneous and unknown origin. How they came into the possession of the National Museum, or where the rest of the collection is—if, indeed, it is in existence—is not now known.

The great interest that attaches to these plants was recognized by me, and as Prof. Leo Lesquereux was at that time engaged in studying and naming the miscellaneous fossil-plant material in the National Museum, they were sent to him for restudy, and his report was published[1] in 1888. Lesquereux changed a number of Hall's generic references—for example, *Sphenopteris* and *Trichopteris* to *Thyrsopteris*—but was evidently somewhat confused by the presence of apparent dicotyledonous leaves, which he forced into or compared with certain genera of ferns and cycads. He referred them to the Jurassic, his statement being as follows: "What seems to me to be conclusive of the oolitic age of the plants is the number of fragments of small ferns referable to the genus *Thyrsopteris*, of which Heer has described a number of species from the Jurassic of Siberia."

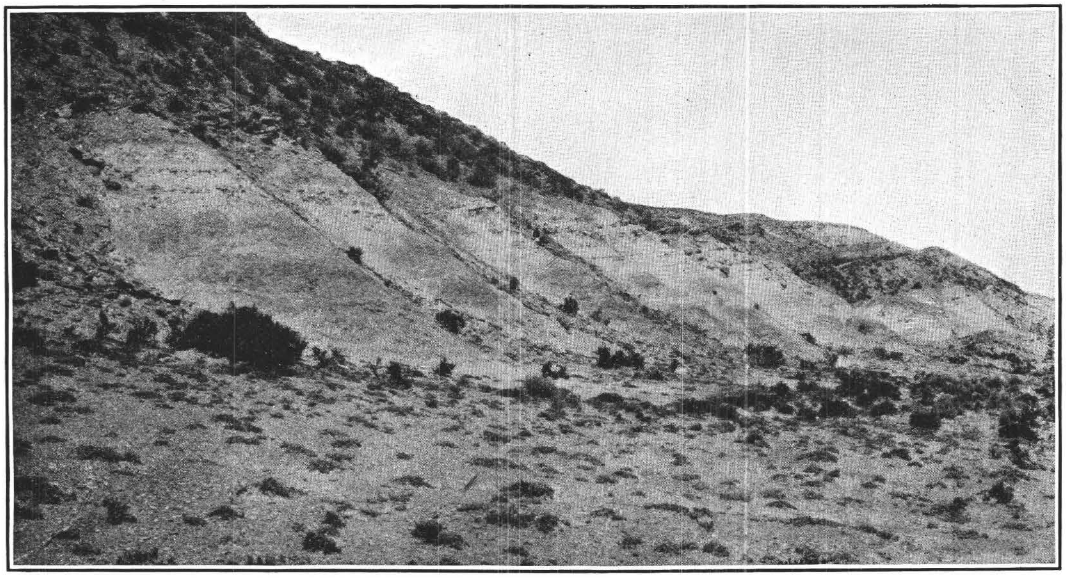
To return to the field relations of these plants, it appears that none of the Government expeditions that operated in this region after the early explorations of Frémont had happened to find the beds containing them, though they are now known to be conspicuous. A. C. Peale, of the Hayden Survey, studied the region a few miles to the north of the Cumberland area during the field season of 1877. He was therefore familiar in a general way with the stratigraphy of this part of Wyoming, and in 1898 he attempted to determine, in the office, from Frémont's account, the locality whence these fossils came but was not able to reach a satisfactory conclusion. The matter then rested for several years, until 1905.

When A. C. Veatch, of the United States Geological Survey, began his study of the coal and oil fields of this general region, Peale called his attention to this unique material and to the desirability of determining the true stratigraphic position of the original locality and of procuring additional collections. From the knowledge Veatch soon acquired of the region, as well as from a careful consideration of the original notes of Frémont and Hall quoted above, the locality that furnished these plants was determined to be on the south bank of Little Muddy Creek, about 1 mile east of the present town of Cumberland. The account of this rediscovery was first given by Veatch[2] in a short article published in June, 1906, and more at length in his formal report[3] on the region in 1907.

[1] Lesquereux, Leo, Recent determinations of fossil plants from Kentucky, Louisiana, Oregon, etc., with descriptions of new species: U. S. Nat. Mus. Proc., vol. 11, pp. 37, 38, 1888.

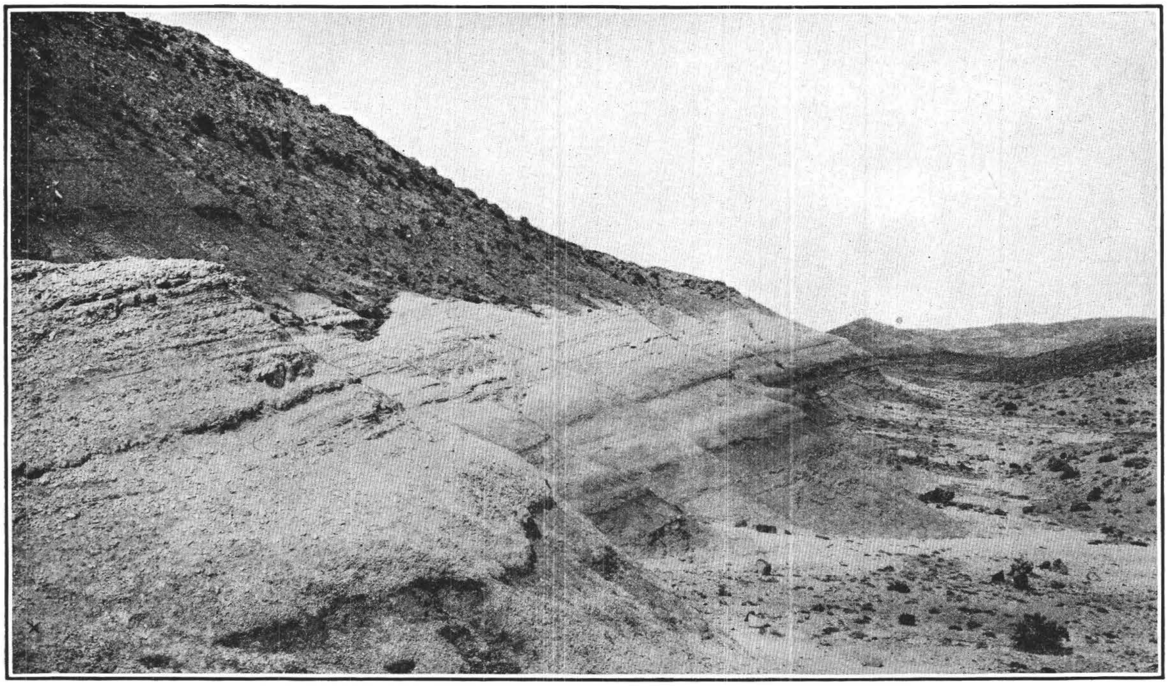
[2] Veatch, A. C., Age and type locality of the supposed Jurassic fossils collected north of Fort Bridger, Wyo., by Frémont in 1843: Am. Jour. Sci., 4th ser., vol. 21, pp. 457-460, 1906.

[3] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 65-69, 1907.



A. PLANT-BEARING SHALE IN FRONTIER FORMATION, 1 MILE EAST OF CUMBERLAND, WYO.

Photograph by T. W. Stanton.



B. WHITE PLANT-BEARING SHALE IN FRONTIER FORMATION SOUTH OF LITTLE MUDDY CREEK, NEAR CUMBERLAND, WYO.

Probably very near the original Frémont locality. Photograph by T. W. Stanton.

Veatch made a considerable collection of plants on the north side of Little Muddy Creek, in sec. 29, T. 19 N., R. 116 W., and in this collection the matrix, as well as a number of species, are absolutely identical with the original material collected by Frémont and preserved in the United States National Museum. There can be no doubt, therefore, that the beds from which Veatch's collection was obtained are not only at the same horizon but at the same or approximately the same locality as that which furnished the Frémont collection of 1843.

STRATIGRAPHIC RELATIONS.

The plants described in this paper occur in what is now known as the Frontier formation. This formation was named by W. C. Knight[1] in 1902 from the coal town of Frontier, near which the beds are well exposed. It was defined as being "composed of very thick beds of compact sandstone, with shales and coals having an approximate thickness of 2,000 feet." Knight stated that it was characterized by the presence of *Ostrea soleniscus*, a long, slender oyster which has a maximum length of 12 inches, but subsequent study has shown that this species also occurs several thousand feet above the designated top of the Frontier formation.

The Frontier formation was further described by Veatch[2] as follows:

> The pronounced sandstone layer or group of sandstone layers, occasionally conglomeratic and containing numerous specimens of the elongate oyster mentioned, produces a pronounced ridge, which was named Oyster Ridge by Hayden in 1872. This name was adopted by the King Survey and used on the maps of that organization. This group of sandstones has therefore been named the Oyster Ridge sandstone member of the Frontier formation. At several places minor sandstones or oyster-bearing ridges occur above the Oyster Ridge sandstone. * * * The Oyster Ridge sandstone is generally about 200 feet thick. Beneath the Oyster Ridge sandstone there are other sandstone layers, which produce pronounced ridges, but these, except near the northern extremity of the map, are definitely separated from and not readily confused with the main Oyster Ridge sandstone. The total thickness of this formation ranges from 2,200 to 2,600 feet. It is exposed along the east side of Mammoth Hollow throughout this area, and on the west side north of Hams Fork and between Little Muddy and Clear creeks. It outcrops west of the great Absaroka fault from the Evanston-Fort Bridger road south to Sulphur Creek.

[1] Knight, W. C., Coal fields of southern Uinta County, Wyo.: Geol. Soc. America Bull., vol. 13, pp. 542-544, 1902.

[2] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 65, 1907.

The stratum that undoubtedly supplied the plants collected by Frémont and that was rediscovered by Veatch is about 1,200 feet below the top of the Oyster Ridge sandstone. It is also below the several minor sandstone ridges mentioned by Veatch. The fossiliferous layer is a hard, brittle white clay only a few inches thick, in the midst of white clay shales, which in the exposure near Cumberland are about 30 feet thick. (See Pl. XXVII.) This almost snow-white band of shales is very conspicuous and may be traced for miles. The layer containing the plants was found to be fossiliferous at nearly every foot of its exposure, and in some places it is literally packed with remains, especially ferns, which, at least at the Cumberland locality, are the dominant types. This great abundance of plants in the bed makes it difficult to procure large or perfect specimens.

AGE OF THE FRONTIER FORMATION.

As already stated the plant-bearing bed discovered by Frémont and now placed in the Frontier formation was tentatively regarded by Hall as of Jurassic age, and this reference was accepted by Lesquereux, who restudied a portion of the original collection in 1888. Long before this date, however, the beds had come to be recognized as belonging to the Upper Cretaceous. Thus, in 1870, when Hayden[3] gave the name Oyster Ridge to the conspicuous sandstone ridge near Sulphur Creek, he said: "It [Oyster Ridge] is composed mostly of gray and yellow-gray sandstone, capped with a calcareous sandstone, filled with a small species of *Ostrea*, and belongs, I think, to the upper portion of the Cretaceous group—probably No. 5." This is a virtual reference to the Fox Hills sandstone, though that term was not actually employed.

Later, however, Oyster Ridge was directly referred to the Fox Hills by both the Hayden and the King surveys, and it is so assigned on the map of this region published by the King Survey.

It is difficult to ascertain just when the Oyster Ridge sandstone and the associated sandstones, shales, and coals of the Frontier formation were first regarded as of Colorado age. At least as early as 1877 Meek[4] described invertebrates that he recognized as of this age,

[3] Hayden, F. V., Geology of the Missouri Valley: U. S. Geol. Survey Terr., Prel. Rept. for 1870, p. 149, 1871.

[4] Meek, F. B., U. S. Geol. Expl. 40th Par. Rept., vol. 4, pl. 1, p. 143, 1877.

from the vicinity of Sulphur Creek, 3 miles west of Oyster Ridge, where they occur in a heavy sandstone which is the same as the Oyster Ridge sandstone but is in the western limb of the syncline.

This condition was also recognized and briefly alluded to in 1892 by Stanton.[1] In a longer paper published the following year Stanton [2] described a number of the invertebrates from the Sulphur Creek area which he regarded as of undoubted Colorado age.

Although Knight,[3] when he named the Frontier formation, did not definitely fix its age, he took occasion to say that he could "not find a Fox Hills fauna such as is common to the Fox Hills of the eastern part of Wyoming" and, at least by inference, placed it lower than Fox Hills. Veatch [4] also obtained evidence which in his opinion strengthened the reference of the formation to the Colorado. He also mentions the discovery of numerous specimens of *Inoceramus exogyroides*, an invertebrate held to be of Benton age, 3,000 feet above the top of the formation, or approximately in the middle of the overlying Hilliard formation. Mr. Stanton informs me that he has since procured a distinctly Benton fauna from the same sandstone lentil from which Veatch collected, in the Hilliard formation about 3,000 feet above its base. Mr. Stanton has been kind enough to supply the following account of the invertebrates and their occurrence:

The evidence from the invertebrate faunas that the Frontier formation and the lower half of the Hilliard formation are of the age of the Colorado group was presented by Veatch [5] in 1907. Most of the Frontier invertebrates then known came from the upper part of the formation and from localities near the Union Pacific Railroad, 20 to 30 miles south of Cumberland. They include a number of very characteristic Colorado group species, which, in connection with the known stratigraphic relations and the fauna of the underlying beds, justified the reference of the whole Frontier formation, including the plant-bearing bed near Cumberland, to the Colorado group.

Later collections and observations have confirmed and strengthened the evidence for the Colorado age of both the Frontier formation and the lower 3,000 feet or more of the overlying Hilliard formation, and they have a more direct bearing on the age of the plant bed because their relations to it are definitely determined. The white shales associated with the plant bed may be traced along the strike for many miles north and south of Cumberland. To the north they have been recognized near Glencoe, Oakley, and as far as Kemmerer, holding the same position far beneath the Kemmerer coal, which is mined at all these places. Two collections received from the late Robert Forrester have been identified as follows:

120 feet above Kemmerer coal, near Oakley, Wyo.:

- Ostrea sp.
- Inoceramus related to I. deformis Meek.
- Inoceramus sp.
- Veniella goniphora Meek.
- Baculites gracilis Shumard?
- Scaphites ventricosus Meek and Hayden?

Roof of Kemmerer coal, Glencoe mine, Glencoe, Wyo.:

- Ostrea sp.
- Avicula gastrodes Meek.
- Inoceramus labiatus Schlotheim?
- Nemodon? sp.
- Cardium pauperculum Meek.
- Mactra? sp.
- Corbula sp.
- Melania? sp.
- Scaphites ventricosus Meek and Hayden.

All the identified forms in these two lots are characteristic of the fauna of the Colorado group, and most of them in other regions would indicate the upper part of the group, but in this western Wyoming area the Upper Cretaceous sediments are abnormally thick and many species seem to have an unusual vertical range, indicating rapid sedimentation. Thus the sandstone lentils near the middle of the Hilliard formation about 3 miles northwest of Kemmerer, though fully 3,000 feet above the horizon of the two collections last mentioned, still yield a characteristic Colorado fauna. Veatch recorded the presence of *Inoceramus exogyroides* in these lentils and correctly assigned the beds to the Colorado group. In 1913 I collected from these sandstones, which, according to Veatch, lie from 3,000 to 3,800 feet above the base of the Hilliard formation, the following species:

- Ostrea soleniscus Meek.
- Avicula gastrodes Meek?
- Inoceramus umbonatus Meek and Hayden.
- Inoceramus exogyroides Meek and Hayden.
- Inoceramus cf. I. undabundus Meek and Hayden.
- Inoceramus fragilis Hall and Meek?
- Cardium pauperculum Meek.
- Cyprimeria? sp.
- Donax oblonga Stanton.
- Tellina? sp.
- Mactra emmonsi Meek.
- Mactra sp.
- Martesia? sp.
- Pugnellus fusiformis (Meek).
- Placenticeras sp. cf. P. pseudoplacenta Hyatt.

None of the species in this list is known to range above the Colorado group. The first two species of *Inoceramus* are especially abundant and are characteristic of a horizon near the top of the Colorado not far below the Eagle sandstone on Missouri River below Fort Benton, Mont. The *Donax* and the *Pugnellus* are equally characteristic of a sandstone in the Colorado group above the principal coal bed at Coalville, Utah.

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[1] Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, p. 105, 1892.

[2] Stanton, T. W., The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, 1893.

[3] Knight, W. C., Coal fields of Southern Uinta County, Wyo.: Geol. Soc. America Bull., vol. 13, p. 543, 1902.

[4] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 69, 1907.

[5] Veatch, A. C., op. cit., pp. 66-68, 71, 72.

The evidence of the plants as to the age of the beds containing them was first believed to be in substantial accord with that of the invertebrates. In my report[1] on the plants collected by Veatch I made the following statement regarding their position: "The age, so far as I am able to fix it, is the lower part of the Upper Cretaceous, about the position of the Turonian, possibly a little lower."

The Colorado age of the Frontier formation, as based on stratigraphic position and the evidence of the invertebrates, is here accepted. It is but fair to state, however, that the critical study of the plants does not lend conclusive support to their reference to the Colorado. Inasmuch as practically all the forms are new to science, the interpretation of their bearing on the question of age must be made through their affinities, and these, so far as they can be made out, appear to favor a position stratigraphically higher than the Colorado. This evidence may be briefly reviewed as follows:

The spleenwort (*Asplenium occidentale*) belongs to the same group as and is pretty closely related to an unpublished species from the Farmington sandstone member of the Kirtland shale (Montana group) of San Juan County, N. Mex. The shield fern (*Dryopteris coloradensis*) is strongly suggestive of an unpublished species from the Vermejo formation of the Raton Mesa region of Colorado and New Mexico. The *Anemia* is very closely related to and perhaps identical with a species common in the Eocene of Europe but also reported from the Montana at Point of Rocks, Wyo. Among the dicotyledons, *Cinnamomum hesperium* is hardly distinguishable, except in size, from *Cinnamomum wardii*, from the upper part of the Adaville formation at Hodges Pass, a few miles north of the Cumberland localities. *Dewalquea pulchella* and *Dryandroides lanceolata* are so close to *Dewalquea insignis* and *Dryandroides quercinea*, respectively, from the Upper Senonian of Westphalia, that it is perhaps doubtful if they should be maintained as distinct. *Quercus stantoni* is very similar to *Quercus formosa*, also from the Senonian of Westphalia. *Ficus fremonti* agrees in shape with *Ficus proteoides* Lesquereux, and in shape, size, and nervation with *Ficus lanceolata acuminata* Ettingshausen, as figured by Lesquereux, from the Dakota sandstone. This is the only species that appears to show any special likeness to forms from beds whose position is lower than that assigned to the plant beds at Cumberland.

The foregoing is not the only evidence for assigning the Frontier formation to a position higher than the Colorado, though the additional evidence is not so strong as it was supposed at one time to be. In 1907 A. R. Schultz, of the United States Geological Survey, began an investigation of the coal resources of the so-called Rock Springs dome, about 75 miles east of the Cumberland area. Incidentally to this study Schultz procured a number of very interesting collections of fossil plants, mainly from thin, indurated clay partings in coal. The age of these plants has been fixed as near the middle of the Mesaverde formation (Montana group), in what has been called the Rock Springs coal group. The most abundant plants are ferns of the genera *Gleichenia* and *Anemia*, and the dicotyledons are comparatively few. This flora has a facies strikingly similar to that of the flora from the Frontier formation, and as several species appeared to be in common, I held that the plant-bearing beds at Cumberland and Rock Springs were identical in age. A critical study of the Frontier flora, however, discloses the fact that there are apparently no dicotyledons and few if any ferns common to the two areas.

GENERAL FEATURES OF THE FLORA.

SPECIES NOW RECOGNIZED.

Before proceeding to a discussion of the various aspects of this flora, it will be of interest to present the following complete list of the forms now recognized:

Tapeinidium? undulatum (Hall) n. comb.
Microtaenia variabilis n. gen. and n. sp.
Microtaenia paucifolia (Hall) n. comb.
Dennstaedtia? fremonti (Hall) n. comb.
Dryopteris coloradensis n. sp.
Asplenium occidentale n. sp.
Anemia fremonti n. sp.
Equisetum sp.
Smilax? coloradensis n. sp.
Myrica nervosa n. sp.
Salix cumberlandensis n. sp.
Salix frontierensis n. sp.
Quercus stantoni n. sp.
Ficus fremonti n. sp.
Ficus? sp.
Ficus? sp.
Cinnamomum hesperium n. sp.
Cinnamomum? sp.

[1] Knowlton, F. H., in Veatch, A. C., Age and type localities of supposed Jurassic fossils collected north of Fort Bridger, Wyo., by Frémont in 1843: Am. Jour. Sci., 4th ser., vol. 21, p. 459, 1906.

Dryandroides lanceolata n. sp.
Aralia veatchii n. sp.
Staphylea? fremonti n. sp.
Dewalquea pulchella n. sp.
Phyllites ficifolia n. sp.
Phyllites dentata n. sp.
Phyllites.

LOCALITIES AND COLLECTORS.

1. Probably on the south bank of Little Muddy Creek about 1 mile east of the present town of Cumberland, Wyo. Collected by J. C. Frémont August 19, 1843. Below is a list of the species described by Hall with their present disposition:

Sphenopteris fremonti Hall=Dennstaedtia? fremonti.
Sphenopteris triloba Hall=Microtaenia paucifolia.
Sphenopteris? paucifolia Hall=Microtaenia paucifolia.
Sphenopteris? trifoliata Hall.
Glossopteris phillipsi?=Ficus fremonti.
Pecopteris undulata Hall=Tapeinidium? undulatum.
Pecopteris undulata var.=Tapeinidium? undulatum.
Pecopteris? odontopteroides Hall=Tapeinidium? undulatum.
Trichopteris filamentosa Hall=rootlets of ferns.
Trichopteris gracilis Hall=rootlets of ferns.
Leaf of dicotyledonous plant?=Phyllites fremonti Unger.[1]

2. North branch of Little Muddy Creek 1 mile east of Cumberland, Wyo. Collected by A. C. Veatch August 3, 1906.

Tapeinidium? undulatum.
Dryopteris coloradensis.
Equisetum sp.
Aralia veatchii.
Dewalquea pulchella.

3. Approximately same locality as No. 2. Collected by T. W. Stanton and F. H. Knowlton August 5, 1908.

Tapeinidium? undulatum.
Microtaenia variabilis.
Microtaenia paucifolia.
Dennstaedtia? fremonti.
Asplenium occidentale.
Anemia fremonti.
Ficus fremonti.
Staphylea? fremonti.
Phyllites ficifolia.
Insect mine in leaflet of Staphylea.

4. Mine No. 1, Cumberland, Wyo. Collected by F. H. Knowlton August 6, 1908.

Smilax? coloradensis.

[1] This is apparently not from the Frontier formation but probably from the Green River formation 40 or 50 miles east of the Cumberland locality. (See p. 94.)

5. About half a mile east of Cumberland, Wyo. Collected by T. W. Stanton and F. H. Knowlton August 5, 1908.

Ficus? sp.
Ficus? sp.
Cinnamomum? sp.

6. About 1 mile east of Cumberland, Wyo. Same horizon as principal Cumberland locality but at a slightly different point. Collected by A. C. Peale August 18, 1909.

Ficus fremonti.
Aralia veatchii.

7. About $1\frac{1}{2}$ miles south of Cumberland, Wyo., in the SE. $\frac{1}{4}$ sec. 6, T. 18 N., R. 116 W. Same horizon as locality 1 mile east of Cumberland, and probably near the original Frémont locality. Collected by T. W. Stanton September 1, 1913.

Tapeinidium? undulatum.
Myrica nervosa.
Salix cumberlandensis.
Salix.
Quercus stantoni.
Ficus fremonti.
Cinnamomum hesperium.
Dryandroides lanceolatum.
Phyllites dentata.
Phyllites.

8. About 1 mile east of Oakley and 3 miles southeast of Kemmerer, Wyo., in the SW. $\frac{1}{4}$ sec. 3, T. 21 N., R. 115 W. Collected by T. W. Stanton September 2, 1913.

Ficus fremonti.
Quercus stantoni.
Fragments of dicotyledons, not determinable.

BIOLOGIC ASPECTS OF THE FLORA.

The known flora from the Frontier formation near Cumberland embraces 25 forms, of which 7 are ferns, 1 an *Equisetum*, 1 a monocotyledon (*Smilax*), and the remaining 16 dicotyledons. As regards the relative abundance of the different types, it is probable that the ferns outnumber the other forms by perhaps two to one. Several of the dicotyledons are based on single specimens, but there is hardly a piece of matrix without fragments of ferns.

The first four species of ferns enumerated in the list on page 77 possess great biologic interest. They form a natural group that, from their peculiar and well-marked type of fructification, marks them as being undoubtedly davallioid—that is, clearly allied to the group of mainly tropical ferns of which the genus *Davallia* is the central form. They are entirely unlike anything now living in the New World and appear to find their closest relatives among species now living in Polynesia. Thus the *Tapeinidium*, although far from being conspecific with any living form of the genus, appears to be most closely related to *Tapeinidium pinnatum* (Cavanilles) C. Christensen, a species widely dispersed in Malaysia and Polynesia. The two species called *Microtaenia* are so wholly unlike any living or fossil form known that it has been necessary to create a new genus for their reception. They are very abundant in individuals, showing that they formed a well-established element in the Frontier flora. The species referred to *Dennstaedtia* is not so well established as either of the first three forms in the list and is based on a few fragments that may possibly represent an extreme modification of *Microtaenia paucifolia*. The genus *Dennstaedtia* is a large group comprising more than 60 species. They are of wide, mainly tropical distribution, only one species (*D. punctilobula*), the so-called hay-scented fern, inhabiting North America; this species is quite unlike the fossil form under discussion.

The single species of shield fern (*Dryopteris*) is of an ordinary type, but the spleenwort (*Asplenium occidentale*) belongs in the group of living species of which *A. hemitonites* Linné is the type. *Anemia* is also a large genus of almost exclusively tropical American forms, only two inhabiting the United States—one in peninsular Florida, the other in southern Texas and extending into adjacent parts of Mexico.

The horse-tail (*Equisetum* sp.) is so poorly represented that it has little value beyond indicating the presence of this type of vegetation.

The smilax, the only form referred to the monocotyledons, is based on a single specimen and is of doubtful biologic value.

The dicotyledons are represented by a number of well-known types. They include a coriaceous-leaved waxberry (*Myrica*), two willows (*Salix*), and a small-leaved oak (*Quercus*), all of which are very modern in appearance. The named species of fig (*Ficus fremonti*) is so placed on account of its general resemblance to and affinity with certain described fossil species, and not on account of its relationship with living members of the genus. *Ficus* is a vast, mainly tropical group comprising over 600 species. The named form referred to *Cinnamomum*, the well-known cinnamon tree, is of the type of an unidentified living species from China. The genus is not now a native of the New World, its center of distribution being tropical and subtropical portions of southeastern Asia. The species of *Dryandroides*, if correctly placed, is of importance as showing the presence of the Proteaceae in this country during early Upper Cretaceous time, but it is so fragmentary that I can not be certain of its position.

PHYSICAL AND CLIMATIC CONDITIONS INDICATED.

From the facts now available it appears unquestionable that at least the major portion of the Frontier formation was laid down in fresh water. This is proved by the numerous, thick, and widespread beds of coal it contains. The coal swamps of that epoch, which must have been of wide extent and long duration, might well have been and doubtless were but little above sea level, for sandstones containing oysters occur both below and above certain of the coal beds, showing slight oscillation that permitted the access of at least brackish water. No strictly marine organisms are known. About 1,000 feet below the top of the formation there are several thick beds of unios which indicate that the water at that time was fresh. There is nothing in the flora to indicate that any of its members required or indeed could tolerate a saline habitat; on the contrary, they could have found a congenial home only in or near fresh-water swamps and forests.

The climate during Frontier time appears to have been tropical or subtropical, as is shown in a number of ways. Thus, one of the most abundant of the ferns (*Tapeinidium*) was indeterminate in growth, a condition that could survive to the extent here indicated only in the absence of frosts. The most abundant elements in this flora are the ferns, and of these the davallioid forms (*Tapeinidium*, *Microtaenia*, and *Dennstaedtia*), to which may be added the *Anemia*, all call for a tropical or subtropical habitat. The spleenwort (*Asplenium*), if its affinity has been correctly interpreted, likewise calls for at least a subtropical setting, as does the single shield fern (*Dryopteris*). The smilax is too incompletely known to permit a generalization concerning its climatic environment, though it must have been as warm as warm temperate and might well enough have been still warmer. The waxberry (*Myrica*), the oak (*Quercus*), and the willows (*Salix*), on the other hand, might not be out of place in a temperate region, but the figs (*Ficus*) and the cinnamon trees (*Cinnamomum*) certainly required a tropical or subtropical location.

EVIDENCE OF INSECTS IN FRONTIER TIME.

An interesting though very meager fragment of information concerning the insect life of Frontier time has resulted from this study. Evidence of the presence of insects was noted on two leaves. One of these leaves (see Pl. XXXV, fig. 5), now named *Ficus fremonti*, was found by Frémont and is fortunately one of those in the collection of the United States National Museum. This specimen was figured by Hall,[1] who noted the presence of a cluster of circular bodies on one side of the leaf. He was uncertain as to the nature of these bodies, and as he had referred the leaf to *Glossopteris phillipsi*, a fern, he suggested that they might possibly represent the fruiting stage, though he adds: "This structure is so partial that it can only with doubt be referred to the fructification of the plant; and it is not improbable that the same may be some parasitic body or the eggs of an insect which have been deposited upon the leaf." This specimen was shown to Dr. August Busck, of the Bureau of Entomology, who at once recognized these circular bodies as an undoubted insect egg mass, probably of a microlepidopterous insect.

The other specimen, shown in Plate XXXIII, figure 5, is a leaflet of *Staphylea? fremonti* in which a symmetrically looping mine has been made in the leaf substance by an insect larva. This Dr. Busck pronounced also to be the work of a microlepidopter, possibly belonging to the genus *Phylloenistis*. The mine appears to increase slightly in size from the apex of the leaflet toward the base, the exit being the basal margin next to the midrib. The work of this Frontier insect is absolutely similar in character to that of forms now living, a fact which would seem to indicate that the habits of life have persisted with no observable change from middle Cretaceous time to the present.

[1] Hall, James, in Frémont, J. C., Report of the exploring expedition to the Rocky Mountains in the year 1842, and to Oregon and North California in the years 1843–44: Twenty-eighth Cong., 2d sess., House Executive Doc. 166, pl. 2, figs. 5b, 5c, 1845.

THE FLORA.

Family POLYPODIACEAE.[2]

Tapeinidium? undulatum (Hall) Knowlton, n. comb.

Plate XXVIII, figures 1–4.

Pecopteris undulata Hall, in Frémont, Report of the exploring expedition to the Rocky Mountains in 1842, etc., Appendix B, p. 306, pl. 1, figs. 1a, 1b, 1845.

Pecopteris undulata Hall, var., idem, p. 306, pl. 1, figs. 2, 2a, 2b.

Pecopteris? odontopteroides Hall, idem, p. 306, pl. 1, figs. 3, 4.

Outline and habit of whole frond not known but presumed to be simply pinnate, lanceolate in outline, gradually narrowed to the apex (base not seen); rachis strong, ridged, in places slightly winged; pinnae numerous, at right angles to the rachis, sessile, linear in general outline, sharp-pointed at apex, cut in varying degree into numerous rounded, slightly oblique or fan-shaped lobes which are entire or slightly erose-dentate; the lobes decrease in size apically, becoming merely undulations, the tip being almost or quite entire; upper pinnae reduced in size, with undulate or almost entire margins; nervation of pinnae consisting of a very strong, grooved midvein, the lobes provided with a thin, delicate midvein and usually about three pairs of once-forked veins.

This species is exceedingly abundant, probably the most abundant plant found in these beds, as there is hardly a piece of matrix that does not contain a fragment. In spite of its abundance, however, it is very rarely that specimens of considerable size and completeness are procured. It was apparently very brittle and easily broken up before it was entombed. The most complete example thus far found is that shown in figure 3, which has a preserved length of 12 centimeters but was undoubtedly considerably longer than this when perfect. The

[2] In the study of the ferns, especially the first four species, I have had the benefit of the assistance and critical judgment of Mr. W. R. Maxon, of the United States National Museum. My thanks are due to Mr. Maxon for detecting and pointing out affinities and interrelationships that would otherwise have been overlooked.

width, of course, varies according to the position in the frond, the maximum width being 6 or 8 centimeters. In the upper part of the frond the pinnae are continuous, but in the middle and lower parts some of them are separated by a distance of once or twice their width.

An interesting feature connected with the manner of growth in this fern is that it appears to be indeterminate in growth—that is, the apical bud continued active and the frond continued to grow indefinitely. This is a condition not unknown among living ferns, though its recorded occurrences are not numerous. It is presumed to occur, at least to a noticeable degree, only in ferns of a tropical habitat, where absence of frost would permit the delicate growing tip to survive.

It has been difficult to place this fern biologically, and for information and advice concerning its position I am greatly indebted to Mr. W. R. Maxon, of the United States National Museum. It has, at least superficially, some features of resemblance to *Gleichenia*, such as the size and shape of the pinnae and the thin right-angled insertion on the rachis, but on closer inspection it is seen that the lobes or segments of the pinnae are really oblique or somewhat unequal-sided. The forked veins also exclude the present form from *Gleichenia*.

In habit this form somewhat approaches certain species of *Dryopteris*, but, all things considered, its characteristic features appear to be davallioid and to approach most closely those of *Tapeinidium*, a small genus of fern species of pinnate form, mainly natives of the Polynesian Islands.

Although Hall described this fern under two specific names and one varietal name, the distinctions are based mainly on size and it is not believed that they can be maintained. Thus the type of his *Pecopteris undulata* (his Pl. I, fig. 1a) is evidently a segment from the middle part of a large frond, where the pinnae are separated by a considerable interval, as shown in Plate XXVIII, figures 1 and 4. Hall's *Pecopteris? odontopteroides* (his Pl. I, figs. 3, 4) is based on small pinnae with undulate or slightly cut margins that can be duplicated in the upper portion of the frond shown in Plate XXVIII, figure 3. The form described by Hall as a variety of *Pecopteris undulata* (his Pl. I, fig. 2) is also a segment from the middle or lower part of a very large frond, and the pinnae, although broader than any others noted, are not cut so deeply by the lobes as many smaller ones. If it has been correctly drawn, however, it appears to be slightly different from the normal forms, but even so it is hardly entitled to separate recognition. The other specimens referred to this variety (Hall's Pl. I, figs. 2a, 2b) are clearly segments with nearly entire pinnae from near the apex of a frond of the normal type.

The nervation of the pinnules shown by Hall in his Plate I, figures 1b and 2a, is incorrect, as the lateral nerves are shown as simple and unforked, although he describes the veins in the text as forking. As may be seen from the enlargement shown in figure 2a, the nervation consists of a thin, delicate midvein and two or three pairs of once-forking veins.

The only specimen of the original Frémont collection known to be extant is one of the types of *Pecopteris? odontopteroides*, figured by Hall in his Plate I, figure 4. It is No. 30848 of the United States National Museum collections.

Occurrence: Frontier formation, about 1 mile east of Cumberland, Wyo. Collected originally by J. C. Frémont August 19, 1843. Subsequently collected by A. C. Veatch in 1906 and by F. H. Knowlton and T. W. Stanton in 1908.

Genus MICROTAENIA[1] Knowlton, n. gen.

Small davallioid, pinnate herbaceous ferns, with close, linear, acute pinnules; lower pinnules barren, entire or slightly crenulate-margined; middle pinnules incompletely fertile; upper ones more completely or wholly fertile, reduced, becoming undulate, then cut nearly to the midvein into sharp-pointed lobes; sori large, terminal, somewhat elongate, occupying the whole of the tips of the lobes.

Type, *Microtaenia variabilis*.

Microtaenia variabilis Knowlton, n. sp.

Plate XXIX, figures 1–4a.

Size and shape of whole frond unknown but apparently at least bipinnate, the divisions (frond?) lanceolate in outline, narrowed at base, acutish at apex; rachis slender, distinctly sulcate; segments or pinnules numerous, approximately at right angles to the rachis, close to

[1] From μικρος, small, and ταινια, Latin taenia, a ribbon, in allusion to the narrow, ribbon-like pinnules.

distant, linear and grasslike in shape, slenderly acuminate at apex, truncate or very slightly heart-shaped or halberd-shaped at base, closely sessile; lower barren pinnae entire or very slightly undulate; middle pinnules incompletely fertile, the fertile portion reduced, cut nearly to the midvein into sharp-pointed lobes; sori terminal or elongate, occupying nearly the whole outer part of the lobe; nervation of pinnules obscure, consisting of a very strong, sulcate midvein and apparently delicate, once-forked lateral veins which are at a low, almost right angle with the midvein.

This very strongly marked type is represented by a large number of specimens, some of which, it will be seen, are exceptionally well preserved. In spite of the profusion of specimens, however, none are so complete as to give incontestable evidence as to the size and shape of the whole frond, though it appears to have been at least bipinnate. The two largest segments preserved, shown in figures 1 and 2, are from the lowest portion of the frond, but neither quite reaches the base. They are narrowly lanceolate in outline, narrowing below to their point of attachment. Another specimen not figured shows that the apex also narrows and becomes acutish. The largest of the segments has a preserved length of 10 centimeters and a maximum width of about 4 centimeters. Its full length was probably not less than 15 or 18 centimeters.

The pinnules are all approximately at right angles to the rachis. In the specimen shown in figure 2, which must be very near the base of the frond, the pinnules are close together, but in the upper portion they become more distant, and in the specimen shown in figure 1 they are separated by more than the width of the pinnules. In other specimens, such as those shown on the left of figure 2 and in figure 4, the pinnules are separated by two or three times their width. The pinnules clearly are more distant in the middle and upper portions, where the frond is becoming fertile.

Most of the barren pinnules are entire or nearly so, as shown, for instance, in figure 1, but a tendency to variation is constantly manifest. Thus, in figure 2, which to all intents and purposes is about the same as figure 1, the pinnules show a decided tendency to be undulate margined and some of them to become distinctly lobed near the tips. In the fragmentary specimen on the left of the stone shown in figure 2 the exceedingly long, narrow pinnule is lobed up to the point where it becomes fertile, as are the other, broken pinnules, though the undulate lobed to strongly cut fertile portions are well shown in figure 3. None of these pinnules is completely fertile, each having a short barren, undulate-lobed portion near the base. In the specimen shown in figure 4a the whole of the pinnule has become fertile.

The sori are perhaps best shown in figure 3. They are seen to be terminal and somewhat elongate and to occupy the whole of the tips of the lobes.

The relationships of this fern are not easy to determine. That it is extremely variable in a number of particulars has been brought out in the above discussion. In certain specimens in which the barren pinnules are more or less undulate lobed this species appears to approach what is here called *Tapeinidium? undulatum.* Some specimens of that species have pinnules only slightly lobed and are almost impossible to distinguish from the present form. The character of the midvein is exactly the same in both forms—that is, it is strong and deeply sulcate, thus producing the appearance of two lines when seen from the upper side of the pinnule.

So far as can be learned by study of the figures given by Hall and such of the original material as is now accessible, Frémont did not collect specimens of *Microtaenia variabilis* unless the fertile upper portion of Hall's *Sphenopteris triloba* (his Pl. II, fig. 2) is an isolated fragment of a pinnule.

Occurrence: Frontier formation, 1½ miles east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton August 5, 1908.

Microtaenia paucifolia (Hall) Knowlton, n. comb.

Plate XXX, figures 1, 2.

Sphenopteris? paucifolia Hall, in Frémont, op. cit., Appendix B, p. 304, pl. 2, figs. 1, 1a, b, c, d.
Sphenopteris? trifoliata Hall, idem, pl. 2, fig. 2.

Similar in general effect to the type species but evidently more finely divided, probably tripinnatified, the rachis much more slender; complete barren pinnules not seen; basal barren portion of fertile pinnules strongly undulate lobed; fertile pinnules very short, with only two or three lobes on each side; sori terminal, occupying the whole of the tip.

There is more or less uncertainty regarding the status of this form. It is represented by only four or five very fragmentary specimens, all of which show the fertile pinnules but give very little evidence regarding the barren portions. In the first place, it appears to be more finely divided than *M. variabilis,* as shown in one of Hall's figures (his Pl. II, fig. 1) of *Sphenopteris? paucifolia,* though none of the recent specimens is sufficiently complete to show this feature. The specimen shown in Hall's figure is certainly tripinnatified, with the pinnules short and very much reduced.

The only evidence regarding the character of the barren pinnules is shown in figure 2, where the basal portions of three or four of the lower pinnules are seen to be undulate lobed before they pass into the deeply lobed, fertile portion.

The specimen named *Sphenopteris triloba* by Hall is probably only a smaller and more reduced state of *S. paucifolia* in which the fertile lobes are reduced to three. It may be that the pinnules are broken at the tips, but as the specimen is not now known to be extant, it is impossible to settle this point.

In the upper portion of Hall's figure 2 he shows the axis apparently passing into a fertile portion (enlarged in his fig. 2d), but this portion is only accidentally in that position and has no organic connection with the rest of the specimen. It appears to be an isolated fragment of a fertile pinnule of *M. variabilis.*

Occurrence: Frontier formation, 1½ miles east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton August 5, 1908.

Dennstaedtia? fremonti (Hall) Knowlton, n. comb.

Plate XXX, figure 5; Plate XXXI, figure 1.

Sphenopteris fremonti Hall, in Frémont, op. cit., Appendix B, p. 304, pl. 2, figs. 3, 3a.

Size and shape of whole frond unknown but probably at least tripinnate or tripinnatified; main rachis exceedingly strong, ridged; pinnae approximately at right angles to the rachis, linear or lanceolate, with the secondary rachis sulcate; pinnules rather remote, subovate, somewhat decurrent at base, about three or four lobed; sori large, terminal on the tips of the lobes.

This form is represented by so few and so fragmentary specimens that it must stand as insufficiently characterized. The most important features that can be made out are the exceedingly thick main rachis; small, few-lobed pinnules; and rather large, terminal sori.

As regards the probable affinity of this form the best that can be said is that it is undoubtedly a davallioid fern, which as a matter of convenience is tentatively referred to the genus *Dennstaedtia.*

Occurrence: Frontier formation, about 1 mile east of Cumberland, Wyo. Collected by J. C. Frémont August 19, 1843, and by F. H. Knowlton and T. W. Stanton August 5, 1908.

Dryopteris coloradensis Knowlton, n. sp.

Plate XXX, figures 3, 4.

Outline of whole frond not known but evidently of large size and at least bipinnatified; rachis strong, round; pinnules at an angle of about 30°, alternate, rather remote, linear-lanceolate, acuminate at apex, broadest at base, sessile, cut more than half the distance to the secondary rachis into numerous close, slightly scythe-shaped, obtusely pointed, or somewhat acute lobes; small upper lobes entire, larger lobes uneven or in places sharply serrate; secondary rachis slender; nervation of the lobes consisting of a thin, slightly flexuose midvein and five or six pairs of delicate, once-forked veins, the fork occurring just above the midvein; fructification not seen.

This form is represented by several pieces, two of the most complete of which are figured. From the presence of large pieces of stems intermingled with the fronds and presumed to belong with them, it is assumed that this fern was probably of large size, but the direct evidence is only sufficient to say that it is at least bipinnatified. Under the circumstances measurements are of comparatively little value, though it may be stated that the pinnules range from 5 or 6 to 10 centimeters or more in length and from 8 to 18 millimeters in width.

Occurrence: Frontier formation, about 1 mile east of Cumberland, Wyo. Collected by A. C. Veatch in 1906.

Asplenium occidentale Knowlton, n. sp.

Plate XXXI, figures 2–5.

Although this form is represented by a large number of specimens, they are all so fragmentary and disconnected that it is impossible to gain an adequate conception of the frond as a whole. Under the circumstances it seems best simply to figure a number of the best-preserved fragments and describe them as fully as possible, but to leave to the future its definite allocation. It was evidently a fern of considerable size, as may be seen from the example shown in figure 4. This has a preserved length of 7 centimeters and a width of 3.5 centimeters but was probably considerably larger. The margin is undulate-lobed and has a few fine, sharp teeth. The apex in other specimens is shown to be strongly toothed. The nervation consists of a very stout midvein and strong veins that arise at an angle of probably 40° but curve outward until they are nearly at right angles to the midvein. The veins fork usually very close to the midvein and once or twice above.

The specimen shown in figure 2 consists of two pinnules attached to a minute piece of the rachis. Each is rounded on the lower side, so that they produce together a deeply heart-shaped base. The tip of the left-hand pinnule shows the strong teeth above mentioned.

In figure 5 two examples are shown; the lower is about the size of the one last described, the upper much smaller. The margin of the upper one is strongly undulate-toothed, becoming in the upright segment almost lobed. The nervation is of the same character as that in the large example (fig. 4), described above, except that there is usually only one fork in the nerves and this is near the midvein.

On account of the uncertainty attending the assignment of this form it is obviously unwise to attempt comparisons with either living or fossil species. It is placed in the genus *Asplenium* on the ground of its resemblance—fancied or real—to the living *Asplenium hemionites* Linné, but more complete material will be necessary before its status can be fixed. It is believed, however, that enough of it is here described and figured to permit its subsequent recognition, not only in the Frontier formation but elsewhere.

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton in 1908.

Family SCHIZAEACEAE.

Anemia fremonti Knowlton, n. sp.

Plate XXXI, figure 6; Plate XXXII, figures 1–3.

Outline of whole front not known; stipe long, slender, dichotomous; frond bipinnate, possibly tripinnate; pinnae narrowly deltoid; pinnules arising at an acute angle, linear-lanceolate, sessile and decurrent or lower ones nearly free; pinnules cut, especially near the base, into deep, sharp-toothed, entire, forward-pointing lobes, which decrease apically so that the terminal fourth is entire or merely crenulate; middle and upper pinnules becoming more and more entire toward the apex, which is only crenulate; nervation rather sparse, at a very acute angle, nerves once or twice forked; fertile frond not found.

This species is represented by a large number of specimens, but unfortunately all are so fragmentary that it is impossible to make out the shape and size of the whole frond. Some evidence to show that the frond was very large and several times compounded is afforded by the presence of certain fragments disposed in such a way on the matrix as to suggest the possibility of their organic connection, but no such union has been seen. A dichotomous branching of the slender rachis, such as is shown in figure 3, is all the branching that has been observed. The longest segment of rachis observed (fig. 3) is 6 centimeters long but was certainly considerably longer when perfect. The best-preserved pinna, shown in figure 1, is 14 centimeters long, of which at least 2 centimeters is made up of secondary rachis. It is approximately 6 centimeters broad between the tips of the lower pinnules. The manner and extent of the marginal cutting of the pinnules is so well shown in the figure that it is not necessary to describe them at greater length.

This species is exceedingly close to *Anemia subcretacea* (Saporta) Gardner and Ettingshausen,[1] a species that was described from specimens obtained in the Eocene travertines of Sézanne and was subsequently found to be abundant in the Eocene of Bournemouth, England. The present form appears to differ slightly in its broader pinnae, generally less sharply cut pinnules, and more erect nervation, but at best the difference is not great.

Gardner and Ettingshausen referred Lesquereux's *Gymnogramma haydenii*,[2] from the divide

[1] Gardner, J. S., and Ettingshausen, Constantin von, Monograph of the British Eocene flora, vol. 7, p. 45, pls. 8, 9, 1880.

[2] U. S. Geol. Survey Terr. Rept., vol. 7, p. 59, pl. 5, figs. 1–3, 1878.

between the headwaters of Snake River and Yellowstone Lake, to their *Anemia subcretacea*, and in this reference Lesquereux concurred. The specimen shown in figure 3 of Lesquereux's plate is considerably like the specimens from Cumberland, but those shown in the other figures are quite different.

At one time Newberry was of the opinion that he had found *Anemia subcretacea* at a number of localities, as Point of Rocks, Wyo. (Montana), Erie, Colo. (Laramie), and Bellingham Bay and Carbonado, Wash. (Eocene), but in his formal report[1] he inclined to regard them as representing a well-marked, robust variety. This work was edited by Hollick, who substituted the name *Anemia perplexa* for the reason that *A. subcretacea* was considered nomenclatorially untenable. The specimens figured by Newberry are very unlike the present species, and furthermore, it would seem to be wise not to regard them as identical with the European form.

A fine large species of *Anemia* from the Raton formation of Colorado is described by me in a paper now in press,[2] but it is quite different from *Anemia gracillinea*.

Fragmentary specimens of *Anemia* have been found at many localities in the Rocky Mountain region, ranging in age from early Montana to Laramie, but none of them appear to agree very closely with the present species.

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton in 1908.

Family EQUISETACEÆ.

Equisetum sp.

Plate XXXIII, figure 6.

The collection made near Cumberland by Veatch contains a single specimen with its counterpart that apparently represents the underground stem of an *Equisetum*. It is about 9 centimeters long, has a maximum diameter of nearly 1 centimeter, and is more or less constricted or cut up into short segments 10 to 15 millimeters in length. It is irregularly ridged or wrinkled longitudinally but otherwise has no marks or features of diagnostic value.

[1] Newberry, J. S., The later extinct floras of North America: U. S Geol. Survey Mon. 25, p. 4, 1898.

[2] Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, p. 285, pl. 54, fig. 2 (in press).

Beyond the fact of attesting the presence of vegetation of this type in the Frontier formation this specimen is of little value, as it could probably not be recognized or discriminated if found elsewhere. For this reason there is little use in attempting comparisons with described species, though incidentally it may be compared as being similar in type to *Equisetum prelaevigatum* Cockerell (*E. laevigatum* Lesquereux[3]), from the Denver formation of Colorado.

Occurrence: Frontier formation, north side of Little Muddy Creek, about 1 mile east of Cumberland, Wyo., in sec. 29, T. 19 N., R. 116 W. Collected by A. C. Veatch in 1905.

Family SMILACEÆ.

Smilax? coloradensis Knowlton, n. sp.

Plate XXXIII, figure 1.

Leaf small, membranaceous, regularly elliptical, abruptly rounded below to a very slightly heart-shaped base, apex destroyed but apparently rather obtusely pointed; three-ribbed from base, the midrib slightly the stronger, lateral ribs passing up nearly or quite to the apex, each with several branches on the outside which join and produce a semblance of an additional rib on each side; no secondaries observed on the midrib, but a few strong nervilles between the ribs; fine nervation not retained.

The specimen figured is all that was found of this form. It is about 5 centimeters long and 3.5 centimeters wide. The nervation is so poorly preserved that hardly anything but the main ribs is retained. It is for this reason that the generic reference has been questioned, though it has the size, shape, thickness, and, so far as can be made out, the essential nervation of certain living forms of the genus. More and better material will be necessary to settle the matter fully.

Occurrence: Frontier formation, dump of mine No. 1, Cumberland, Wyo. Collected by F. H. Knowlton August 5, 1908.

Family MYRICACEÆ.

Myrica nervosa Knowlton, n. sp.

Plate XXXIV, figure 1.

In the small collection obtained about 1½ miles south of Cumberland, Wyo., there are a number of fragmentary leaves of *Myrica*. The

[3] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 68, pl. 6, fig. 6, 1878.

nervation is very distinct and characteristic, and although the specimens are so much broken that the size and shape can not be fully made out, it seems best to put the form on record so that it may be looked for in the future.

This species is narrowly lanceolate, probably acuminate at base and apex, and has perfectly entire margins. The length was apparently 8 or 9 centimeters and the width about 2 centimeters. The leaf substance is thick and leathery, as shown by the wrinkled appearance of the leaves. The midrib is exceedingly strong. The secondary nervation is thin and irregular, at an angle of 50° or more, much curved upward, each principal nerve arching just outside the margin and producing an intramarginal "stitch." There are numerous intermediate secondaries which pass up and join the bows of the larger nerves, or disappear in a network of nervilles. The finer nervation produces a network of irregular areas.

This species is, in a way, of the type of *Myrica torreyi* Lesquereux, of the Montana group and slightly younger horizons. It differs markedly from that species, however, in its smaller size, entire instead of serrate margins, and secondaries of two sizes, the larger ones forming the intramarginal vein. The nervation is also at a more acute angle than in *M. torreyi*.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as plant beds 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

Family SALICACEAE.

Salix cumberlandensis Knowlton, n. sp.

Plate XXXVIII, figure 3.

Leaf firm in texture, lanceolate, 8 centimeters long, 2 centimeters wide, abruptly rounded below to the short, thick petiole, broadest at and below the lower third of the blade, whence it is gradually narrowed to the slenderly acuminate apex; margin finely and evenly crenate throughout; midrib very thick, especially below; secondaries strong, 16 or more pairs, alternate, emerging at an angle of 30° or 35°, much curved upward and apparently effused near the margin; finer nervation not retained.

This handsome little species is represented only by the very perfect example figured. It is well marked by its narrowly oblong-lanceolate outline, abruptly rounded base, finely crenulate margin, and numerous strong, apparently camptodrome secondaries.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as the plant beds 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

Salix frontierensis Knowlton, n. sp.

Plate XXXV, figure 4a.

Leaf small, apparently rather thick, elliptical lanceolate, broadest at a point below the middle, whence it rounds rather abruptly to the short, thick petiole; apex destroyed but apparently acuminate; margin perfectly entire; midrib very strong for a short distance, then much thinner; secondaries 10 or 12 pairs, very thin and delicate, curved upward, camptodrome; finer nervation obscure.

The little leaf figured is unfortunately the only one of this kind noted in the collection. It was about 3.5 centimeters long and 1.3 centimeters wide; the petiole is about 3 millimeters long.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as plant beds 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

Family FAGACEAE.

Quercus stantoni Knowlton, n. sp.

Plate XXXIII, figures 2–4.

Leaves membranaceous, rather broadly lanceolate, long, wedge-shaped at base, much more abruptly narrowed above to an obtusely acuminate apex; margin entire below, coarsely few-toothed or lobed above, the teeth separated by shallow sinuses, sharp, mucronate-tipped; petiole strong, at least 1.5 centimeters long; midrib very strong below, not much thinning above; secondaries about 10 or 12 pairs, mainly alternate, at an angle of 45°, running nearly straight to the teeth below, slightly curved upward above; nervilles numerous, strong, irregular, finer nervation forming a coarse, irregularly quadrangular network.

This species is represented by nearly a dozen specimens, none of which, however, is complete. The length, including the petiole, must have been at least 10 or 12 centimeters and the width between 3 and 4 centimeters. The species is well marked by the long, wedge-shaped base, more obtuse apex, and coarse marginal teeth or lobes, which are all mucronate-tipped, thus indicating that it is a member of the black-oak group. In figure 3 is shown a cluster of three leaves that were probably attached to the same branch, though the actual union is not shown. The best preserved of these gives a very satisfactory view of the lower half of the blade, with its strong petiole and mucronate teeth. In figure 2 is shown a very complete apical portion of a leaf of the same size as the one in figure 3. The basal portion of another well-preserved leaf is seen in figure 4.

Among fossil species of *Quercus* the present species is rather closely related apparently to a number from the Senonian of Haldene, Westphalia, as described by Hosius and Von der Marck.[1] It is perhaps nearest to *Quercus formosa*, from which it differs in being broader and in having larger, sharper, mucronate-tipped teeth. From *Quercus sphenobasis* it differs in its fewer, larger teeth and fewer secondaries.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as plant beds 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

Family MORACEAE.

Ficus fremonti Knowlton, n. sp.

Plate XXXIV, figures 4–6; Plate XXXV, figures 4c, 5.

Glossopteris phillipsii? Brongniart. Hall, in Frémont, op., cit., Appendix B, p. 305, pl. 2, figs. 5, 5a–c. Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 37, 1888.

Leaves small, very thick and coriaceous, narrowly lanceolate, broadest below the middle, whence they narrow below to a rather long, wedge-shaped base and above to a very long, narrow acuminate apex; margin perfectly entire; petiole short (1 centimeter), relatively strong; midrib very strong; secondaries immersed in the substance of the leaf and indistinct, numerous, at an acute angle, camptodrome; finer nervation obscure.

This form is represented by 25 or more specimens, few of which are perfect. It is a small, very narrowly lanceolate leaf, 6 to 8 or 9 centimeters long and 1 to 2 centimeters wide, with a petiole 1 centimeter or slightly over in length. It is especially distinguished by its long, narrowly acuminate apex.

The species here called *Ficus fremonti* has had a most interesting history. It was first collected by Frémont in 1843 and was identified by Hall as *Glossopteris phillipsii*, for the reason, he adds, that Brongniart's species afforded "the only description and figure accessible to me to which this fossil bears any near resemblance." Examination of Brongniart's figure[2] shows that this form certainly does resemble it so far as size and shape go but is totally different in nervation. *Glossopteris phillipsii* has of course a pteroid nervation with close, parallel, forking veins, but the secondary nerves in the leaves here described, as may be seen from the figures, are distinctly those of a dicotyledon.

Fortunately, two of the original Frémont specimens (Hall's figs. 5 and 5b) are preserved in the United States National Museum and are shown here (Pl. XXXIV, fig. 6; Pl. XXXV, fig. 5). These leaves passed under Lesquereux's eye, and although he lists them under *Glossopteris phillipsii* he makes the following statement:[3] "This is remarkably similar in form of leaves and nervation to *Glossochlamys transmutans* Gardner and Ettingshausen (British Eocene flora, pl. 3, fig. 3; pl. 12, fig. 8). The specimens of Frémont show indistinctly nervilles between the lateral nerves composing irregular, square meshes."

The figures of *Glossochlamys transmutans* given by Gardner and Ettingshausen show that to all intents and purposes this form is a dicotyledon, and in fact these authors admit that Saporta, whom they consulted, objected to the reference of this fossil to a fern, and Heer stated flatly that "it is not a fern, but a leaf of a dicotyledon." There can be absolutely no question about it—the leaves under consideration belong to a dicotyledon and have nothing to do with ferns.

It was largely on the basis of Hall's identification of these leaves as *Glossopteris phillipsii* that the beds were referred to the Jurassic. On this point Hall says: "The geological position of the fossil is so well ascertained to be the schists of the upper part of the Oolitic period

[1] Hosius, A., and Von der Marck, W., Flora der westfälischen Kriedeformation: Palaeontographica, vol. 26, p. 164 [40], pl. 31, fig. 81, 1880.

[2] Brongniart, Adolph, Histoire des végéteaux fossiles, p. 225, pl. 61 bis, fig. 2, 1828.

[3] Lesquereux, Leo, Recent determinations of fossil plants from Kentucky, Louisiana, * * * : U. S. Nat. Mus. Proc., vol. 11, p. 37, 1888.

that, relying upon the evidence afforded by a single species, we might regard it as a strong argument for referring all the other specimens to the same geological period."

Ficus fremonti agrees very well in shape with *Ficus proteoides* Lesquereux,[1] from the Dakota sandstone of Kansas, but the latter is a much larger leaf and has a more open nervation. In shape, size, and nervation it is even closer to *Ficus lanceolata acuminata* Ettingshausen, as figured by Lesquereux,[2] from the Dakota sandstone of Kansas. This species, however, is somewhat longer and broader and has the nervation more regular and at a less acute angle of divergence.

As stated on page 80, one of the original specimens figured by Hall showed on one side of the leaf round bodies which have now been identified as the egg mass of an insect, probably a microlepidopterous insect. It is shown in figure 5 of Plate XXXVI.

Occurrence: Frontier formation, about 1 mile east of Cumberland, Wyo. Originally collected by J. C. Frémont August 19, 1843; subsequently found at or near the same place by F. H. Knowlton and T. W. Stanton in 1908.

Ficus? sp.

Plate XXXV, figure 1.

A small collection made from a rather coarse-grained shaly sandstone about 300 feet above the main plant locality east of Cumberland contains a number of fragmentary leaves that seem to belong to *Ficus*, but there are little more than outlines to afford basis for a judgment. The leaf shown in figure 1 is one of the best preserved of these specimens. It is ovate, with an abruptly rounded truncate base, probably obtusely acuminate apex, and entire margins. The length was about 10 or 11 centimeters and the width nearly 5 centimeters. Even the primary nervation is so obscure that it is made out with difficulty. It consists of a fairly strong midrib and apparently a strong rib or secondary arising near the base and passing up for a long distance, but it is more or less uncertain.

This form is so obscure that it is of little value, and except for the desirability of enumerating all the plants present in this region, it might well be discarded. It simply calls attention to the presence of a large leaf whose more definite placing must be left to the future.

Occurrence: Frontier formation, mine No. 1, half a mile east of Cumberland, Wyo. Collected by T. W. Stanton and F. H. Knowlton in 1908.

Ficus? sp.

Plate XXXIV, figures 2, 3.

The collection obtained half a mile east of Cumberland contains a number of narrow leaves that are included here only on the ground that it seems desirable to enumerate everything known from this general region. They are preserved in a coarse-grained sandstone that has obscured most of the characteristic features—in fact, about all that can be made out is the outline and the thick midrib. They are narrowly lanceolate leaves that are rather abruptly rounded to the base and apparently long acuminate at the apex. The length is about 10 centimeters and the width a little over 2 centimeters. The midrib is strong, and there is some slight indication of secondary branches, but they are very uncertain.

This form might be compared with a number of long, narrow-leaved species of *Ficus* or certain entire-leaved species of *Salix*, but absence of essential features makes definite comparisons of little value.

Occurrence: Frontier formation, half a mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton August 5, 1908.

Family LAURACEAE.

Cinnamomum hesperium Knowlton, n. sp.

Plate XXXVIII, figure 2.

Leaf semicoriaceous or finer in texture, narrowly lanceolate, broadest near the middle, whence it narrows in almost the same degree to both base and apex; length 7 centimeters including the petiole, which is about 8 millimeters long; width about 13 millimeters; petiole relatively short, stout; midrib very strong below, becoming much thinner in the upper half of the blade; lateral ribs at an acute angle, arising at a point about 5 millimeters above the base of the blade, passing up and joining the lowest pair of secondaries near or above the middle, each with two or

[1] Lesquereux, Leo, Flora of the Dakota group: U. S. Geol. Survey Mon. 17, p. 77, pl. 12, fig. 2, 1892.

[2] Idem, p. 85, pl. 13, fig. 4.

three secondary branches on the outside; secondaries on the midrib three pairs, alternate, lowest arising far below the middle of the blade, arching upward and running along near and gradually lost in the margin; nervilles obscure, apparently close, parallel, unbroken, and at right angles to the ribs and secondaries.

This species is represented only by the example figured, which fortunately is practically perfect, so that its characters can be made out with certainty. It is with much hesitation described as new. At one time it was identified with a specimen from Hodges Pass, Wyo., described and figured by Ward [1] under the name *Cinnamomum lanceolatum* (Unger) Heer but later given the name *C. wardii* Knowlton [2] on the ground that it was not conspecific with the European species. Except in the matter of size these two leaves are undoubtedly close. Thus, *C. wardii* is 15 centimeters long and 2.5 centimeters wide, *C. hesperium* is 6 centimeters long and 1.4 centimeters wide. There are also other slight differences. In *C. wardii* the base is more obtuse and rounded, the lateral ribs at a less acute angle and without outside secondaries, and the secondaries on the midrib are closer and more numerous, but these are all comparatively unimportant divergences that might possibly break down if a series was available for comparison instead of a single leaf of each form.

The leaf found near Cumberland, Wyo., is also strikingly similar in size, shape, and general appearance to *Cinnamomum salicifolium* Staub,[3] from the well-known Tertiary beds at Sotzka, in Styria, but here again there are noticeable slight differences. Thus there are no outside secondaries on the lateral ribs, and the secondaries on the midrib are more numerous and confined to the upper half or upper third of the leaf.

Cinnamomum salicifolium was segregated by Staub from *C. lanceolatum* (Unger) Heer, on the basis of its generally narrower shape, higher secondaries, etc., but the difference is not great.

The geologic horizon at which the leaf *C. wardii* was found is more or less in doubt. The specimen was supposed by Ward to be from beds of Laramie age as then interpreted, but the work of Veatch appears to place it in the upper part of the Adaville formation of the Montana group, or nearly 10,000 feet above the horizon which supplied the Cumberland leaf. The species was not found in any of the recent collections made in this general region.

Although these two species (*C. wardii* and what is here called *C. hesperium*) are undoubtedly close together, the best that can be done under the circumstances, considering the differences in size and nervation already pointed out, as well as the apparent disparity in age, is to regard them as distinct until additional material can be obtained.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. Same bed as plant locality 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

Cinnamomum? sp.

Plate XXXV, figure 2.

There are in the collection several very fragmentary leaves that appear to belong to the genus *Cinnamomum,* though they are obscure at critical points. The one figured is ovate-lanceolate and has a rounded wedge-shaped base and an acuminate apex. The length is 9 centimeters and the width a little less than 5 centimeters. The midrib is strong; the lateral ribs are somewhat thinner and pass up nearly to the apex. There are several secondary branches on the outside of the lateral ribs, but otherwise the nervation can not be made out.

Occurrence: Frontier formation, half a mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton August 5, 1908.

Family PROTEACEAE.

Dryandroides lanceolata Knowlton, n. sp.

Plate XXXIV, figure 7.

Leaves coriaceous, narrowly lanceolate, base not seen but apparently rather abruptly narrowed to a short, wedge-shaped basal portion, prolonged above into a very long, acuminate apex which is minutely emarginate at the tip; margin in lower and middle portions distinctly toothed, the teeth sharp pointed, separated by very shallow sinuses; margin in upper portion

[1] Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., pl. 46, fig. 12, 1886.

[2] Knowlton, F. H., A catalogue of the Cretaceous and Tertiary plants of North America: U. S. Geol. Survey Bull. 152, p. 69, 1898.

[3] Staub, Moriz, Die Geschichte des genus *Cinnamomum,* p. 65, pl. 12, figs. 7-14, 1905.

undulate and finally entire; midrib very strong; secondaries numerous (probably at least 15 pairs), alternate, at an angle of 35° or 40°, considerably curved upward, entering the teeth or arching and each joining the secondary next above and sending a short, outside branch to the tooth; secondaries in the narrowed, entire apical portion of the blade arching upward for a considerable distance and disappearing in or near the margin; nervilles numerous, mainly broken and at right angles to the secondaries.

The portions of the two leaves shown in figure 7 are all that has been observed of this well-marked form. It is not possible to ascertain the exact length, but it could hardly have been less than 11 or 12 centimeters. The greatest width is slightly less than 2 centimeters.

The large segment referred to this species is certainly very oaklike in appearance, but the long, slenderly acuminate apical portion is much less so, and it seems best referred to the genus *Dryandroides*. It is, for instance, very similar to *D. quercinea* Velenovsky,[1] from the Cretaceous of Bohemia. It is, however, a larger, longer leaf, with a narrower apical portion, fewer lower teeth, and fewer secondaries at a more acute angle.

Dryandroides quercinea has been reported by Hollick[2] from the Magothy formation at Gay Head, Marthas Vineyard, Mass., but this reference depends on two fragmentary leaves and is open to some question.

The only other species of *Dryandroides* tentatively accepted as North American was described by Lesquereux[3] under the name *Quercus cleburni*. It comes from Black Buttes, Wyo., and is very different from the present form; in fact, it is doubtful if it should be placed in *Dryandroides*.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as plant bed 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

[1] Velenovsky, J., Die Flora der böhmischen Kreideformation: Beitr. Paläontologie Oesterr.-Ungarns u. des Orients, Band 3, Heft 1, p. 33 (8), pl. 10 (2), 1883.

[2] Hollick, Arthur, The Cretaceous flora of southern New York and New England: U. S. Geol. Survey Mon. 50, p. 60, pl. 8, figs. 18, 19, 1906.

[3] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 154, pl. 20, fig. 2, 1878.

Family RANUNCULACEAE?

Dewalquea pulchella Knowlton, n. sp.

Plate XXXVI, figures 1–3; Plate XXXVII, figures 1–3.

Leaves of medium or small size, palmately decompound, the segments usually five but occasionally six in number; petiole extremely long, much longer than the longest foliar segment, splitting at top into two nearly equal branches, one of which usually gives rise to two and the other to three segments, though the middle segment in a five-parted leaf may be nearly or quite free; segments all narrowly linear-lanceolate, of approximately the same size, the other segments slightly inequilateral, the middle one in some leaves slightly smaller than the others, all long and very narrowly wedge-shaped at base, acuminate at apex; margin of segments usually entire for a short distance at the base, thence strongly and sharply serrate; midrib strong, straight; secondaries obscure owing to the thickness of the leaf substance, numerous, apparently subopposite, at an angle of about 40°, slightly curved upward, all but the lower ones craspedodrome and ending in the marginal teeth; finer nervation not retained.

This splendid species is represented by nearly twenty specimens, six or seven of which have been figured. In none of the specimens are all the segments preserved entire, but some are nearly perfect, and hardly any of them is so fragmentary as not to show the manner in which the segments arise from the top of the petiole. Apparently in a majority of the leaves of this genus from other areas, as described, the segments are so broken and detached that it becomes a matter of difficulty to interpret them satisfactorily. The leaves here described, however, are so well preserved that there can be absolutely no question as to their being congeneric with the type and typical species from European deposits, from which the genus was first made known.

The present leaves are rather small compared with those of typical members of the genus. None of the segments exceed 8 or 9 centimeters in length and 1.5 centimeters in width, and apparently most of them are only 6 or 7 centimeters long and 1 centimeter or less in width. The segments are cut so deeply that they are almost free, and there is very little evidence of their being unequal-sided at the base. In only one specimen, that shown in Plate XXXVI, figure 3, is there six segments, all the remainder having five very symmetrically spaced divisions.

The petiole, which is preserved entire in several specimens, is extremely long and slender. In the leaf shown in Plate XXXVII, figure 2, for instance, it is nearly 5 centimeters long and probably exceeds the length of the segments. The average length is about 4 centimeters.

This species is very closely related to *Dewalquea insignis* Hosius and Von der Marck,[1] from the Upper Senonian of Westphalia—so closely related, in fact, that it would perhaps do no great violence to call them the same. The present form differs from the Westphalian species in its generally smaller size, longer petiole, usually fewer segments with much larger, sharper teeth, and, so far as can be made out, fewer, more curved secondaries. These, however, are all minor differences that might well be covered by individual variation; but in consideration also of the difference in geographic and stratigraphic position, it is perhaps as well to consider the Wyoming form under another name.

Dewalquea insignis was recorded by Heer[2] from both the Atane and Patoot beds of Greenland, and by Hollick[3] from the Cretaceous of Staten Island, but as Berry[4] has recently pointed out, "both these determinations are based upon fragments of single leaves and are, in the writer's judgment, entirely untrustworthy."

The genus *Dewalquea* was established by Saporta and Marion[5] in 1874, and was based on two species (*Dewalquea haldemiana* and *D. aquisgranensis*) from the Senonian of Westphalia, sent to them by Debey under the manuscript names *Araliophyllum* and *Grevillea*, and one (*D. gelindensis*) collected by themselves from the Paleocene of Gelinden, Belgium. Since that date 10 additional species, all from the Upper Cretaceous, have been named by different authors. Of these one (*D. grönlandica* Heer) is from the Patoot and Atane beds of Greenland, two (*D. dakotensis* Lesquereux and *D. primordialis* Lesquereux) from the Dakota sandstone of Kansas and Minnesota respectively, one (*D. trifoliata* Newberry) from the Raritan formation of New Jersey, and one (*D. smithi* Berry) from the Tuscaloosa formation of Alabama and the Black Creek formation (Middendorf arkose member) of South Carolina.

Of the Greenland and American species all but one (*D. smithi* Berry)[6] have leaves with only three segments or leaflets and are very unlike *D. insignis* or *D. pulchella*. The species described by Berry is a very handsome one; the leaves have five segments which are from 8 to 16 centimeters in length and sharply serrate, and the lateral segments are curiously unequal-sided at the base. This is undoubtedly a *Dewalquea*, but it is very distinct from the species here described.

The systematic affiliations of the genus *Dewalquea* are still more or less obscure. As may be inferred from the names suggested by Debey, he regarded it as belonging either in the Araliaceae or in the Proteaceae, but when Saporta and Marion established the genus they took occasion to review the matter with great care, and after comparing it with several genera such as *Aralia*, *Ampelopsis*, and *Arisaema* (a monocotyledon of the family Araceae) concluded that it had the greatest affinity with the tribe Helleboreae of the family Ranunculaceae. The Helleboreae in the living flora are herbaceous, but Saporta and Marion state that the presence of a Cretaceous or early Eocene shrubby ancestor would be quite in accord with the evolutionary history of some other groups.

Although these authors pointed out the reasons opposing the reference of *Dewalquea* to the Araliaceae, such a reference seems to the writer to be entitled to further consideration. It is, for instance, difficult to escape the conviction that certain leaves from the Dakota sandstone referred to *Aralia* may well have been ancestral to leaves of *Dewalquea* of the type of *D. insignis*, *D. pulchella*, etc. Take, for example, the species described by

[1] Hosius, A., and Von der Marck, W., Die Flora der westfälischen Kreideformation: Palaeontographica, vol. 26, p. 172 (48), pl. 32, figs. 111-113; pl. 33, fig. 109; pl. 34, fig. 110, 1880.

[2] Heer, Oswald, Flora fossilis arctica, vol. 6, Abt. 2, p. 86, pl. 25, fig. 7, pl. 33, figs. 14-16, 1882; vol. 7, p. 37, pl. 58, fig. 3; pl. 62, fig. 7, 1883.

[3] Hollick, Arthur, The Cretaceous flora of southern New York and New England: U. S. Geol. Survey Mon. 50, p. 106, pl. 8, fig. 24, 1906.

[4] Berry, E. W., The Upper Cretaceous and Eocene floras of South Carolina and Georgia: U S. Geol. Survey Prof. Paper 84, p. 42, 1914.

[5] Saporta, Gaston de, and Marion, A. F., Essai sur l'état de la végétation à l'époque des marnes heersiennes de Gelinden: Acad. roy. Belgique Mem. cour. et des sav. étrang., vol. 37, p. 55, 1874.

[6] Berry, E. W., op. cit., p. 41, pl. 8, figs. 3-9 (restoration, fig. 1 in text).

Lesquereux[1] as *Aralia wellingtoniana.* This is a medium-sized leaf with five deeply cut, sharply serrate lobes in which the secondary nervation is close, parallel, and craspedodrome in the upper portions. If the separation of these lobes were continued a short distance until the lobes were nearly or quite free, though still showing the method of origin from the branches of the petiole, a palmately decompound leaf would result that seemingly would be a *Dewalquea.* A further step in this process is shown in one of the Dakota leaves figured by Lesquereux[2] under the name *Aralia saportanea* var. *deformata.* Here the central lobe is reduced and cut almost to the base. The lateral lobes are also deeply cut and the margin below the major fork of the petiole is reduced to a very narrow web. A very slight continuation of this lobing would make these segments free or at least cut them to the branches of the petiole. Hence it seems to the writer a less violent assumption to derive the decompound, coriaceous-leaved species of *Dewalquea* from an equally coriaceous deeply lobed *Aralia* of the type above indicated than to suppose them to be the Cretaceous ancestors of the living herbaceous Helleboreae.

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo., in sec. 29, T. 19 N., T. 116 W. Collected by A. C. Veatch in August, 1905.

Family ARALIACEÆ.

Aralia veatchii Knowlton, n. sp.

Plate XXXVI, figure 4; Plate XXXVII, figure 4; Plate XXXVIII, figure 1; Plate XXXIX.

Aralia cf. *A. saportana* Lesquereux. Knowlton, in Veatch, Am. Jour. Sci., 4th ser., vol. 21, p. 459, 1906.

Outline of whole leaf not known, but clearly a leaf of large size and firm texture; palmately three-lobed and, presumably at least, five-lobed, the central lobes lanceolate, slenderly acuminate at apex, slightly contracted at the base; margin conspicuously toothed, the teeth sharp pointed, separated by shallow sinuses; lateral lobes at an angle of about 45° with the middle lobe and separated from it by a deep narrow sinus, margin entire below, becoming toothed above like the central lobe; nervation of lobes consisting of a very strong midrib and 12 or 14 pairs of fairly strong secondaries which emerge at an angle of 45° or 50°, are nearly straight, and end in the marginal teeth; nervation of lateral lobes similar, but secondaries more curved upward and camptodrome in the lower untoothed portion; finer nervation consisting of numerous strong nervilles, which are irregular and in places broken, and finer quadrangular areas.

The above description is in the main drawn from the specimen shown in Plate XXXVI, figure 4, which is the best one available. It consists of a nearly perfect central lobe and a small portion of one lateral lobe, the two being separated by a deep, narrow sinus. It is impossible to ascertain the size of this leaf when it was perfect, or to determine whether it had more than three lobes. It must have been 17 or 18 centimeters long and presumably 20 centimeters or more broad between the tips of the lateral lobes. From its analogy with a species to which it is presumed to be related, it is thought probably to have been five-lobed, but this is not known.

If I am correct in referring the other specimens here figured (Pl. XXXIX) to *Aralia veatchii*, the whole leaf was much larger than the dimensions given above. Thus, the specimen shown in Plate XXXVIII, figure 1, could hardly have been less than 20 centimeters in length and 7 or 8 centimeters in greatest width. In Plate XXXIX there are portions of three leaves or, more properly, lobes, which, while not now in actual organic connection, are so placed as to lend support to the idea that this was a huge five-lobed leaf. The central lobe, if it is such, was about 20 centimeters long and 7 centimeters wide, and the other was about 16 centimeters long and 6 centimeters wide. Both of these are more elliptical-lanceolate in shape than that shown in figure 1, and the margin is less sharply toothed. The fragment of a leaf given in Plate XXXVII, figure 4, is quite distinctly undulate-toothed. The nervation, however, is practically the same in all the specimens figured under this name, and this is one of the strong reasons for considering them all as conspecific.

There seems to be little or no doubt as to the propriety of referring these leaves to the genus *Aralia* on the basis of their resemblance to leaves from different horizons that have been so regarded. One of the species that is perhaps nearest to the present species, as exemplified in Plate XXXVI, figure 4, is *Aralia saportanea*

[1] Lesquereux, Leo, The flora of the Dakota group: U. S. Geol. Survey Mon. 17, pl. 22, fig. 2, 1891.

[2] Idem, pl. 23, fig 1.

Lesquereux,[1] from the Dakota sandstone of Kansas. The Dakota species is a smaller form and has the lateral lobes at a much more acute angle, the margins less conspicuously toothed, and the secondaries more curved upward, but they may well enough have belonged to the same genus.

Occurrence: Frontier formation, north side of Little Muddy Creek, about 1 mile east of Cumberland, Wyo., in sec. 29, T. 19 N., R. 116 W. Collected by A. C. Veatch in 1905.

Family STAPHYLEACEAE?

Staphylea? fremonti Knowlton, n. sp.

Plate XXXII, figures 4, 5; Plate XXXIII, figure 5.

Leaves trifoliolate, the leaflets petioled, all arising from the same point at the top of the main petiole; leaflets all of about the same size, elliptical-lanceolate, broadest near or just below the middle, whence they are gradually rounded or narrowed to the wedge-shaped base and to an acuminate apex; margin of leaflets perfectly entire; midrib exceedingly strong, straight; secondary nervation obscured by the thick substance of the leaflet; secondaries emerging at a low angle, close, nearly parallel, camptodrome, arching, and apparently joining well below the margin; finer nervation not discernible.

This beautiful species is represented by the two specimens figured, as well as their counterparts and a number of detached leaflets. They have a thick general petiole of unknown length but at least 1 centimeter long. Standing on the top are the petioles of the leaflets, each of which is from 5 to 8 millimeters in length. The petiole of the middle leaflet is uniformly a little shorter than the lateral one. The leaflets are 3.5 to 4 centimeters long and about 12 millimeters wide. The leaflets are very thick in texture and, with the exception of the extremely strong midrib, the secondary nervation has been observed in only one or two leaflets. Here it is seen to be thin, close, nearly parallel, and arching some distance below the margin.

There is some uncertainty as to the propriety of this generic reference. These leaves appear to be close enough to the living *Staphylea trifolia* Lesquereux to warrant their being considered as congeneric with it, though there are some differences. Thus, in the living form the lateral leaflets are sessile and the central one is short-stalked, whereas in the fossil form the central leaflet has a markedly shorter stalk than the lateral ones. The margin in the living leaf is finely, sharply serrate, but in the fossil leaf it is entire. Again, the texture in *S. fremonti* was evidently much thicker than in *S. trifolia*. The shape, size, and nervation are approximately the same in both forms.

It was at first thought possible that the leaves under consideration might be congeneric with *Dewalquea trifoliata* Newberry,[2] from the Raritan formation of New Jersey, especially in view of a statement made by Berry[3] to the effect that "it is remarkable that where this genus has been found in abundance, two species are usually described—one entire and one with toothed margins," the inference being that both forms probably grew on the same plant. This condition can not be true in the present instance, for the leaves under discussion are clearly trifoliolate, while in *Dewalquea* the leaf is merely palmately decompound.

One of the leaflets (Pl. XXXIII, fig. 5) shows a mine made in the leaf substance by an insect larva. (See p. 80.)

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton in 1908.

Unknown systematic position.

Phyllites ficifolia Knowlton, n. sp.

Plate XXXV, figure 3.

The leaf figured is all that was noted of this form. It was evidently a leaf some 15 or 18 centimeters in length and about 6 centimeters in width. It appears to have been elliptical-lanceolate, very gradually narrowed at the base, and presumably acuminate at the apex. The margin is indistinct. There is some evidence to show that there were a few low teeth, but this is not certain. The midrib was relatively strong. The secondaries, of which there were probably about a dozen pairs, were alternate, at an angle of 35° or 40°, remote in the middle of the blade, somewhat curved upward, and presumably camptodrome. None of the finer nervation can be made out.

This is probably a *Ficus*, but in the absence of definite knowledge concerning certain of the essential characters it seems best to leave its allocation to further and better material.

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, p. 61, pl. 8, fig. 1, 1883.

[2] Newberry, J. S., The flora of the Amboy clays: U. S. Geol. Survey Mon. 26, p. 129, pl. 22, figs. 4-7, 1895.

[3] Berry, E. W., The Upper Cretaceous and Eocene floras of South Carolina and Georgia: U. S. Geol. Survey Prof. Paper 84, p. 42, 1914.

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton in 1908.

Phyllites dentata Knowlton, n. sp.

Plate XXXIV, figure 8.

The example figured is all that was found of this form. It is a segment apparently from the middle portion of a narrowly lanceolate leaf of membranaceous texture. It was acuminate at the apex, but the base is not known. The margin is provided with numerous low, sharp-pointed teeth. The nervation consists of a rather strong midrib and several pairs of alternate thin secondaries which arise at a low angle and arch and join well inside the margin, sending branches from the outside to the marginal teeth. There are a few intermediate secondaries. The nervilles are numerous, rather strong, and usually broken, forming irregular areas.

This leaf, although a mere fragment, is so entirely distinct from any other form found in these beds that it merits recognition.

Occurrence: Frontier formation, 1 mile east of Cumberland, Wyo. Collected by F. H. Knowlton and T. W. Stanton in 1908.

Phyllites sp.

Plate XXXV, figure 4b.

The basal portion of the leaf here figured seems to represent a very distinct form that can probably be recognized if found in the future. It appears to have been ovate, the base at first abruptly rounded, then projected downward into a wedge-shaped portion. The rather slender, curved petiole is apparently complete. The margin is entire. The nervation consists of a rather slender midrib, a pair of very slender secondaries just above the basal margin of the blade, and a pair of opposite secondaries some distance above the base. These upper secondaries, or perhaps "ribs," have branches on the outside that curve upward along and perhaps end in the margin. These "ribs" do not join with the midrib where they come into contact with it but are distinct and run down along the midrib almost to the base of the leaf. The finer nervation can not be made out with certainty.

Occurrence: Frontier formation, 1½ miles south of Cumberland, Wyo., in the SE. ¼ sec. 6, T. 18 N., R. 116 W. From same horizon as plant beds 1 mile east of Cumberland. Collected by T. W. Stanton September 1, 1913.

FORMS EXCLUDED FROM THIS FLORA.

Genus TRICHOPTERIS.

Trichopteris filamentosa Hall, in Frémont, op. cit., Appendix B, p. 306, pl. 2, fig. 6, 1845.
Trichopteris gracilis Hall, idem, p. 307, pl. 1, fig. 5.

This genus with two species was established by Hall, but clearly the forms are only rootlets of ferns.

Phyllites fremonti Unger.

Phyllites fremonti Unger, Genera et species plantarum fossilium, p. 503, 1850. Leaf of a dicotyledonous plant (?) Hall, in Frémont, op. cit., Appendix B, p. 307, p. 2, fig. 4, 1845.

There is much doubt about the propriety of including this species in the present flora. It was placed by Hall at the end of the description of this flora, with the following remarks:

> Locality in the neighborhood of the specimens containing the preceding fossils and regarded by Capt. Frémont as belonging to the same formation. The rock containing them is a soft or very partially indurated clay, very unlike the hard and brittle mass containing the other species.

The probability that it did not come from the vicinity of the Cumberland locality is further strengthened by the chance statement "Fr. Aug. 17, and No. 201 of collection," which appears to mean that it was collected on Friday, August 17, whereas the others are recorded under the date of August 19. Frémont's itinerary for the earlier date [1] indicates that on that day the expedition encamped on Blacks Fork of Green River, some 40 miles east of the locality reached on August 19. In the low hills bordering the stream he found "strata containing handsome and very distinct vegetable fossils." This locality is presumably in the Green River formation, and if the above reasoning is correct, it appears to dispose of the reference of this species to the Colorado flora under consideration. The type specimen is now lost, and hence it is impossible to study the matrix in which it was preserved.

This leaf was named and described by Unger as *Phyllites fremonti,* from Hall's figure, and Unger fell into the usual error of ascribing it to Oregon, as the expedition went to "Oregon and north California." The above history has been given at some length for the purpose of setting forth the unsatisfactory status of this species and thus preventing future misunderstanding.

[1] Frémont, J. C., op. cit., p. 130.

PLATES XXVIII–XXXIX.

PLATE XXVIII.

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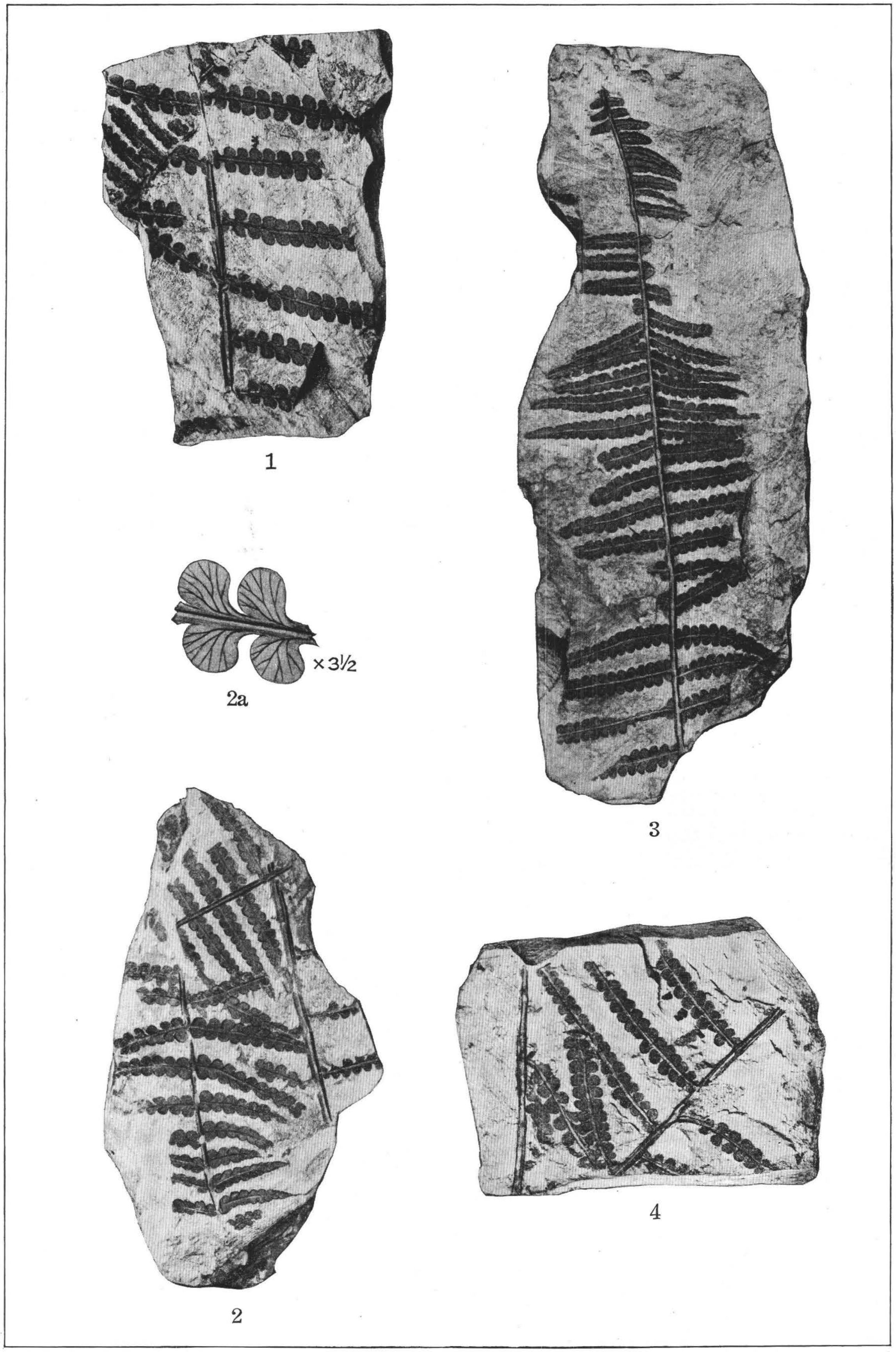
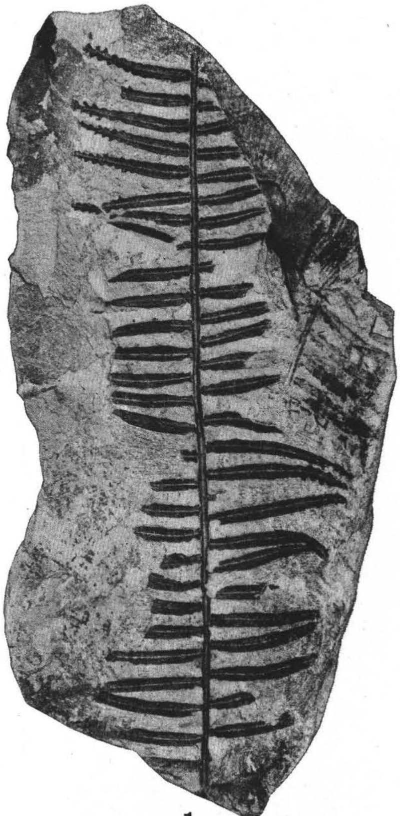


FOSSIL FLORA FROM THE FRONTIER FORMATION.



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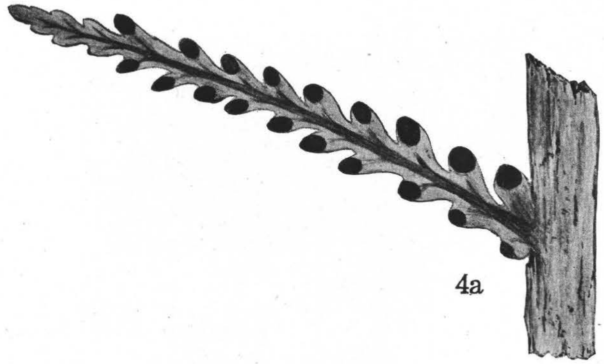

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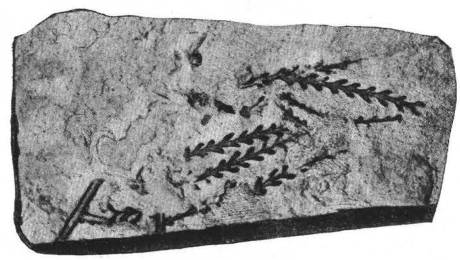

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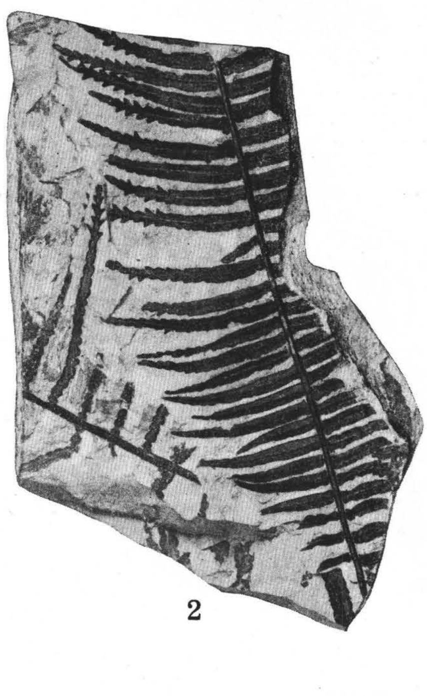

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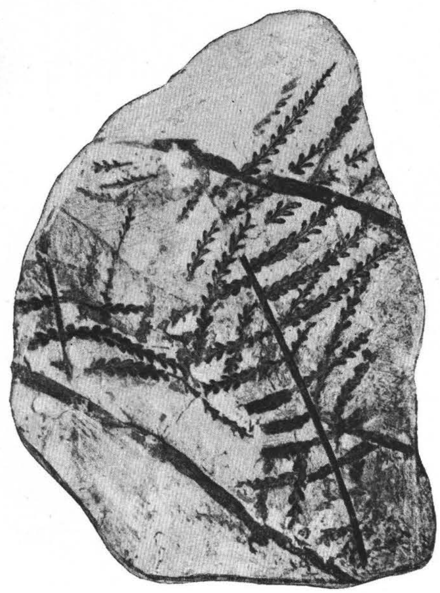

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FOSSIL FLORA FROM THE FRONTIER FORMATION.

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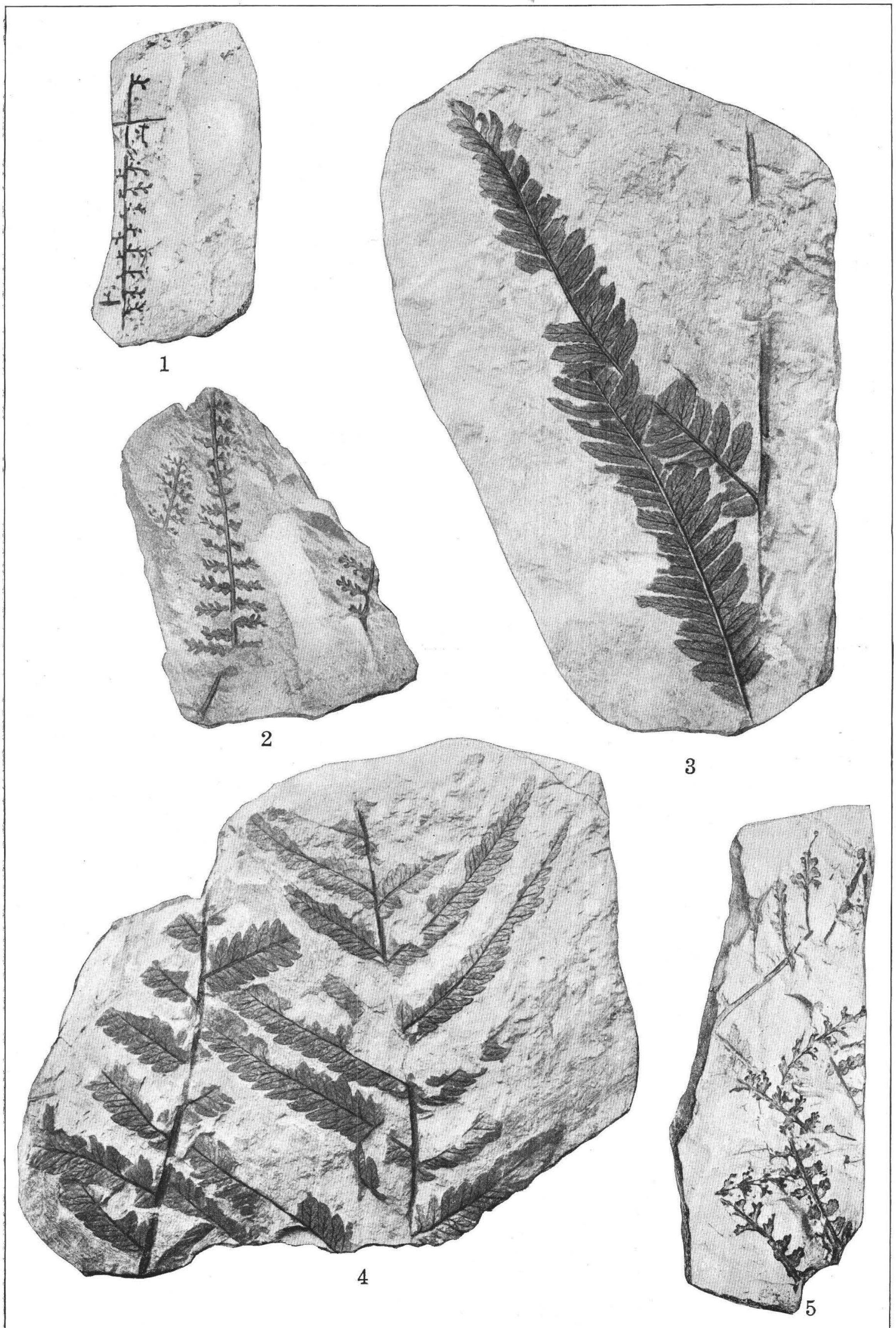

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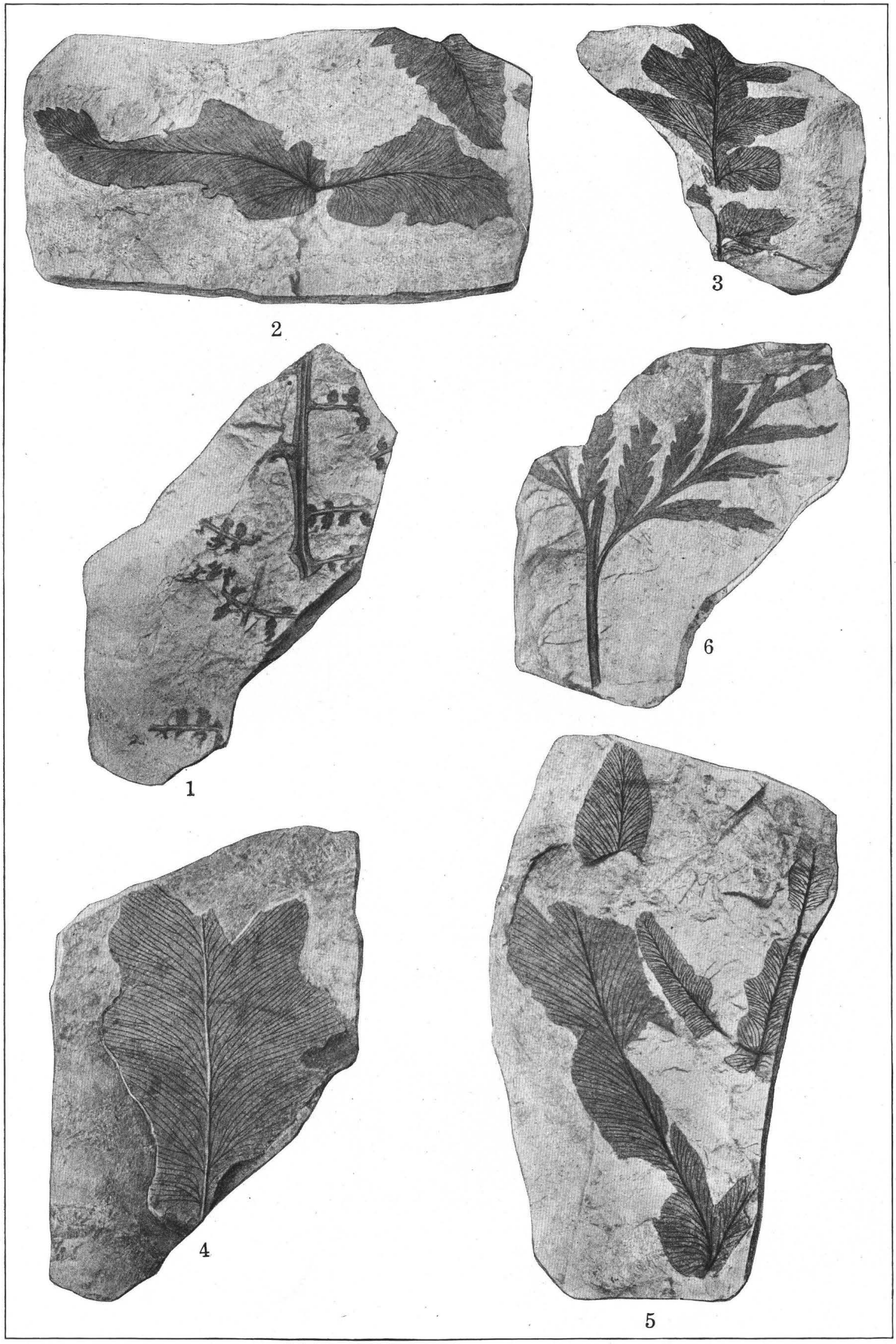

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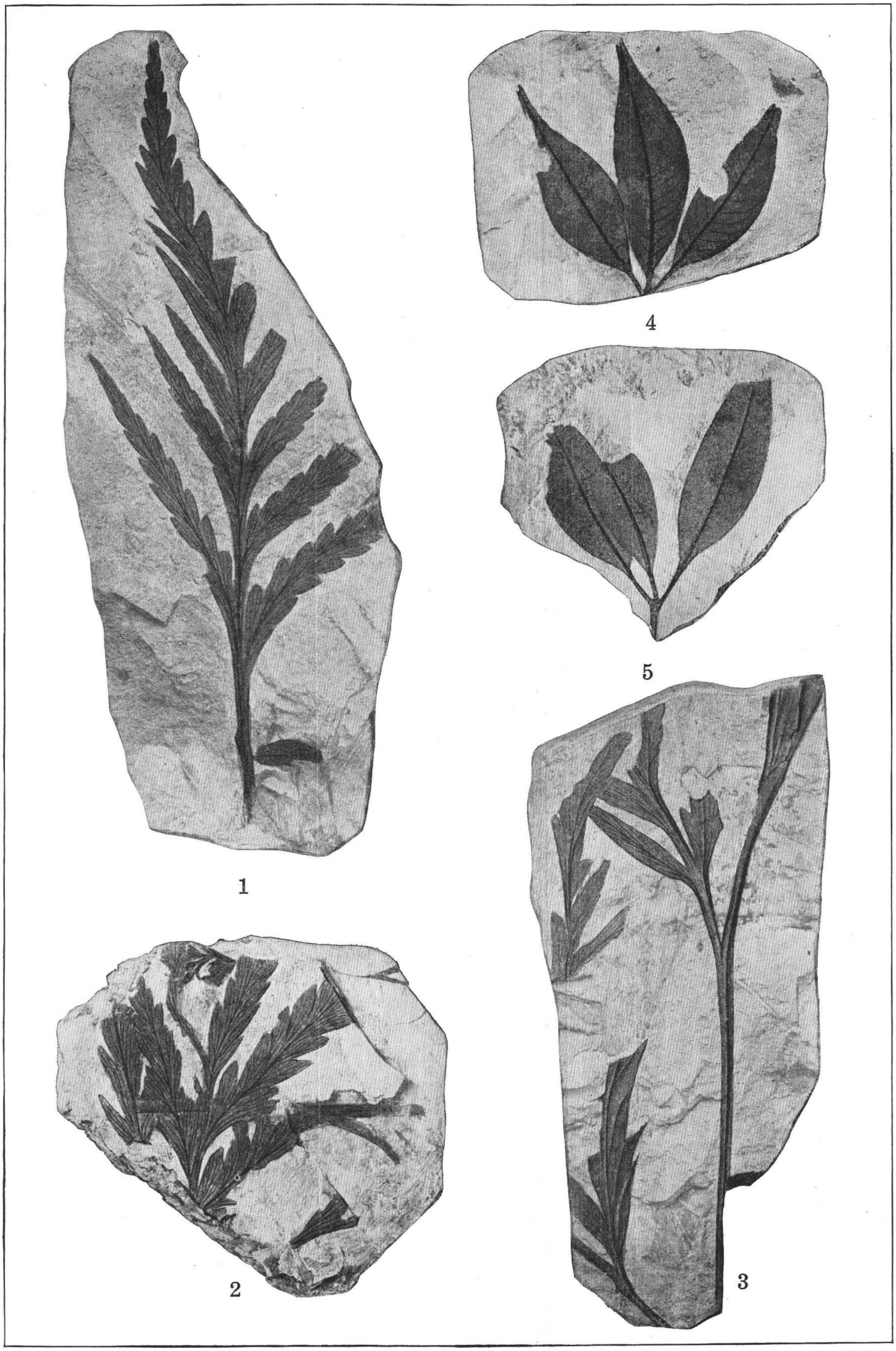

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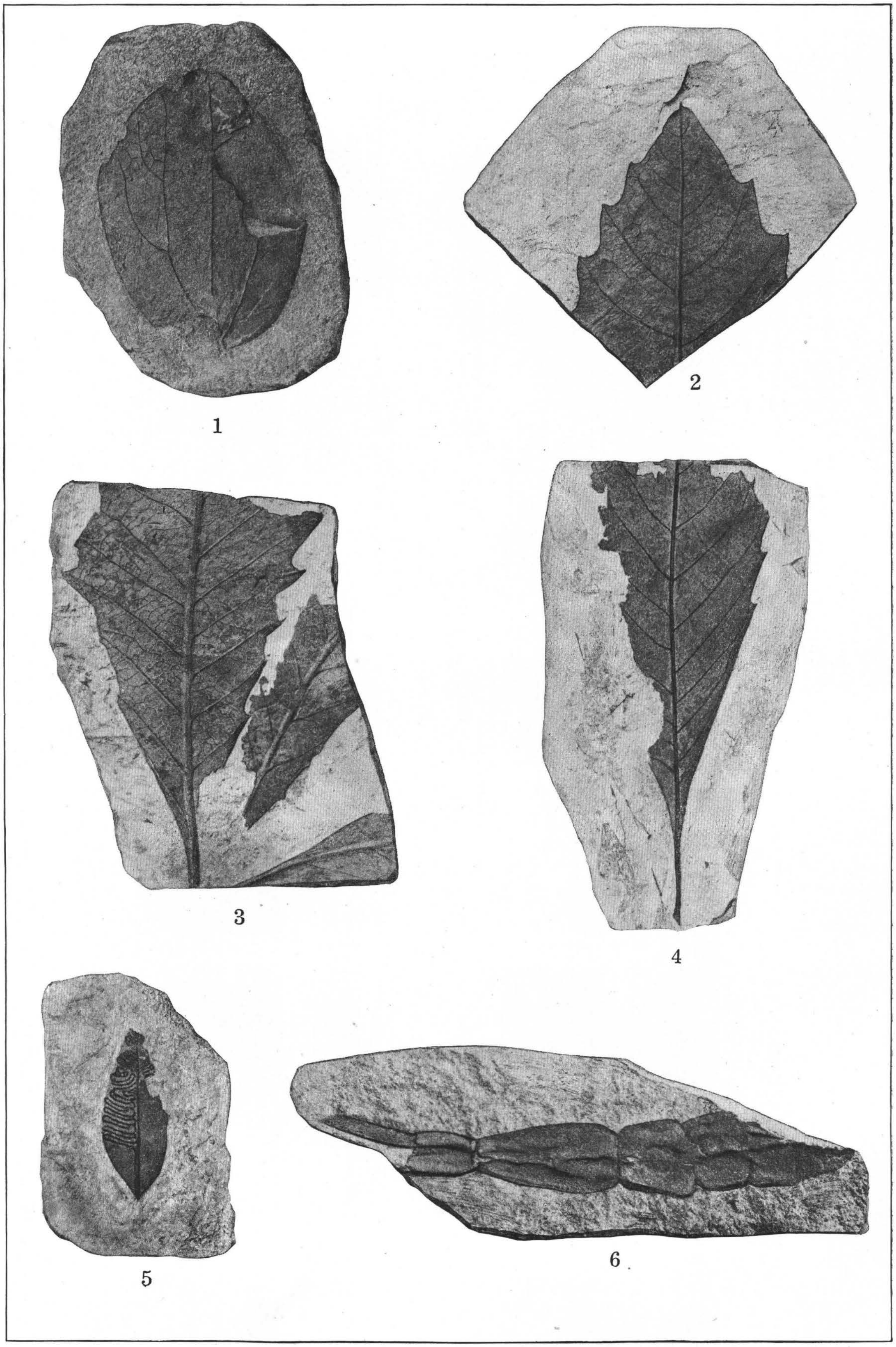

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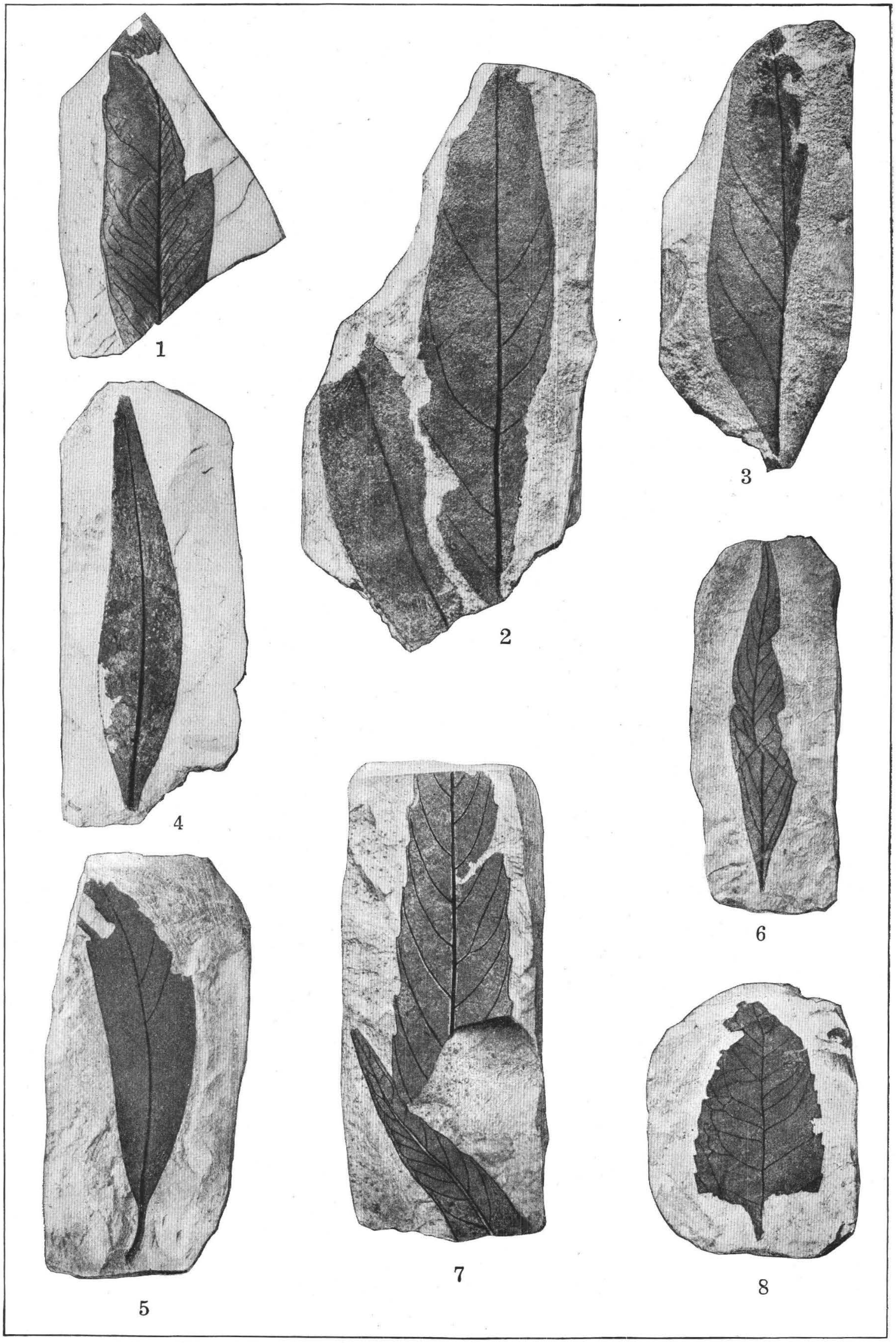

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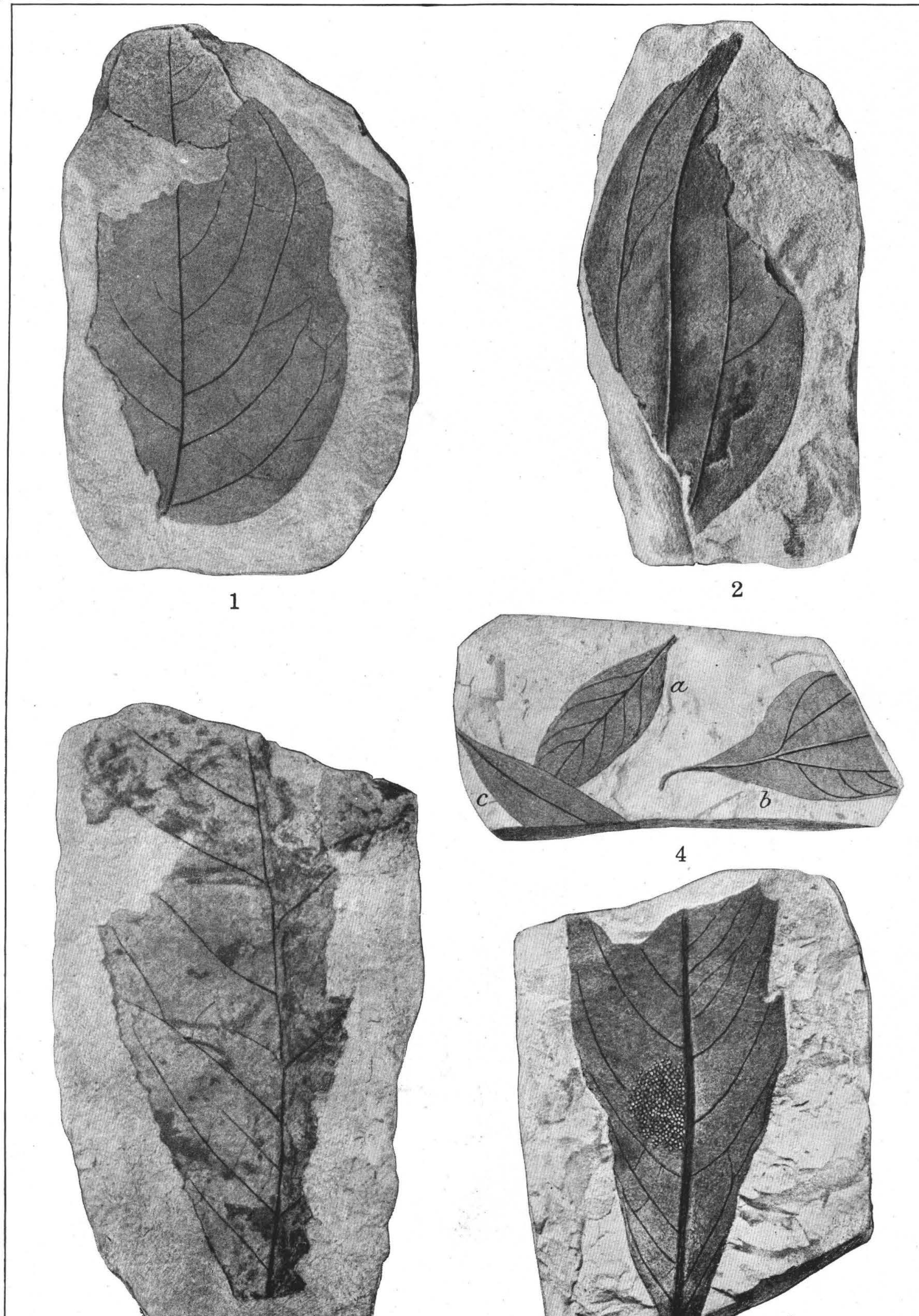

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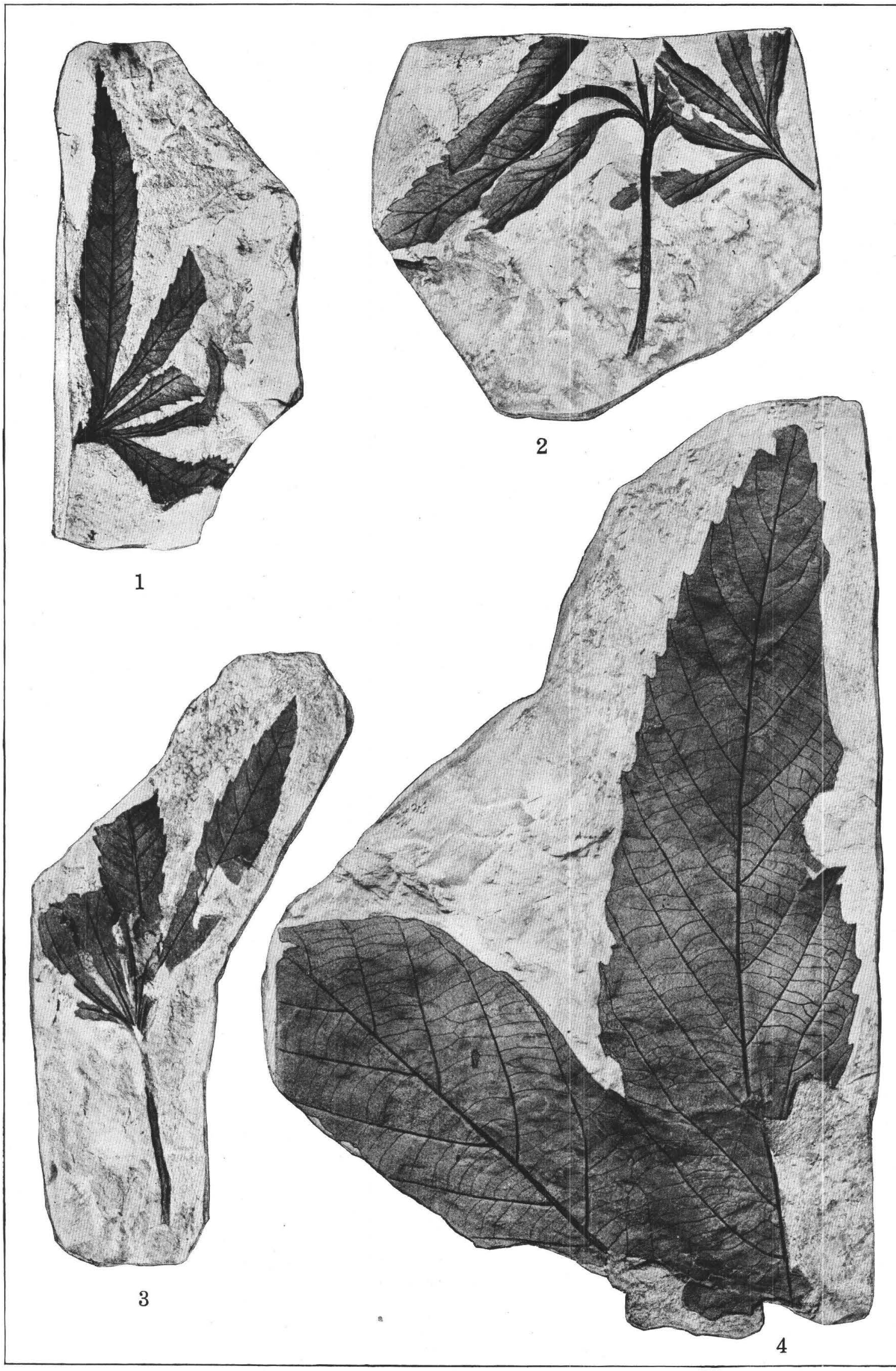

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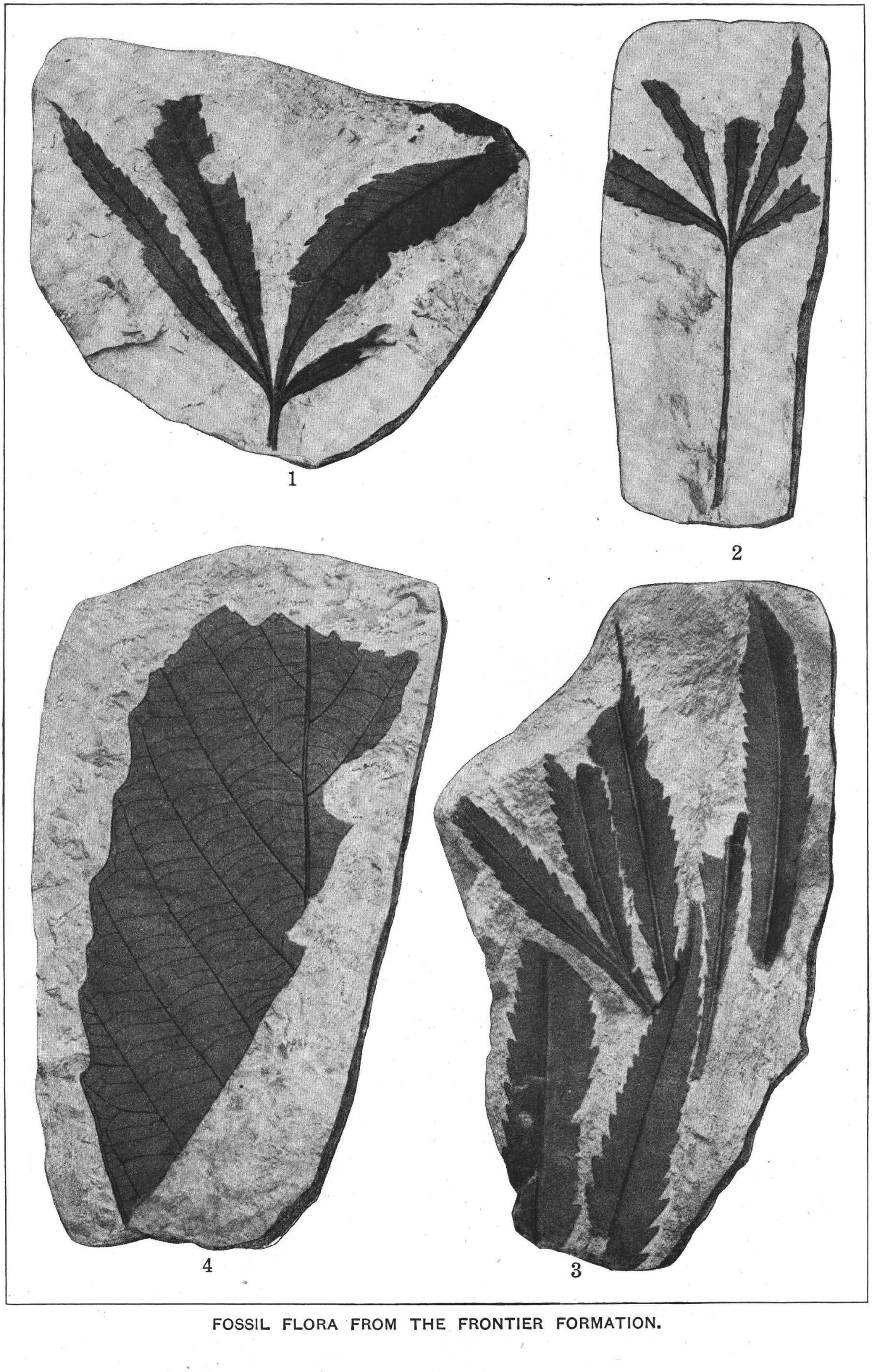

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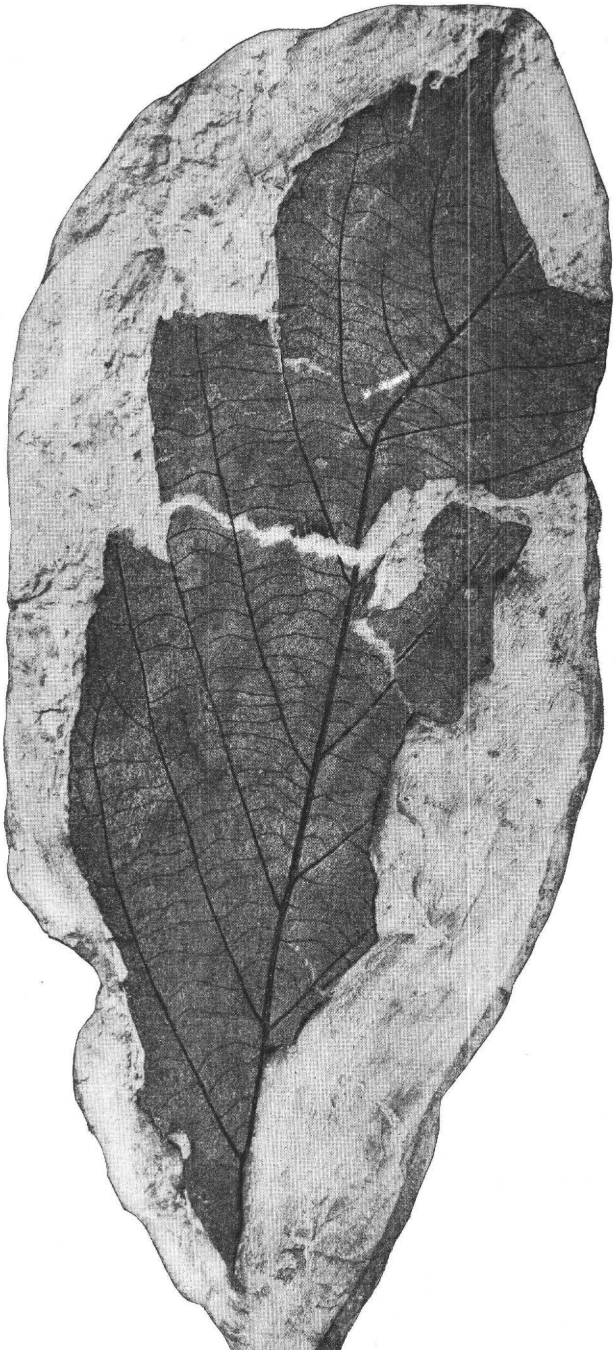

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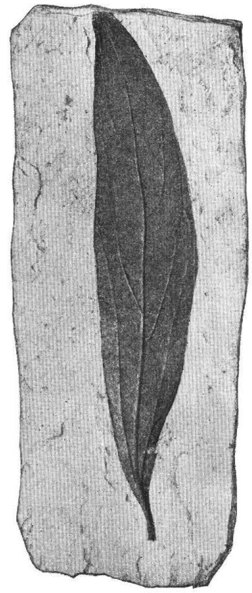

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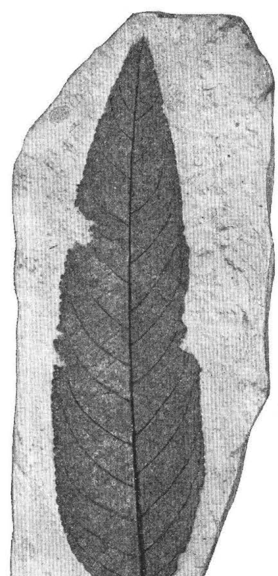

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FOSSIL FLORA FROM THE FRONTIER FORMATION.

FOSSIL FLORA FROM THE FRONTIER FORMATION.

PLATE XXXIX.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 108—G

ORBITOID FORAMINIFERA OF THE GENUS ORTHOPHRAGMINA FROM GEORGIA AND FLORIDA

PAPERS BY

C. W. COOKE AND J. A. CUSHMAN

Published December 12, 1917

Shorter contributions to general geology, 1917

(Pages 109–124)

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1917

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ILLUSTRATIONS.

THE STRATIGRAPHIC POSITION AND FAUNAL ASSOCIATES OF THE ORBITOID FORAMINIFERA OF THE GENUS ORTHOPHRAGMINA FROM GEORGIA AND FLORIDA.

By Charles Wythe Cooke.

INTRODUCTION.

The present short paper is designed to furnish information regarding the stratigraphic relations of the species of *Orthophragmina* described by Mr. Cushman in the succeeding paper and to enumerate the other organisms found in association with them, and thereby make evident the value of these species in the investigation of problems of geologic correlation. Evidence, chiefly paleontologic, presented in a recent paper [1] in my opinion shows that the Ocala limestone is of upper Eocene age. The occurrence of *Orthophragmina* at numerous exposures which are referred to the Ocala on the basis of physical and faunal resemblance is in accord with the deduction from other paleontologic data and corroborates the reference to the upper Eocene of the part of the formation in which they are found.

The orbitoid Foraminifera described by Mr. Cushman in the accompanying paper were obtained from the Ocala limestone in three regions—on Chipola River at Marianna, Jackson County, Fla.; at several localities on Flint River, Ga., between the crossing of the Seaboard Air Line Railway in Sumter County, about 8 miles west of Cordele, and Bainbridge, Decatur County; and on Suwannee River in Suwannee County, Fla. The positions of the stations have been plotted on the maps, text figures 19 and 20. Some of these occurrences are believed to represent the upper part of the Ocala limestone, but the exact stratigraphic position of most of them in the formation has not been definitely ascertained. The collections obtained on Flint River above Albany (characterized by the presence of *Orthophragmina flintensis* Cushman) represent a horizon lower in the formation than those obtained at the other localities cited in this paper.

The following is a list of the species of *Orthophragmina* described by Mr. Cushman, with the station numbers of the localities at which they were found:

Orthophragmina flintensis Cushman, n. sp. 7115, 7116, 7117, 7119, 7237.

Orthophragmina floridana Cushman, n. sp. 6768.

Orthophragmina americana Cushman, n. sp. 3387, 6768.

Orthophragmina mariannensis Cushman, n. sp. 3387, 6768.

Orthophragmina mariannensis var. *papillata* Cushman, n. var. 6768, 7126, 7129, 7191, 7192.

Orthophragmina georgiana Cushman, n. sp. 3387, 7097, 7099, 7126, 7348.

Orthophragmina vaughani Cushman, n. sp. 3387.

LOCALITIES ON CHIPOLA RIVER.

Stations 6768, 7191, 7192.—The following sections at Marianna are quoted from my paper on the age of the Ocala limestone: [2]

Section on the west bank of Chipola River at the wagon bridge one-half mile east of Marianna, Fla.

	Feet.
Marianna limestone:	
5. Alternating hard and softer beds of light-colored limestone, very hard and compact in places, locally semicrystalline. The lower portion contains a considerable amount of glauconite. The upper portion has been quarried for building stone and contains *Orbitoides*, *Pecten poulsoni* (var.?), *Clypeaster rogersi*, and casts of other fossils. The floor of the bridge is 9 feet above the base of this bed	33
Ocala limestone:	
4. Concealed	3
3. Hard creamy-white semicrystalline limestone, apparently a more indurated phase of bed No. 1. Contains *Orbitoides* (stellately marked species), *Arca*, *Glycymeris*, *Amusium ocalanum*, *Plicatula* (Ocala species), *Venericardia*	$1\frac{1}{3}$
2. Concealed	4

[1] Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, pp. 107-117, 1915.

[2] Idem, p. 109.

Ocala limestone—Continued.	Feet.
1. Soft cream-colored porous limestone or marl, composed largely of Foraminifera loosely packed together. Contains *Nummulites*, *Orbitoides* (stellately marked species), Bryozoa, *Amusium ocalanum*, *Cardium*. Extends beneath water in the river	5

The intervals concealed at the bridge are exposed near the mouth of the cavern about 200 yards below the bridge, where the following supplementary section was observed:

Section 200 yards below the wagon bridge east of Marianna, Fla.

	Feet.
Marianna limestone:	
5. White limestone, the same as bed No. 5 of the section at the bridge	33
Ocala limestone.	
4. Soft cream-colored limestone with several species of *Orbitoides* and some Bryozoa	1
3. Hard semicrystalline pinkish limestone with large *Orbitoides*, *Flabellum*, and *Amusium ocalanum*	6½
2. Soft granular cream-colored limestone, much like No. 1 of section at bridge but with fewer Foraminifera. Contains *Orbitoides* (stellately marked species), *Flabellum*, Bryozoa, *Terebratulina lachryma*?, *Natica*, *Arca*, *Pecten indecisus*, *Amusium ocalanum*, and *Plicatula* (Ocala species)	3
1. Concealed to water level in Chipola River	3

From bed 1 of the first section (station 6768) Mr. Cushman records *Orthophragmina floridana*, *O. americana*, *O. mariannensis*, and *O. mariannensis* var. *papillata*. The last-named variety occurs also in bed 3 of the first section (station 7192) and in bed 2 of the second section (station 7191).

LOCALITIES ON FLINT RIVER.

Station 7237.—Small quarry on the Averitt property, 300 or 400 yards southwest of the corner of lots 7 and 26, half a mile east of Hugenen Ferry and 1 mile south of Daphne station, Crisp County.

The rock at this locality is a soft white limestone containing *Orthophragmina flintensis* Cushman, numerous Bryozoa, and an undetermined pecten, probably *Amusium ocalanum* (Dall). An analysis of the limestone from this locality given by Brantley[1] shows 85 per cent calcium carbonate. Better exposures of this rock occur in a sink about 300 yards east of the quarry, where 23 feet of soft argillaceous white limestone containing small specks of glauconite is overlain by 18 feet of reddish sandy loam. The course of an underground stream that flows through this sink can be traced northwestward by means of long, narrow, slot-shaped sinks which expose it at intervals to Gum Creek.

[1] Brantley, J. E., Limestones and marls of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 21, p. 158, 1916.

Station 7115.—East bank of Flint River at bend to west 6 miles below Burke Ferry and about 6 miles above the bridge of the Georgia Southwestern & Gulf Railway near Warwick, Worth County.

The material exposed consists of white, compact limestone rising 5 feet above water level and overlain by flint boulders, sand, and gravel. *Orthophragmina flintensis* and *Operculina* sp. were collected here.

Stations 7116, 7117.—Bluff on the west bank of Flint River about 1¾ miles above the bridge of the Georgia Southwestern & Gulf Railway near Oakfield.

The section at this locality is as follows:

Section on Flint River near Oakfield.

	Feet.
3. Covered slope to top of hill	22
2. Hard ledges of compact white semicrystalline limestone (station 7117)	3
1. Compact white limestone, mostly soft but with harder places. Contains (station 7116) *Orthophragmina flintensis* and *Laganum*? *crustuloides* (Morton)? To water level at 4-foot stage	20

From bed 2 were collected the following:

Foraminifera:
  Orthophragmina flintensis Cushman.
Bryozoa:
  Several species.
Echinodermata:
  Laganum? crustuloides (Morton)?
Mollusca:
  Ostrea sp.
  Pecten perplanus Morton.
  Pecten suwaneënsis Dall.

Station 7119.—East bank of Flint River, about 16 miles above Albany, in Worth County, near the Dougherty County line.

The rock here consists of 5 feet of limestone, the upper part white, and the lower part gray, overlain by flint fragments. It contains *Orthophragmina flintensis* Cushman, *Operculina* sp., and *Pecten suwaneënsis* Dall.

Station 7126.—East bank of Flint River at Dry Bread Shoals, Mitchell County, 8½ or 9 miles below Newton.

The following species were collected from lumps of hard limestone excavated from the channel:

Foraminifera:
  Orthophragmina mariannensis var. papillata Cushman.
  Orthophragmina georgiana Cushman.

Anthozoa:
- Trochoseris n. sp.

Echinodermata:
- Cidaris georgiana Twitchell.
- Laganum? crustuloides (Morton)?
- Oligopygus haldermani (Conrad).

Mollusca:
- Mitra sp.
- Chama sp.
- Limopsis sp.
- Barbatia sp.

Mollusca—Continued.
- Ostrea trigonalis Conrad.
- Amusium ocalanum (Dall).
- Pecten perplanus Morton.
- Spondylus sp.
- Plicatula, Ocala sp.
- Mya? sp.
- Venericardia vicksburgiana Dall.
- Venericardia sp.
- Crassatellites sp.

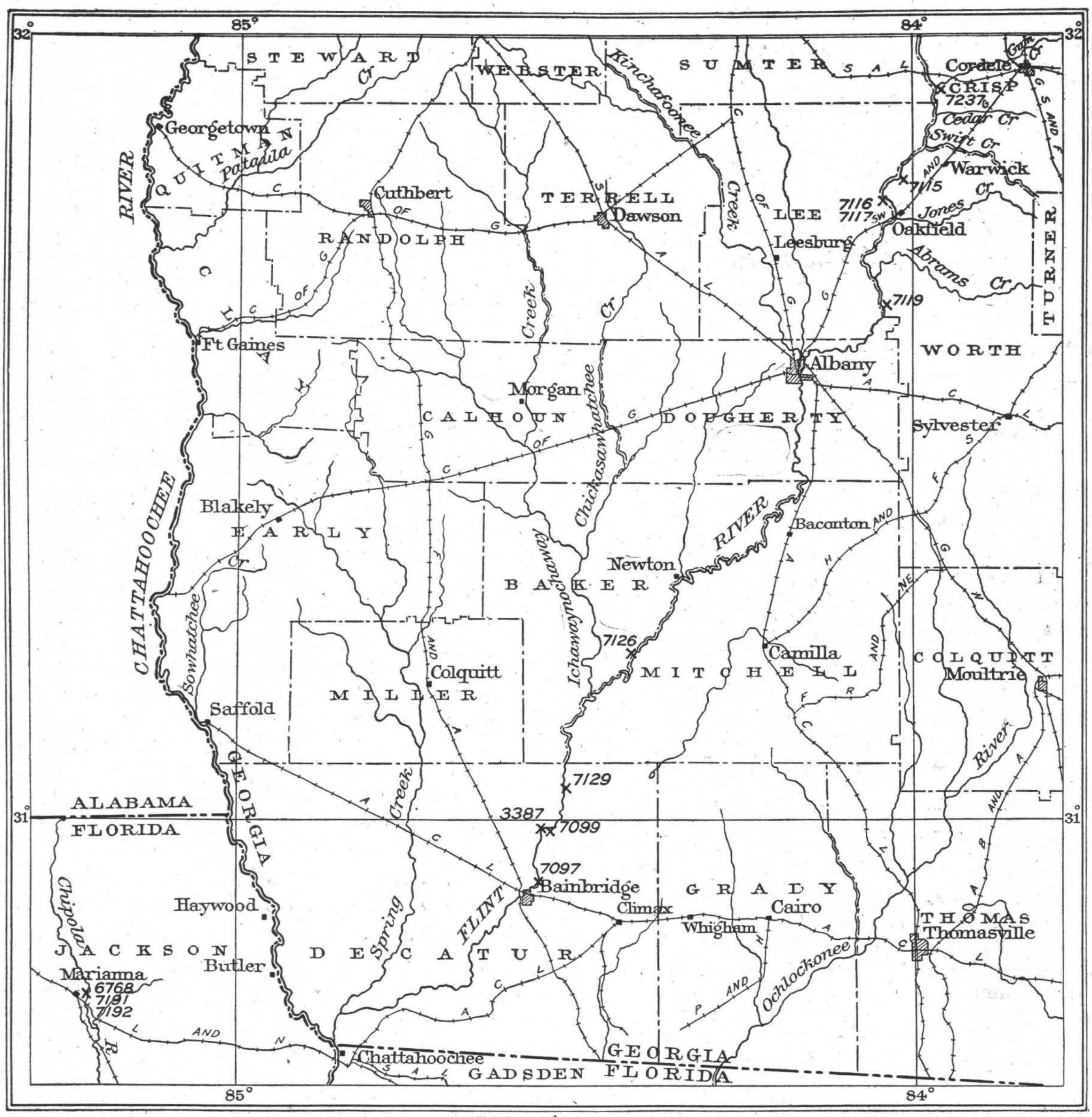


FIGURE 19.—Map showing position of stations on Chipola River, Fla., and Flint River, Ga., at which specimens of *Orthophragmina* were collected.

Station 7129.—East bank of Flint River 1 mile below Windell's Landing and about 15 miles above Bainbridge, in Decatur County.

Orthophragmina mariannensis var. *papillata* Cushman and an undetermined species of *Pecten* were found in 5 feet of irregularly weathered pinkish limestone.

Stations 3387, 7097, 7099.—Species of *Orthophragmina* have been obtained from the Ocala limestone at three localities near Bainbridge, the stratigraphic relations of which are nearly identical. The Ocala limestone is the oldest formation in the vicinity of Bainbridge, and all the exposures of it appear to represent a single horizon. It is a soft, coarsely granular white to yellow limestone and is composed largely of tests of Foraminifera and Bryozoa, which on exposed surfaces have become firmly cemented or "casehardened" into a brittle semicrystalline limestone but which when freshly exposed are only slightly coherent. The rock appears to lie very nearly horizontal, but the upper surface is exceedingly irregular and jagged, with pinnacles extending in places to 20 feet above water level. The irregularity is due in part to erosion prior to the deposition of the overlying materials and in part to subsequent solution.

The Ocala is overlain unconformably by a complex series of red and variegated sands and carbonaceous clays containing chert fragments with impressions and siliceous pseudomorphs of mollusks and corals of earliest Chattahoochee age. The Ocala itself appears to have been subjected in less degree to the silicifying agencies, for chert fragments carrying Ocala fossils are occasionally found. The accidental inclusion of some of these fragments in the collections of the coralliferous chert has unfortunately been interpreted as a mingling of the Ocala and Chattahoochee faunas.[1]

The following species have been identified in the Ocala limestone from localities near Bainbridge:

Station 7099. East bank of Flint River, half a mile above Red Bluff:
- Foraminifera:
  - Orthophragmina georgiana Cushman.
- Bryozoa:
  - Many species.
- Echinodermata:
  - Oligopygus haldermani (Conrad).
  - Agassizia conradi (Bouvé).

Stations 3387, 6159, 7098. Red Bluff, Flint River, 7 miles above Bainbridge:
- Foraminifera:
  - Orthophragmina americana Cushman.
  - Orthophragmina mariannensis Cushman.
  - Orthophragmina georgiana Cushman.
  - Orthophragmina vaughani Cushman.
- Bryozoa:
  - Many species.
- Echinodermata:
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Cassidulus (Pygorhynchus) georgiensis Twitchell.
  - Agassizia conradi (Bouvé).

[1] Dall, W. H., A contribution to the invertebrate fauna of the Oligocene beds of Flint River, Ga.: U. S. Nat. Mus. Proc., vol. 51, p. 488, 1916.

Station 3387, 6159, 7098, Red Bluff, Flint River, etc.—Con.
- Mollusca:
  - Pecten perplanus Morton.
  - Pecten indecisus Dall.
  - Pecten suwaneënsis Dall.
  - Amusium ocalanum (Dall).

Station 7097.—Bluff on east bank of Flint River near the old factory three-fourths mile northeast of the Atlantic Coast Line Railway station at Bainbridge:
- Foraminifera:
  - Orthophragmina georgiana Cushman and many others.
- Bryozoa:
  - About 34 species, most of them new.
- Echinodermata:
  - Cidaris georgiana Twitchell.
  - Cassidulus (Pygorhynchus) conradi (Conrad).
  - Oligopygus haldermani (Conrad).
  - Agassizia conradi (Bouvé).
  - Eupatagus carolinensis Clark?
- Mollusca:
  - Ostrea, 2 sp.
  - Pecten perplanus Morton.
  - Amusium ocalanum (Dall).
  - Plicatula, Ocala sp.
  - Cardium sp.

LOCALITY ON SUWANNEE RIVER.

Station 7348.—Left bank of Suwannee River 84½ miles above its mouth, 9 miles above Branford, and about 1 mile above Troy Springs. (See fig. 20.)

There is at this place a small exposure of cream-colored orbitoidal limestone containing *Orthophragmina georgiana* Cushman, *Pecten perplanus* Morton, and *Pecten indecisus* Dall. The exposure is believed to represent a horizon well up in the Ocala limestone but not the topmost.

FAUNAL ASSOCIATES OF SPECIES OF ORTHOPHRAGMINA.

The species which have been found associated with each species of *Orthophragmina* are listed below:

Orthophragmina flintensis Cushman.
- Operculina sp.
- Laganum? crustuloides (Morton)?
- Ostrea sp.
- Pecten perplanus Morton.
- Pecten suwaneënsis Dall.
- Amusium ocalanum (Dall).

Orthophragmina floridana Cushman.
- Orthophragmina americana Cushman.
- Orthophragmina mariannensis Cushman.
- Orthophragmina mariannensis var. papillata Cushman.
- Flabellum sp.
- Terebratulina lachryma (Morton)?
- Pecten indecisus Dall.
- Amusium ocalanum (Dall).
- Plicatula, Ocala sp.

- Orthophragmina americana Cushman.
  - Orthophragmina floridana Cushman.
  - Orthophragmina mariannensis Cushman.
  - Orthophragmina mariannensis var. papillata Cushman.
  - Orthophragmina georgiana Cushman.
  - Orthophragmina vaughani Cushman.
  - Flabellum sp.
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Cassidulus (Pygorhynchus) georgiensis Twitchell.
  - Agassizia conradi (Bouvé).
  - Terebratulina lachryma (Morton)?
  - Pecten indecisus Dall.
  - Pecten perplanus Morton.

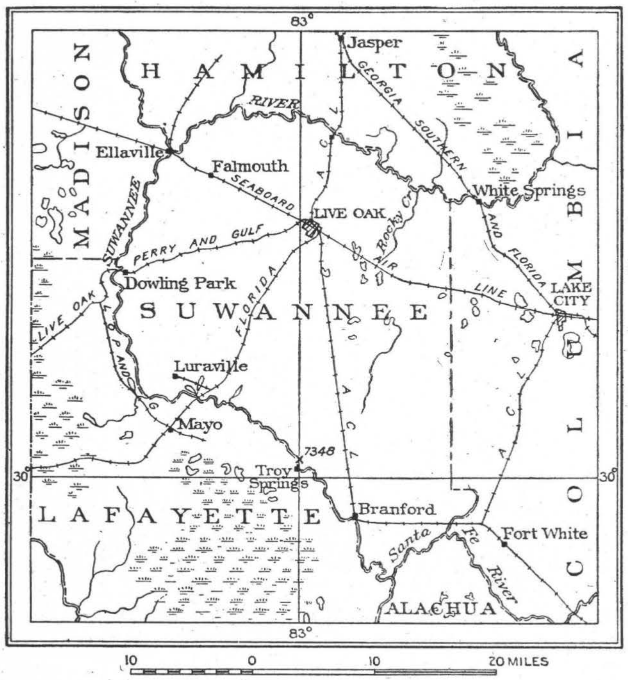


FIGURE 20.—Map showing position of station 7348, Troy Springs, on Suwannee River, Fla.

  - Pecten suwaneënsis Dall.
  - Amusium ocalanum (Dall).
  - Plicatula, Ocala sp.
- Orthophragmina mariannensis Cushman.
  - Orthophragmina floridana Cushman.
  - Orthophragmina americana Cushman.
  - Orthophragmina mariannensis var. papillata Cushman.
  - Orthophragmina georgiana Cushman.
  - Orthophragmina vaughani Cushman.
  - Flabellum sp.
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Cassidulus (Pygorhynchus) georgiensis Twitchell.
  - Agassizia conradi (Bouvé).
- Orthophragmina mariannensis Cushman—Continued.
  - Terebratulina lachryma (Morton)?
  - Pecten indecisus Dall.
  - Pecten perplanus Morton.
  - Pecten suwaneënsis Dall.
  - Amusium ocalanum (Dall).
  - Plicatula, Ocala sp.
- Orthophragmina mariannensis var. papillata Cushman.
  - Orthophragmina mariannensis Cushman.
  - Orthophragmina floridana Cushman.
  - Orthophragmina americana Cushman.
  - Orthophragmina georgiana Cushman.
  - Flabellum sp.
  - Trochoseris n. sp.
  - Cidaris georgiana Twitchell.
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Terebratulina lachryma (Morton)?
  - Pecten perplanus Morton.
  - Pecten indecisus Dall.
  - Amusium ocalanum (Dall).
  - Spondylus sp.
  - Plicatula, Ocala sp.
  - Venericardia vicksburgiana Dall.
- Orthophragmina georgiana Cushman.
  - Orthophragmina americana Cushman.
  - Orthophragmina mariannensis Cushman.
  - Orthophragmina mariannensis var. papillata Cushman.
  - Orthophragmina vaughani Cushman.
  - Trochoseris n. sp.
  - Cidaris georgiana Twitchell.
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Cassidulus (Pygorhynchus) conradi (Conrad).
  - Cassidulus (Pygorhynchus) georgiensis Twitchell.
  - Agassizia conradi (Bouvé).
  - Eupatagus carolinensis Clark?
  - Ostrea trigonalis Conrad.
  - Pecten suwaneënsis Dall.
  - Pecten perplanus Morton.
  - Pecten indecisus Dall.
  - Amusium ocalanum (Dall).
  - Spondylus sp.
  - Plicatula, Ocala sp.
  - Venericardia vicksburgiana Dall.
- Orthophragmina vaughani Cushman.
  - Orthophragmina georgiana Cushman.
  - Orthophragmina americana Cushman.
  - Orthophragmina mariannensis Cushman.
  - Oligopygus haldermani (Conrad).
  - Laganum? crustuloides (Morton)?
  - Pecten perplanus Morton.
  - Pecten indecisus Dall.
  - Pecten suwaneënsis Dall.
  - Amusium ocalanum (Dall).
  - Cassidulus (Pygorhynchus) georgiensis Twitchell.
  - Agassizia conradi (Bouvé).

ORBITOID FORAMINIFERA OF THE GENUS ORTHOPHRAGMINA FROM GEORGIA AND FLORIDA.

By JOSEPH AUGUSTINE CUSHMAN.

The larger orbitoid Foraminifera of the Western Hemisphere are very inadequately known, yet their occurrence in great numbers has been noted in many papers during the last three-quarters of a century. *Lepidocyclina mantelli* (Morton), the type species of that genus, was described by Morton in 1833.

As now known the orbitoid Foraminifera found in beds below the Miocene are grouped largely in three genera, the grouping depending upon the internal structure of the test. In these groups there is a central plane of chambers, known technically as "equatorial chambers," and a mass of more irregularly placed chambers on each side, making up the thickness of the test, known as "lateral chambers." In transverse (vertical) section the equatorial chambers show slight differences, but when cut horizontally, or in the plane in which they lie, those of *Lepidocyclina* typically have a hexagonal form, those of *Orthophragmina* are elongated rectangular, and those of *Orbitoides* are diamond shaped. Because in general *Orbitoides*, with some modifications to be noted in a future paper, is Cretaceous, *Orthophragmina* Eocene, and *Lepidocyclina* Oligocene, much importance is attached to these organisms in the investigation of problems of geologic correlation.

The specimens described here belong to the second of the genera mentioned, *Orthophragmina*. Although not limited to this genus, the stellate form or stellately marked surface is rather characteristic of a number of the species. Bagg [1] and Cooke [2] have referred to "stellately marked" orbitoid Foraminifera, all of which have proved on examination to be *Orthophragmina*. Two of the species here described are circular and not stellately marked, but the others are distinctly stellate, either in form or markings.

After a careful study of the species all seem to be new, although one or two of them are somewhat related to certain European species, as is noted in the descriptions. The specimens as a rule occur in soft chalky limestone and do not section well to show the finer structure of the interior.

Data in regard to material are included in the description of each species.

Orthophragmina flintensis Cushman, n. sp.

Plate XL, figures 1, 2.

Test small, circular, about 5 millimeters in diameter; central portion thickened, gradually sloping to the periphery; surface slightly pustulate but not papillate, almost smooth, the raised pustules generally in concentric lines.

Horizontal section shows very narrow rectangular equatorial chambers and the embryonic chambers consisting of a small circular chamber nearly surrounded by the elongate second chamber (Pl. XL, fig. 2).

Type specimen from U. S. G. S. collection 7117, from Ocala limestone in bluff on west bank of Flint River $1\frac{3}{4}$ miles above the Georgia Southwestern & Gulf Railway bridge near Oakfield, Lee County, Ga.; upper bed, No. 2 of section; C. W. Cooke, collector.

Other specimens of this same species from the Ocala limestone are in collections 7116, same locality, No. 1 of section; 7115, east bank of Flint River at bend to west 6 miles below Burke Ferry and about 6 miles above the Georgia Southwestern & Gulf Railway bridge near Warwick, Worth County, Ga., C. W. Cooke, collector; 7119, east bank of Flint River about 16 miles above Albany, in Worth County, Ga., C. W. Cooke, collector; 7237,

[1] Veatch, Otto, and Stephenson, L. W., Preliminary report on the geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26, p. 320, 1911. Identification by R. M. Bagg.

[2] Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, p. 109, 1915.

small quarry on Averitt plantation, 300 or 400 yards southwest of corner of lots 26–27, and half a mile east of Hugenen Ferry, Crisp County, Ga.; C. W. Cooke and J. E. Brantley, collectors.

Material from station 7237 may possibly not be the same, but the horizontal section, which alone was visible, is very similar. The species seem to be fairly common in the fine-grained white Ocala limestone along Flint River at these localities.

Orthophragmina floridana Cushman, n. sp.

Plate XL, figure 3.

Test circular, much flattened, of medium size, 10 to 14 millimeters in diameter, central region very slightly raised and umbonate, thence flattened to the periphery, whole test very thin; surface ornamented throughout with fine but distinctly raised papillæ almost spinose, arranged in concentric lines parallel with the peripheral margin.

Equatorial chambers in horizontal section very narrowly rectangular.

Type specimen from U. S. G. S. collection 6768, from soft white Ocala limestone on Chipola River at wagon bridge half a mile east of Marianna, Fla.; No. 1 of section; C. W. Cooke, collector. This species is abundant at this locality.

In many respects this species resembles *O. archiaci* Schlumberger, but it is a little larger and more flattened, and its surface ornamentation is somewhat different. It is evidently, however, an American relative of this French species.

Orthophragmina americana Cushman, n. sp.

Plate XL, figure 4; Plate XLI, figure 1; Plate XLII, figure 1.

Test large, as much as 45 millimeters in diameter; peripheral margin with a series of projecting angles corresponding to the peripheral terminations of the radiately arranged raised ornamentation or thickenings; peripheral margin very thin, especially at the reentrants between the projecting angles; central region with a thickened umbo about 2 millimeters in diameter, from which radiate the thickened riblike raised areas running from the umbo to the ends of the peripheral angles, highest near the umbo and decreasing in height and increasing in width toward the periphery; nearly 20 radiating ribs in all, some starting from the umbo, others initiated later, not as branches of previous ones but arising in the intermediate area, usually more or less irregular, the angle with the adjacent ones at either side not usually the same; surface comparatively smooth, very slight traces of papillae, usually inconspicuous or lacking.

In vertical section the equatorial chambers are rectangular, the area of the raised radial portions consisting of more numerous lateral chambers in the columns, curving about the axis of the rib at either side, those of the intermediate depressed areas parallel with the equatorial belt of chambers and fewer in number.

In horizontal section the equatorial chambers are rectangular, four to five times as long as wide, those of the axis of the radial portions narrower than those of the intermediate depressed areas.

Type specimen from U. S. G. S. collection 6768, Ocala limestone on Chipola River at wagon bridge a quarter of a mile east of Marianna, Fla.; No. 1 of section; C. W. Cooke, collector.

A specimen referred to this species is from station 3387, Ocala limestone at Red Bluff, on Flint River 7 miles above Bainbridge, Decatur County, Ga.; T. W. Vaughan, collector, 1900.

In some respects this species resembles *O. patellaris* Schlotheim, but it is nearly three times as large and has much finer and clearer-cut radial arms and smaller umbo as well as angular periphery. It is more like *O. munieri* Schlumberger, but it is nearly four times as large and the number of ribs is greater and they do not branch as in *O. munieri*.

O. americana is one of the largest species of the genus.

Orthophragmina mariannensis Cushman, n. sp.

Plate XL, figure 5; Plate XLII, figure 2; Plate XLIV.

Test flattened, conspicuously stellate in outline, the angles extending out acutely with curved reentrants, of medium size, mostly 15 to 18 millimeters in diameter; central region raised, umbonate, from which extend eight to eleven (typically eight) raised ribs, running to the peripheral angles; umbo and ribs finely papillate; depressed areas between, flat and rather remotely and finely papillate except toward the periphery, where the papillae are slightly more conspicuous.

Horizontal section showing much elongated, rectangular equatorial chambers, the lateral chambers irregularly polygonal in section.

Vertical section with the embryonic chambers very unequal, distinct pillars between the vertical rows of lateral chambers, increasing in diameter peripherally.

Type specimen from station 6768, Ocala limestone on Chipola River at wagon bridge half a mile east of Marianna, Fla.; No. 1 of section;[1] C. W. Cooke, collector. Abundant.

One specimen from U. S. G. S. station 3387, Ocala limestone at Red Bluff, on Flint River 7 miles above Bainbridge, Decatur County, Ga.; T. W. Vaughan, collector, 1900.

O. mariannensis somewhat remotely resembles *O. lanceolata* Schlumberger, but it is much larger and has a greater number of ribs, and its surface ornamentation is different.

Orthophragmina mariannensis Cushman, n. sp., var. papillata Cushman, n. var.

Plate XLIII, figure 1; Plate XLIV.

Variety differing from the typical form of the species in the much more prominent, higher ribs, which are semicylindrical and very strongly papillate; number of ribs also slightly greater than in the typical form; a few specimens have 8, but 9 to 12 or even 16 ribs are more frequent.

Occurs in Ocala limestone, with the typical form, at the type locality, U. S. G. S. station 6768, on Chipola River at wagon bridge half a mile east of Marianna, Fla.; No. 1 of section; No. 3 of section at station 7192; C. W. Cooke, collector.

Specimens also from stations 7126, Ocala limestone, east bank of Flint River at Dry Bread Shoals, 8½ or 9 miles below Newton, in Mitchell County, Ga., from lumps blasted from the channel, C. W. Cooke, collector; and 7129, Ocala limestone, east bank of Flint River a mile below Windell's landing, about 6 miles above Red Bluff, Ga.; C. W. Cooke, collector.

There is a single specimen, an impression only, from station 7191, from Ocala limestone at mouth of small cavern about 200 yards southwest of bridge over Chipola River east of Marianna, Fla.; No. 2 of section; C. W. Cooke and W. C. Mansfield, collectors.

[1] Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, p. 109, 1915.

This variety for the most part is that referred to by Cooke in his paper cited above. It is recorded there under the name "*Orbitoides*, stellately marked species."

Orthophragmina georgiana Cushman, n. sp.

Plate XLI, figures 2, 3; Plate XLII, figure 3; Plate XLIII, figures 2, 3.

Test typically almost square in outline, the angles slightly projecting and the sides slightly concave near the angles, convex in the center, small, diameter usually about 6 millimeters for the adult specimens, diagonals of the square occupied by raised radial areas with a central umbonate mass of a little more than a millimeter in diameter, intermediate triangular areas flat and thin; entire surface with very numerous, evenly distributed, prominent papillae, those of the central umbo and the middle line of the radial ridges slightly larger than those of the rest of the surface.

Type specimen from U. S. G. S. collection 3387, Ocala limestone at Red Bluff, on Flint River 7 miles above Bainbridge, Decatur County, Ga.; T. W. Vaughan, collector, 1900. It has also been collected in the Ocala limestone at the following stations: 7097, east bank of Flint River above the old factory, at bend three-quarters of a mile northeast of the Atlantic Coast Line Railway station at Bainbridge, Ga., C. W. Cooke and W. C. Mansfield, collectors; 7099, east bank of Flint River about half a mile above Red Bluff, Decatur County, Ga., C. W. Cooke, collector; 7126, east bank of Flint River at Dry Bread Shoals, 8½ or 9 miles below Newton, in Mitchell County, Ga., from lumps blasted from the channel, C. W. Cooke, collector; 7348, left bank of Suwannee River about a mile above Troy Springs, Fla., C. W. Cooke, collector.

In its general form this species is very much like *O. stellata* D'Archiac as figured by Schlumberger, but it does not seem to have the characteristic increase in width of the equatorial band of chambers toward the periphery in the vertical section along the ray that occurs in that species. On the contrary, in *O. georgiana* the equatorial chambers seem to decrease in width toward the periphery, in this being more like those of *O. lanceolata* Schlumberger. In *O. georgiana* also the radial ribs incline to a thickening in the center.

Orthophragmina vaughani Cushman, n. sp.

Plate XLIII, figures 4, 5.

Test flattened, small, 8 to 10 millimeters in diameter, quadrate or octagonal in outline, stellate; main ornamentation consisting of a central raised umbonate portion with four radiating raised areas to the main angles of the test, broad and rather low, about halfway to the periphery considerably increasing in height and width, finely papillate toward the center, much more coarsely so toward the periphery; intermediate spaces much depressed, with a smooth U-shaped area near the inner angle next to the raised portions; the peripheral part raised and strongly papillate, the peripheral portion of this raised area at the margin strongly convex or even bluntly angled.

The ornamentation of this species is unique.

Type specimen and others from U. S. G. S. station 3387, Ocala limestone, Red Bluff, on Flint River 7 miles above Bainbridge, Decatur County, Ga.; T. W. Vaughan, collector, 1900.

PLATES XL–XLIV.

PLATE XL.

Orthophragmina flintensis Cushman, n. sp. (p. 115).

FIGURE 1. Sectional view of type specimen, × 20, showing proloculum and second chamber which nearly encircles it, and the annular rings of narrowly rectangular chambers. U. S. G. S. station 7115.
FIGURE 2. Accidental section of another specimen, × 20. U. S. G. S. station 7119.

Orthophragmina floridana Cushman, n. sp. (p. 116).

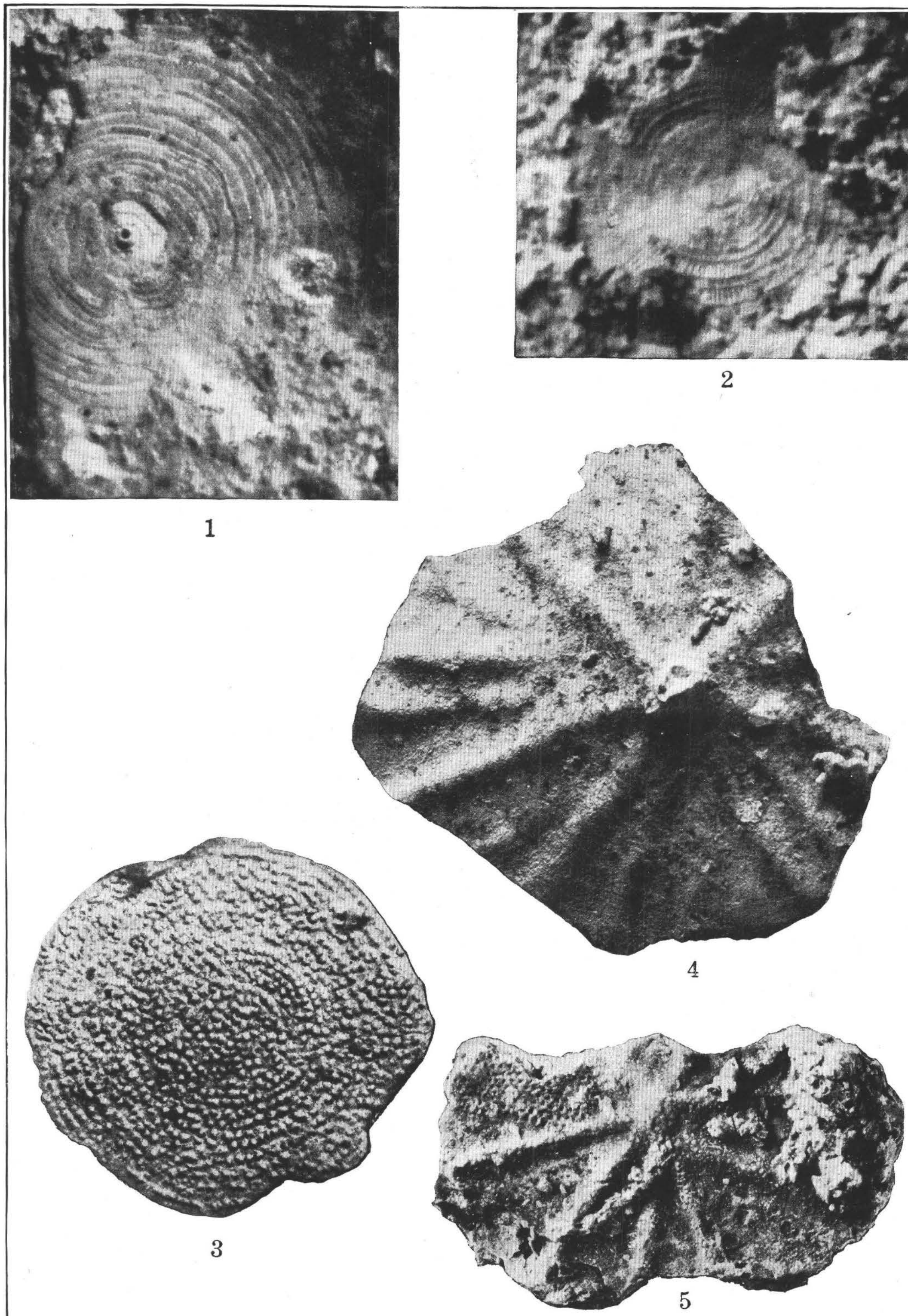
FIGURE 3. Surface view of type specimen, × 8. U. S. G. S. station 6768.

Orthophragmina americana Cushman, n. sp. (p. 116).

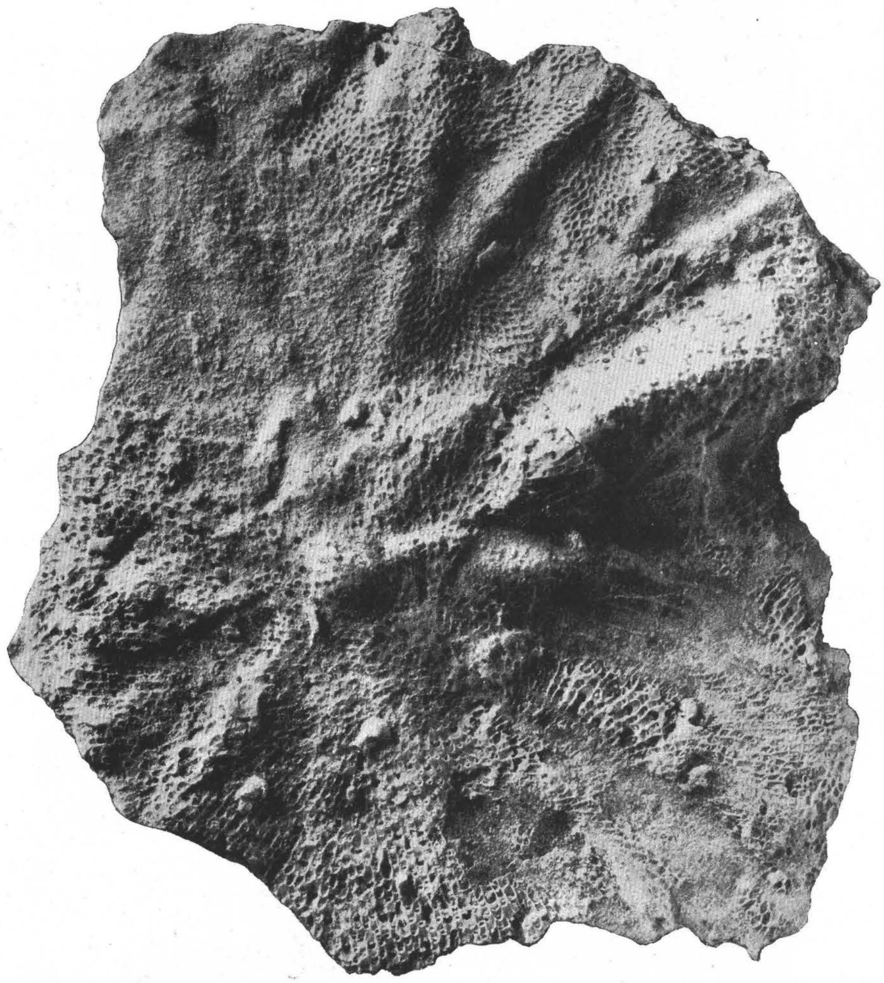
FIGURE 4. Type specimen, × 4. Central portion prominently elevated. U. S. G. S. station 6768.

Orthophragmina mariannensis Cushman, n. sp. (p. 116).

FIGURE 5. Incomplete specimen, × 4. From Marianna, Fla.



SPECIES OF ORTHOPHRAGMINA.



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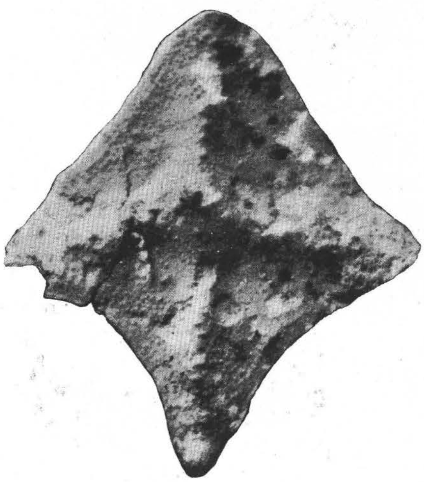

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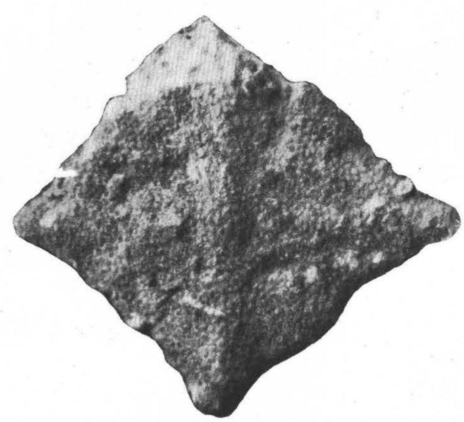

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SPECIES OF ORTHOPHRAGMINA.

PLATE XLI.

Orthophragmina americana Cushman, n. sp. (p. 116).

FIGURE 1. Surface view of a specimen, × 4, largely covered with an incrusting bryozoan. U. S. G. S. station 6768.

Orthophragmina georgiana Cushman, n. sp. (p. 117).

FIGURE 2. Specimen viewed from the exterior, × 8. U. S. G. S. station 7097.
FIGURE 3. Specimen with a more papillate surface, × 8. U. S. G. S. station 7099.

PLATE XLII.

Orthophragmina americana Cushman, n. sp. (p. 116).

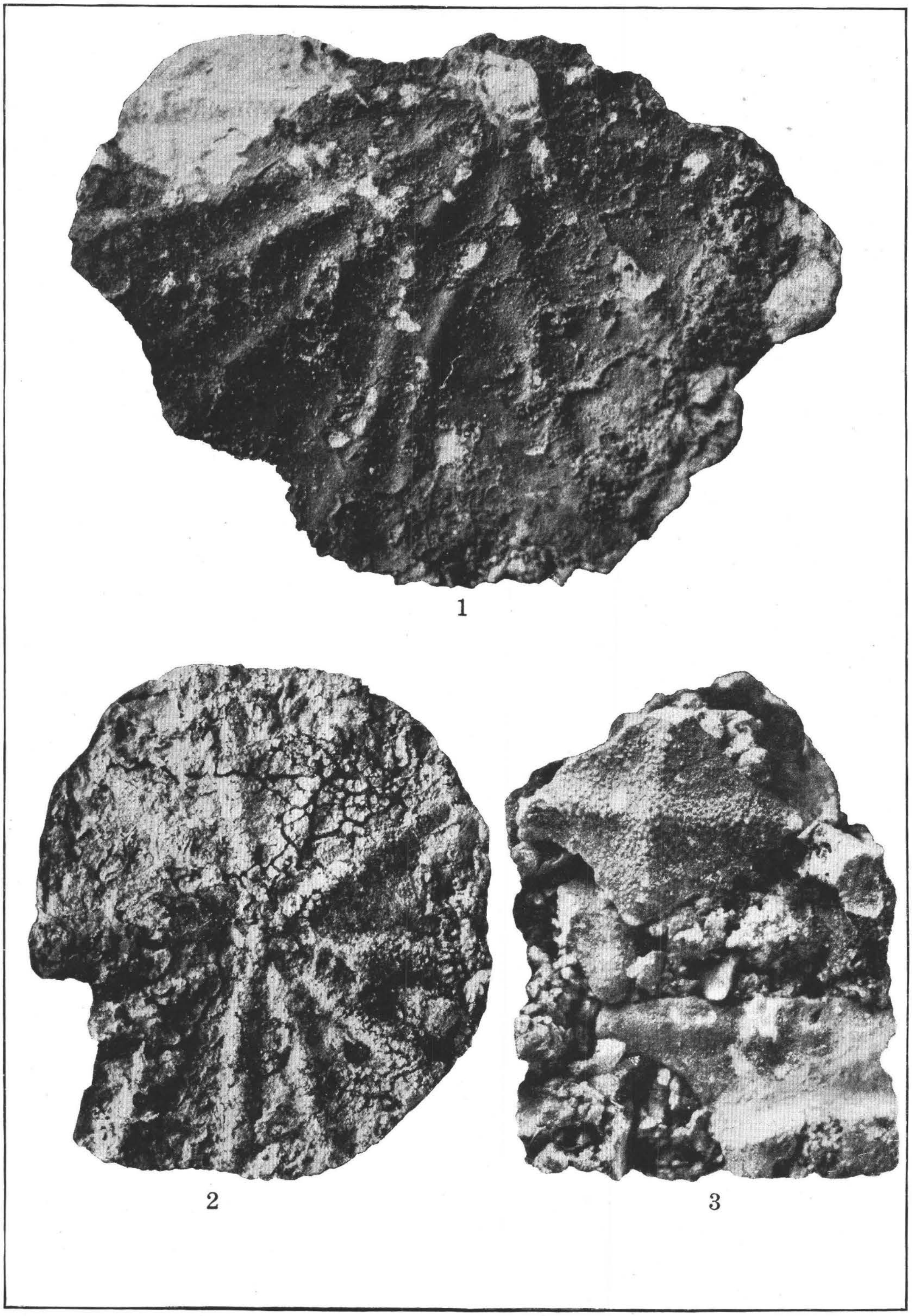
FIGURE 1. Surface view of one-half of a very large specimen, × 4. U. S. G. S. station 3787.

Orthophragmina mariannensis Cushman, n. sp. (p. 116).

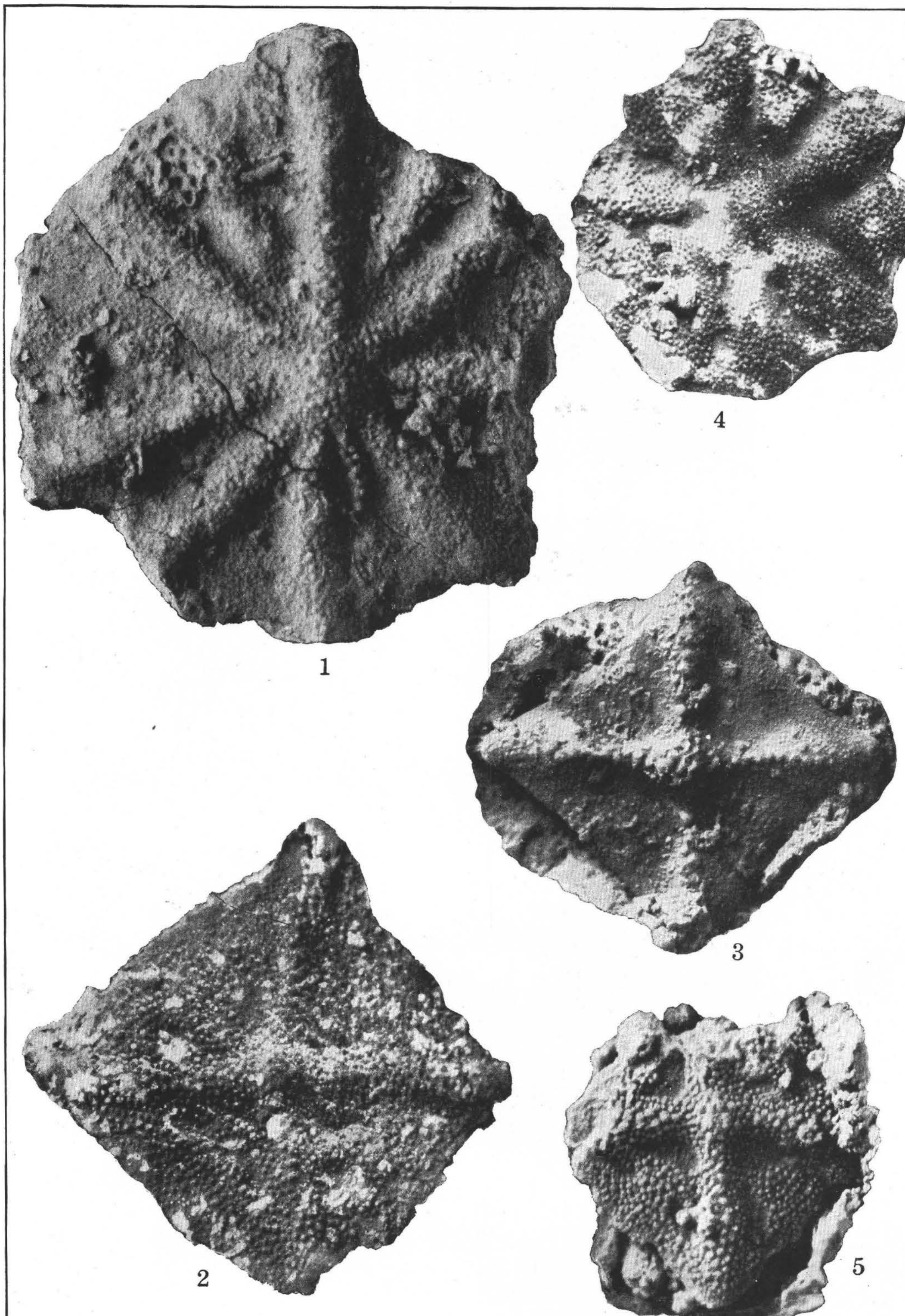
FIGURE 2. Surface view of specimen, × 4. U. S. G. S. station 7191.

Orthophragmina georgiana Cushman, n. sp. (p. 117).

FIGURE 3. Portion of rock fragment with two specimens, the upper one much more papillate than the lower. U. S. G. S. station 7126.



SPECIES OF ORTHOPHRAGMINA.



SPECIES OF ORTHOPHRAGMINA.

PLATE XLIII.

Orthophragmina mariannensis var. papillata Cushman, n. var. (p. 117).

FIGURE 1. Surface view of a fairly complete specimen, × 6. U. S. G. S. station 7126.

Orthophragmina georgiana Cushman, n. sp. (p. 117).

FIGURE 2. Surface view of a nearly complete specimen of the papillate form, × 8. U. S. G. S. station 3387.
FIGURE 3. Surface view of type specimen, × 8. U. S. G. S. station 7348.

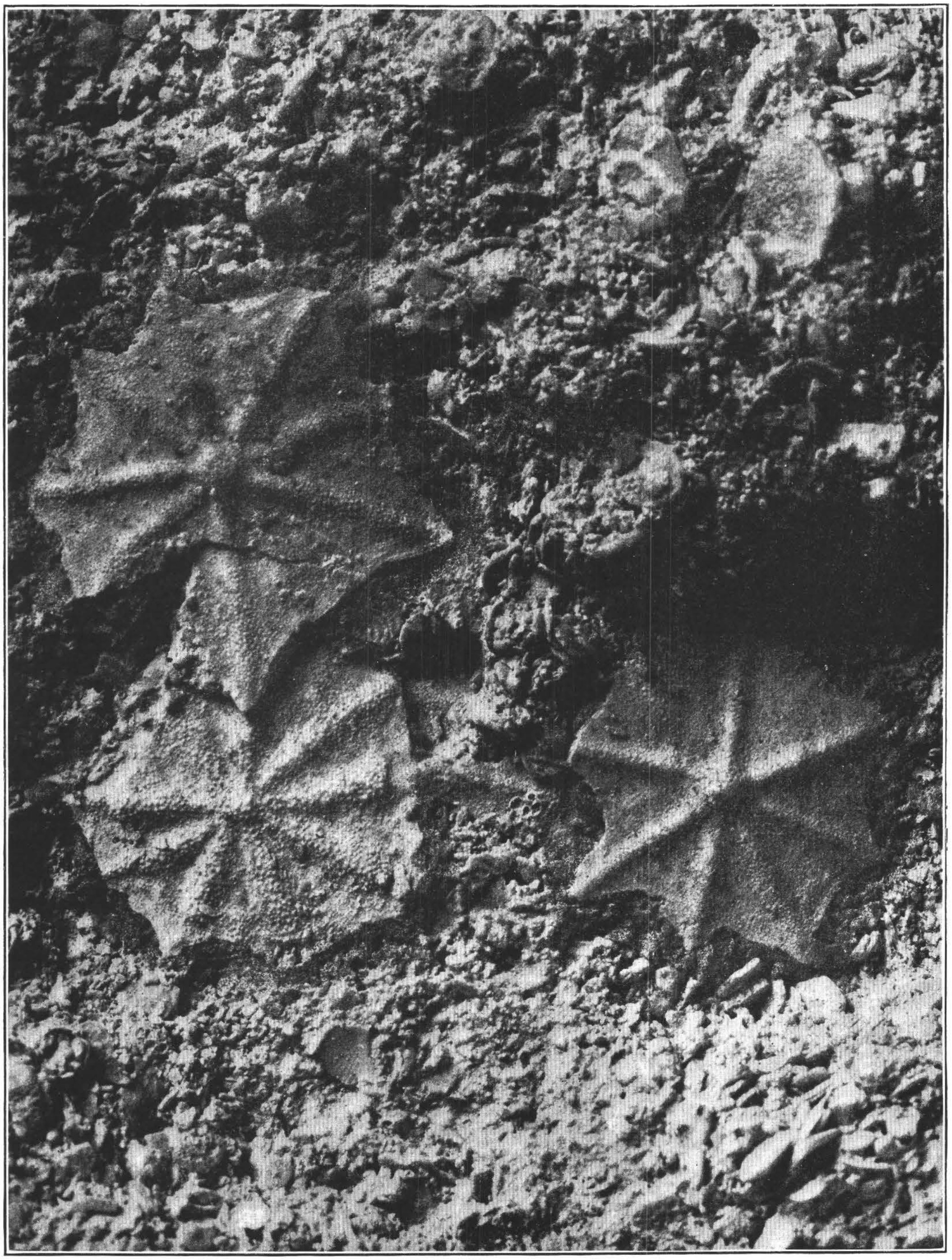
Orthophragmina vaughani Cushman, n. sp. (p. 118).

FIGURE 4. Surface view of type specimen, × 8. U. S. G. S. station 3387.
FIGURE 5. Surface view of a less fully developed specimen from the same station, × 8.

PLATE XLIV.

Orthophragmina mariannensis and var. papillata Cushman, n. sp. an n. var. (**pp. 116, 117.**)

Rock specimen from Marianna, Fla., showing two specimens of the typical form of the species and one of the variety at the lower left, × 4. U. S. G. S. station 6768.



SPECIES OF ORTHOPHRAGMINA.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 108—H

THE PLIOCENE HISTORY OF NORTHERN AND CENTRAL MISSISSIPPI

BY

EUGENE WESLEY SHAW

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CONTENTS.

ILLUSTRATIONS.

THE PLIOCENE HISTORY OF NORTHERN AND CENTRAL MISSISSIPPI.[1]

By Eugene Wesley Shaw.

INTRODUCTION.

The record of Pliocene time in northern and central Mississippi is generally assumed to be scant or lacking. The published geologic maps of this region show no Pliocene formations, and the only deposit in the region that has been assigned to the Pliocene is the unmapped so-called Lafayette formation. This formation, however, in recent years has lost some of its good standing, for several students have become convinced that the material constituting the "Lafayette" in Mississippi has been altogether misinterpreted, most of it being simply more or less weathered material belonging to various underlying formations. Heretofore no stratigraphic record of early and middle Pliocene time and no physiographic record of any part of this epoch have been recognized in this region, and hence if recent views concerning the "Lafayette," commonly regarded as late Pliocene, are correct, knowledge of Pliocene events in this part of the State is very scant indeed. However, recent work on the later Tertiary and Quaternary geology of the Mississippi embayment has brought to light an unexpected amount of data bearing on the Pliocene history of Mississippi, and the object of the present paper is to present some of these data in preliminary form and to point out their apparent significance. They pertain not only to the deposits of the region but also to the surface features. Space is not available for more than an outline of the basis of the conclusions set forth, and the life of the epoch is barely mentioned.

The field work upon which this report is based was done in the years 1912 to 1916, inclusive, and is a part of a general study of the Mississippi embayment planned and arranged for by T. Wayland Vaughan, chief of the section of Coastal Plain investigations of the United States Geological Survey. For several years before 1912 the writer had been studying the surficial geology of the upper part of the Mississippi basin, and thus, although the report deals primarily with only a portion of Mississippi, it is based upon a general study of both the upper and lower parts of the Mississippi basin. It has been the writer's good fortune to see also deposits and surface features more or less closely related to those under discussion in other parts of the Atlantic and Gulf Coastal Plain, including eastern Mexico. In the field work in Mississippi he had the advantage of frequent consultation with Dr. E. N. Lowe, State geologist.

CORRELATION OF DEPOSITS AND SURFACE FEATURES OF LOWER AND UPPER PARTS OF MISSISSIPPI BASIN.

One of the principal objects of the study of the embayment area was the correlation of the late Tertiary and Quaternary deposits and physiographic features of the Mississippi embayment and Gulf coast with those of the upper part of the Mississippi basin. The need for such correlation has long been felt. For example, concerning the field work of R. D. Salisbury in 1889 T. C. Chamberlin[2] says:

> The especial object of this investigation was to determine the relationships between the valley deposits of the lower Mississippi and the glacial deposits of the upper Mississippi. By examining these deposits at the supposed point of their junctions with the border of northern drift it is hoped to demonstrably establish their time ratios and their genesis.

The eleventh and twelfth annual reports of the Survey contain similar statements as to Prof. Salisbury's work. No area offered greater promise for valuable results, for here extensive

[1] In its basis of field work and in its conclusions this paper is closely related to a recent paper by G. C. Matson, entitled "The Pliocene Citronelle formation of the Gulf Coastal Plain" (U. S. Geol. Survey Prof. Paper 98, pp. 187-192, 1916. The writers of the two papers visited critical points in the field together and compared their data and conclusions.

[2] U. S. Geol. Survey Tenth Ann. Rept., pt. 1, p. 129, 1890.

Coastal Plain deposits of late Tertiary and Quaternary age were believed to be contiguous to if indeed not actually interstratified with glacial deposits, and a great trunk stream, along which terraces and other alluvial deposits might be expected flows from one part of the area to the other. In New Jersey, however, deposits of the two classes were found to be more closely connected, though no large stream flows from the deposits of one class to those of the other. As a matter of fact, north of Cairo, Ill., there is a gap of about 40 miles between glacial and Coastal Plain deposits, and in this gap the Mississippi flows through a rather narrow gorge in which there are practically no terrace deposits, so that it is almost impossible to determine the relation of any Quaternary formation of the upper part of the Mississippi basin to any of the lower part. The loess deposits of the two areas, however, can be correlated with a considerable degree of certainty.

Along the lower Wabash and Ohio not only the loess but also two or three low terrace deposits form a practically continuous connection between the Coastal Plain and glacial formations. On both the southeast and southwest borders of Illinois there are scattered patches of gravel that have been called Lafayette and are commonly regarded as late Tertiary. If, as the writer believes, they are of late Tertiary age, they should be of some use in correlating the formations of the two areas. In southwestern Indiana, however, small areas of such gravel have been referred provisionally to the Eocene,[1] because of their position on a plain thought to be Eocene.

Although the correlation of formations and surface features of the upper and lower parts of the Mississippi basin is thus difficult and somewhat unsatisfactory, nevertheless certain significant facts have been ascertained and certain inferences are more or less probable. Some conclusions by the author and others regarding pre-Pliocene and also Quaternary geology and physiography are included in this paper, for upon them depends in part the identification of the Pliocene deposits and surface features of Mississippi. The conclusions having to do with Quaternary geology may be summarized as follows: (1) The main loess of the upper part of the Mississippi basin has been traced almost continuously to that of the lower part, and apparently there are at least two other deposits of loess in both areas, one older and one younger, but both Pleistocene. (2) Two low stream terraces, one probably Illinoian and the other Wisconsin, may be traced from the north into the Mississippi embayment, where both dip down to the present flood plain of the Mississippi. No record of early Pleistocene time (Kansas or Nebraskan) has yet been found adjacent to or near the upper end of the Mississippi embayment. (3) Certain rather extensive gravel deposits along the lower Mississippi are believed to be terrace deposits of Pliocene age and are correlated with most of the scattered patches of gravel in the upper part of the Mississippi basin.

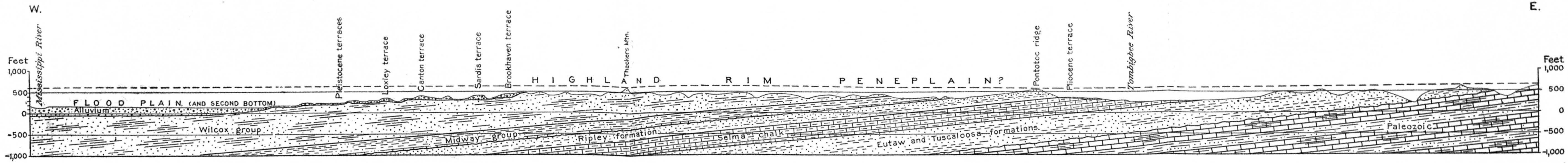
SEDIMENTARY RECORD.

The sedimentary record of Pliocene time in northern and central Mississippi is believed by the writer to consist principally of a part of the materials that have been included in the "Lafayette formation." This formation has heretofore been regarded as the only record of Pliocene time in this region, but some revision in the interpretation of material referred to it is suggested in the following pages. In order to give a clear idea of the basis on which the previous inferences concerning this formation rest, it is necessary to describe briefly the the nature of the underlying formations.

GENERAL CHARACTER OF PRE-PLIOCENE FORMATIONS.

The general distribution of the materials underlying central and northern Mississippi is indicated in figure 21. From this map it is to be seen that these portions of the State are underlain by formations ranging in age from Devonian to Oligocene, and that a large part of the area is underlain by Eocene strata. No Pliocene strata are shown, the "Lafayette" mantle not being mapped. Most of the formations shown consist, like the "Lafayette," largely of irregularly bedded silty sands, but a few consist of limestone or clay. The individual formations have been identified and traced principally by means of their fossil content, lithologic character, and stratigraphic relations, but their fossil content is commonly meager, their lithologic character is

[1] Fuller, M. L., and Clapp, F. G., U. S. Geol. Survey Geol. Atlas, Patoka folio (No. 105), 1904.



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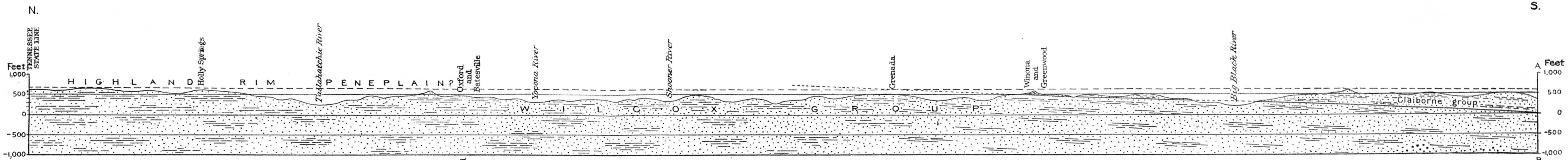

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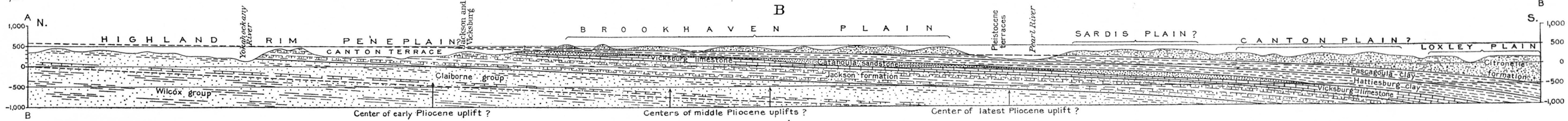

B′

Scale $\frac{1}{500,000}$

5 0 5 10 15 20 25 30 MILES

Generalized East-West and North-South Sections of Mississippi, Each Representing Diagrammatically the General Form of the Surface and Nature of the Underlying Rocks in a Belt 30 or 40 Miles Wide.

A. EAST-WEST SECTION THROUGH OXFORD.

Near the east end the line of the section bends to the northeast. The dip of the paleozoic rocks is not known with certainty, but apparently its direction is southwest, though presumably not at the same rate as that of the coastal plain deposits.

B AND *B′*. NORTH-SOUTH SECTION REPRESENTING A BELT THROUGH THE CENTRAL PART OF THE STATE INCLUDING OXFORD AND JACKSON.

Shows the effect of pliocene (?) uplifts in the south-central part of the state which carried pliocene gravels to a comparatively great altitude.

extremely varied, and their stratigraphic relations are somewhat difficult to determine. All three lines of evidence taken together are so commonly inconclusive that opinions differ as to the identity of some of the most accessible strata—those lying near the surface, abundantly exposed, and known as Lafayette. Some have inferred that most of the beds lying close to the surface belong in this surficial formation, which is described as differing markedly in many respects from the underlying formations; others, particularly more recent workers, have thought that the concept of a blanket formation is incorrect and that most of the sands and other materials so classified belong in fact with the several underlying formations. Indeed, as shown in Plate XLV, most of the "Lafayette" of Mississippi is found where the underlying beds are very sandy.

IDENTIFICATION OF PRE-PLIOCENE FORMATIONS.

The confusion concerning the "Lafayette" appears to be due partly to the lack of diagnostic features in that formation itself and partly to the irregular distribution of such features in underlying formations. Concerning the older rocks, the testimony of fossils is in many places incontrovertible. Remains of land plants are fairly common in some formations and sea shells in others, but nevertheless the mass of material whose age can be directly determined from fossils is a small fraction of that involved in this discussion. In many exposures fossils are not to be found, and in many others only certain beds can be classified with certainty by means of fossils.

The lithologic character of only a few of the formations is sufficiently distinctive to be usable in identification and mapping. The Selma chalk is easily recognized by both its lithologic character and its fossil content, but most of the formations in this region and also in much surrounding territory in the Coastal Plain are made up largely of irregularly stratified sand and silt which include very few beds that are identifiable by their lithologic character.

Many of the individual pre-Pliocene strata are not persistent and hence can not be correlated by continuous tracing over wide areas or by comparing stratigraphic relations. It is therefore difficult to identify much of the material that lies far from beds of known age.

Thus Tertiary and Cretaceous strata that aggregate thousands of feet in thickness and crop out over an area of thousands of square miles include few layers sufficiently persistent and identifiable to be traced far with certainty as to their exact stratigraphic positions. Yet these strata were long ago divided into forma-

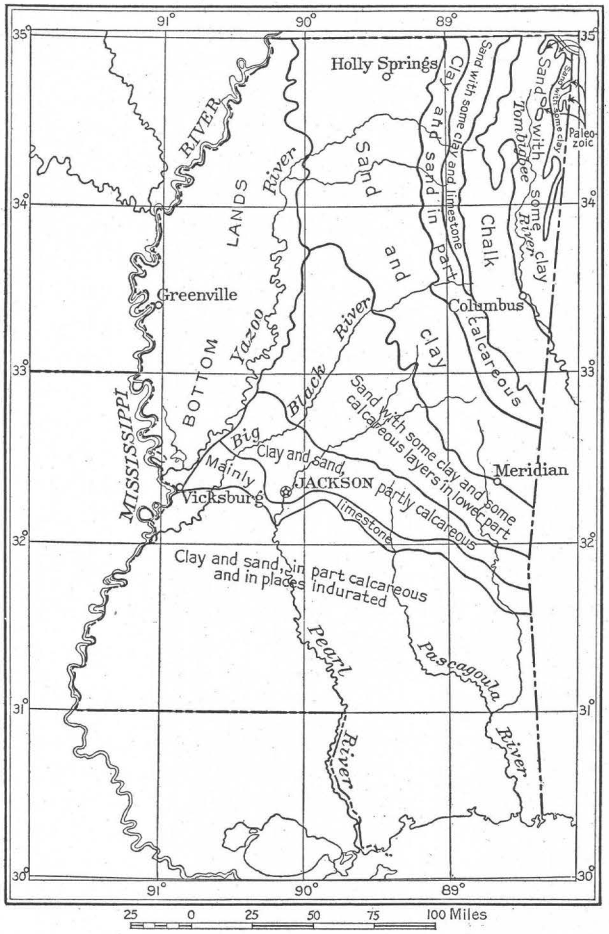

FIGURE 21.—Diagram showing general nature and areal arrangement of materials underlying the surficial deposits of Mississippi.

tions, concerning whose general positions and areas of outcrop there can be no doubt, notwithstanding the fact that there is a lack of agreement as to whether the most accessible strata in the region—those immediately underlying the surface and abundantly exposed in cuts and washes—belong with the underlying strata or constitute, as has been thought for many years, a distinct surficial formation. In the opinion of the writer and others much

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if not most of the material in central and northern Mississippi which has been called Lafayette or Orange sand belongs in fact with the underlying formations and differs from them only in being on the whole more reddened and otherwise weathered. The very fact, however, that such an idea, though tenable, has been so slow in arising is expressive of the difficulty in identifying and tracing the beds.

"LAFAYETTE FORMATION." [1]

GENERAL NATURE.

The "Lafayette formation" as heretofore described [2] is a late Pliocene or early Pleistocene mantle deposit which crops out throughout most of the Coastal Plain of eastern North America and some adjoining territory, an area of more than 200,000 square miles. It consists largely of more or less deeply iron-stained gravel, sand, clay, and loam, the upper part generally massive and the lower stratified. In thickness it ranges from 1 foot to 200 feet or more. Fossils are generally rare, and those that have been found are regarded as out of place and range in age from Devonian to Pleistocene, inclusive. As described, the formation shows little detailed or consistent relation to altitude, topography, physiography, or geologic features. However, though it rests upon rocks of all ages, from pre-Cambrian to late Tertiary, it is scantily developed in the high country of Paleozoic and older rocks bordering the Coastal Plain. Its surface and base are roughly parallel to the present surface, and it underlies uplands, hillsides, and terraces alike. Other Coastal Plain formations have roughly concentric areas of outcrop, the youngest being nearest the sea, but this one mantles all the others.

INTERPRETATIONS.

The interpretations of the "Lafayette formation," though showing more or less variety, fall into four principal classes; the first assumes that it was deposited by flood water from Pleistocene glaciers; the second, that it was laid down during a marine submergence of the Coastal Plain; the third, that it is the product of a less catastrophic process of stream deposition induced by broad uplifts of the Appalachians; and the fourth, that much if not most of it is a more or less weathered portion of the older and underlying formations of the region, a part of it being made up of material of other kinds.

Although Bartram,[3] the Rogerses,[4] Booth,[5] Conrad,[6] Mather,[7] Lyell,[8] and Tuomey [9] had done some work on similar deposits along the Atlantic coast, and Wailes,[10] Safford,[11] and Harper [12] in Tennessee and Mississippi, Tuomey [13] seems to have been the first to attempt an extended interpretation of the "Lafayette" of the Gulf coast. He called it the "Southern Drift" and correlated it with the glacial deposits of northern United States. Wailes had called it "Diluvium or Northern Drift" without attempting an explanation, and Safford and Harper had called it "Orange sand."

It should be remarked that there has been a lack of complete harmony as to what should be included in the formation. Modifications have been made at different times in the 80 years of work upon it, so that although "Southern drift," "Orange sand," and "Lafayette formation" have in a general way a similar significance, they differ somewhat in meaning from time to time and from author to author.

Safford,[11] who introduced the term "Orange sand," applied it not only to what later became McGee's Lafayette and Columbia, but also to deposits of Wilcox age (Eocene), and he classi-

[1] A more complete discussion of the status of the "Lafayette formation" is in preparation.

[2] See particularly the description by Hilgard (Geology and agriculture of Mississippi, 1860) and McGee (U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 347-521, 1891).

[3] Bartram, William, Travels through North and South Carolina, Georgia, east and west Florida, pp. 28-30, 1791.

[4] Rogers, W. B., Report of the geological reconnaissance of the State of Virginia, p. 13, Virginia Board Pub. Works, Philadelphia, 1836. Rogers, H. D., Report on the geological survey of New Jersey, 2d ed., p. 17, 1836.

[5] Booth, J. C., Memoirs of the geological survey of the State of Delaware, pp. 94, 97, 1841.

[6] Conrad, T. A., Observations on a portion of the Atlantic Tertiary region; Nat. Inst. Proc., vol. 1, p. 177, 1842.

[7] Mather, W. W., Geology of New York, pt. 1, pp. 246, 261-268, 274-275, 1843.

[8] Lyell, Charles, jr., On the newer deposits of the Southern States of North America: London Geol. Soc. Quart. Jour., vol. 2, pp. 405-406, 1846; A second visit to the United States, vol. 1, pp. 344-346, vol. 2, pp. 242-266, 1849.

[9] Tuomey, M., Geology of South Carolina, pp. 186, 188, 212, 1848.

[10] Wailes, B. L. C., Report on the agriculture and geology of Mississippi, pp. 245-253, 1854.

[11] Safford, J. M., A geological reconnaissance of Tennessee: Tennessee Geol. Survey First Bienn. Rept., pp. 148, 162, 1856.

[12] Harper, L., Preliminary report on the geology and agriculture of Mississippi, p. 162, 1857.

[13] Tuomey, M., Second biennial report on the geology of Alabama, p. 146, 1858 (transmitted for publication in 1855).

fied both as Cretaceous. Crider,[1] on the other hand, excluded much that had been included by McGee, saying:

He [McGee] likewise included in the term Lafayette 200 feet or more of the Wilcox which belongs to the Eocene. * * * The term as used in this [Crider's] report is restricted to the thin veneering of iron-stained pebbles and sand which overlaps unconformably all the other formations of the State, from the older Paleozoic rocks along Tennessee River to and including the Grand Gulf group of the late Miocene. * * * The thickness of the formation varies from a knife-edge to 50 feet.

Yet McGee[2] states that "It is separated from all of the underlying formations by a noteworthy unconformity."

It seems remarkable that there should be such certainty about the existence of a thing and such difference of opinion as to its whereabouts. The disagreements as to the location of the great unconformity at the base of the formation suggest the query whether it may not after all be at the top—in other words, whether there is any Lafayette.

The writer and others of the section of the Coastal Plain investigations of the United States Geological Survey have traced a part of even Crider's restricted Lafayette into older formations and suspect that a very large part must be so reclassified. For example, the extensive gravel deposits that are well exposed in the pits east of Iuka, regarded by Crider as Lafayette, have been found by L. W. Stephenson and the writer independently to pass beneath Cretaceous formations at Iuka.

Hilgard,[3] the chief student of the "Lafayette" in Mississippi, agreed with Tuomey in his interpretations of the "Southern drift," saying "His [Tuomey's] suggestions regarding the nature and origin of the water which deposited the Orange sand [or 'Southern drift'] formation appear to be confirmed by all the additional observations subsequently made by myself." He says further:

However different may be the geological detail of the Orange sand formation from that of the Northern drift deposits, the evident analogy of their lithological composition and general history would lead us to suppose the two formations to be genetically related. In both cases immense volumes of water destitute, or nearly so, of organic life rushed southward, bearing with them the fragments and detritus of the older formations. * * *

[1] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 45, 1906.

[2] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 497, 1891.

[3] Hilgard, E. W., op. cit., pp. 27-28.

Whether or not the Orange sand deposits contain any material necessarily derived from a high northern latitude still remains to be determined, for thus far the materials for comparison are imperfect on both sides. By far the greater mass of the pebbles occurring in Mississippi appear to be referable to sources lying south of the Ohio River on either side of the Mississippi, while the rocks most common in the drift of Illinois—granite, mica schist, and metamorphic sandstone are either very rare or (like granite) entirely wanting.

Thirty-two years later Hilgard published another paper[4] on the "Lafayette" in which he says that the formation was laid down by running and violently agitated waters at a time of high elevation, particularly of the northern United States, and says that much erosion preceded and followed its deposition.

The hypotheses concerning the "Lafayette" may be summarized as follows, in the order in which they have been advanced and become more or less popular: (1) It was laid down by glacial floods; (2) it is a sea deposit made during rapid submergence; (3) it is a stream deposit; and (4) it is not a formation at all but a hodgepodge of parts of various formations. Parts of it have also from time to time been excluded because of their identification with other formations. But there have been many departures from this general trend. For example, Crider[5] as late as 1906 says that the quartz pebbles are "doubtless the fragments of the great northern drift carried southward by great volumes of cold fresh water at the close of the glacial epoch," thus not only subscribing to the glacial hypothesis but dating the formation at the end of that epoch, whereas most workers have considered it much more ancient. The end of Pleistocene time was probably not more than a tenth and perhaps not more than a twentieth or thirtieth as long ago as the beginning.

The second interpretation, that of deposition by sea water, was best set forth by McGee. By its excellence of logic and presentation of evidence his paper brought the name Lafayette into general use and crystallized ideas concerning its extent and interpretation. McGee's views are suggested by the following quotation:[6]

The record of Lafayette deposition is one of oceanic invasion, not of catastrophic swiftness, yet of such rapidity

[4] Hilgard, E. W., The age and origin of the Lafayette formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 389-402, 1892.

[5] Crider, A. F., op. cit., p. 45.

[6] McGee, W J, op. cit., p. 508.

that the waves rolled over the sinking hills without carving shore lines; without even building broad beaches such as the modern keys of the southern coast; and the inundation was not stayed until it reached inland, drowning the southeastern margins of the continent in a zone 100 to 500 miles wide. * * * The waves and currents spread * * * [the sediment] here and there along the new-made coast, mixing it with the materials gathered from the new-made sea bottom. In this way only could have been accumulated the widespread Lafayette mantle, composed chiefly of residua of slow rock decomposition and subordinately of material from local formations, together with great gravel beds about the waterways. * * * In age the Lafayette formation is many times older than the earliest known Pleistocene deposit, and much newer than any other well-defined formation of the Coastal Plain.

The third interpretation, that the "Lafayette" is a stream deposit, is well set forth by Chamberlin and Salisbury,[1] who say:

It is assumed that the [Pliocene] upward bowing [of the Appalachian province] was felt first in a relatively narrow belt along the predetermined axis, that the rise was gradual, and that the rising arch increased in breadth as it rose.

The result was renewed erosion and increase of load of the streams, and this load was too great for them to carry across the Coastal Plain to the sea. As the uplift progressed the deposit was spread farther and farther toward the sea. Hill and Vaughan [2] place a somewhat similar interpretation on the Uvalde formation, which they say is of the same age as the "Lafayette," though they do not assume a broadening area of uplift and a consequent gradual seaward shifting of gravel. They say: "It does not appear to the writers that it is necessary to postulate a marine submergence or an absolutely horizontal deposition level," and they describe the deposit as occurring on the seaward side of the Balcones scarp, suggesting as conditioning agents (1) cloudburst storms in an arid or semiarid region and (2) gradual uplift of the area on the landward side.

It will be noted that the "Orange sand" or "Lafayette" is regarded as Cretaceous by Safford (1856), as Pliocene by McGee (1891) and by Chamberlin and Salisbury (1906), and as Pleistocene by Tuomey (1855), Smith and Hilgard (different dates), and Crider (1906).

The fourth interpretation of the "Lafayette"—that at least part of it is in reality more or less weathered and slumped portions of underlying formations—may be illustrated by the following quotations from McGee, Vaughan, and Berry.

McGee [3] says: "It should be noted that a part of the deposits designated Orange sand by different geologists consists of rearranged residuary débris of the Tuscaloosa and perhaps other formations."

Vaughan [4] argues that the "Lafayette" around Mount Lebanon and Arcadia, La., is residual and states the grounds for his belief as follows: (1) In it are found "fossils as casts in ferruginous sandstones or as ferruginous replacements," and these fossils are the same as those in the underlying formation; (2) "the transition from the Eocene to the superficial deposits can be traced"; (3) "there are in the specimens from the superficial deposits no indications of their having been waterworn."

Berry [5] says:

In the exposures at Oxford the deposits are a unit with every graduation from unweathered materials below to oxidized and more or less ferruginous sands above. Nowhere in this region is there a line of unconformity or a pebble bed to mark the supposed time interval extending from the early Eocene to the Pliocene. The change in color of the materials, when marked at all, is at varying levels and is due apparently to the depth to which the ferric oxide in the sands has been dehydrated.

A distinct variety of this interpretation worthy of mention has been set forth by Harris,[6] who believes that the "Lafayette" is made up of parts of various formations but that those parts differed originally from other parts of the same formations. He says: "It has been my belief for several years that whenever the shingle of an old shore has been preserved, there will be found 'Orange sand,' be the age of such littoral beds Mesozoic or Cenozoic," and he postulates a gradual seaward shifting of the deposits during emergence of the land.

[1] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, Earth history, pp. 305-306, 1906.

[2] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and the Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 246, 1898.

[3] McGee, W. J., Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 330, 1888.

[4] Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geologist, vol. 15, p. 219, April, 1895.

[5] Berry, E. W., The age of the type exposures of the Lafayette formation: Jour. Geology, vol. 19, p. 251, April-May, 1911.

[6] Harris, G. D., The geology of the Mississippi embayment with special reference to the State of Louisiana: Louisiana Geol. Survey, pt. 6, p. 33, 1902.

BASIS OF VARIOUS INTERPRETATIONS.

The question naturally arises, Why should there be so much difference of opinion concerning the content and interpretation of the "Lafayette"? Surely it is not because the material has failed to receive sufficient attention, for many able investigators have given long study to it in the field, and many others have written and theorized about it. Again, it is not because the formation is inaccessible, for it lies at or near the surface and is abundantly exposed throughout a populous region covering hundreds of thousands of square miles. Why then should ideas concerning it differ so much more widely than those concerning other formations?

In the first place the formation is generally described as being unique, both in development and in constitution, differing more or less markedly from any other ancient or modern deposit, and hence there are few opportunities for making enlightening comparisons. Second, although many investigators regard it as a unit having a persistent and recognizable character for example, McGee[1] says that "as a whole the formation maintains so distinctive and strongly individualized characteristics as to be readily recognized wherever seen * * * it is more uniform petrographically than any other formation of even one-fourth of its extent"; and E. A. Smith[2] says that "the Lafayette has a character * * * so well marked that the observer with any reasonable degree of experience will scarcely ever remain long in doubt as to its identity," yet, as McGee himself says, "this distinctive aspect of the formation is to some extent fortuitous." If it consisted of any single or any small group of diagnostic characteristics there would be less room for doubt. The difficulty arises out of the fact that it consists of a large group of features, several of which may be found together in another formation.

In correlating other deposits fossils are often used, but the "Lafayette," under all interpretations, is regarded as having no index fossils. Fossils are often found in material that had been regarded as Lafayette, but it is always inferred either that they are out of place, having come from some older formation, or that the stratum containing them and all below it should be reclassified and put into the underlying formation, for, remarkable as it may seem, the fossils that are certainly in place are always found to be just such as occur in the formation which happens to lie just below. Under the fourth interpretation the "Lafayette" thus becomes a combination of the nonfossiliferous outcropping portions of several formations.

Stratigraphic relations should be of some use in identifying the "Lafayette," for it is described as being everywhere unconformable at the top and bottom, as resting upon rocks of all ages older than Quaternary, and as lying either at the surface or just below some other surficial deposit. But throughout three-fourths if not nine-tenths of the region under discussion the unconformities can not be found or their location agreed upon. The remaining tenth or fourth is the area of the terrace-deposit phase of the "Lafayette" described below.

Stratification seems to be one of the principal features used in the identification of the "Lafayette," the bedding of which is commonly, especially in the area under discussion, extremely irregular, often being described as jumbled. But irregular bedding is also found in older formations, where it is of the same general type in so far as bedding so varied can be said to follow a general type of irregularity.

Lithology is of some value in identifying the "Lafayette," which lacks limestone and certain other kinds of rock, though it consists of materials so diverse as clay, shale, sand, sandstone, gravel, conglomerate, and iron ore. But the usefulness of lithology for this purpose is reduced by the fact that other formations in the region are lithologically similar to the "Lafayette," though perhaps none others show so great diversity.

Other criteria are often useful in correlation—color, physiographic expression, mode of weathering, etc.—and some of these are involved in the differentiation of the "Lafayette," but apparently no one of them is sufficient. Rather its identification seems to rest on an aggregate of many features, of which any one or even several may be found in some other formation. Some single features, however—for example, the common extreme irregularity of bedding, with clay masses in sand—have generally been believed to be somewhat more characteristic of

[1] McGee, W J, op. cit., p. 489.
[2] Smith, E. A., Am. Assoc. Adv. Sci. Proc., vol. 55, p. 374, 1906.

the "Lafayette" than of other formations. The writer and others regard these irregularities in bedding as characteristic of many Coastal Plain formations and believe that material near the surface does not differ in this respect from that farther down and that parts of the "Lafayette" are terrace deposits. (See Pls. XLVI–XLIX.)

In brief, the basis upon which the first three interpretations of the "Lafayette formation" set forth above have rested is about as follows: First, throughout central and northern Mississippi and also most other parts of the Coastal Plain of the eastern United States, to which all but a very small fraction of the material called Lafayette is confined, the material within 20 to 100 feet of the surface is redder than that below, no matter to what formation the lower material belongs. Second, the material from 1 to 15 or 20 feet below the surface is commonly more faintly stratified and many believe it to be more irregularly stratified than that below. Third, in some places the material within a few feet of the surface contains elements not found in the underlying formations and is set off from them by a rather sharply defined plane, being apparently susceptible of the interpretation that it consists of the remnants of terrace deposits.

Under the fourth interpretation it is contended that much of the "Lafayette" differs from underlying formations only in being, on the whole, redder, except that close to the surface the stratification is fainter or disturbed and the color in many places changed to brown or buff. These features are believed to be much more reasonably regarded as products of the weathering and slumping of the underlying sandy and silty formations, both at the time of their deposition and later than as characteristic of a single formation, especially because (1) the constitution of the material seems to depend everywhere on the constitution of the underlying formation; (2) there is generally no sharp lower limit to the redness and irregular or jumbled bedding, and, on the whole, the faintness of the stratification decreases downward; (3) notwithstanding the general irregularity of bedding and lack of persistent strata and fossils in the pre-Pliocene formations strata called "Lafayette" can here and there be traced continuously into strata belonging unquestionably to an underlying formation. Moreover, characteristic fossils of the underlying formation, particularly impressions of plant leaves, have been found by Lowe,[1] Berry,[1] and others in lenses of soft clay, some of which are extensive and evenly laminated, and therefore could not possibly have been taken bodily from some older formation and incorporated in the "Lafayette." It is regarded as a significant fact that the fossils from the "Lafayette formation" described as transported and redeposited are either silicified Paleozoic fossils in hard pebbles or are characteristic of the particular formation which happens to underlie the "Lafayette" at the place of their occurrence.

TERRACE DEPOSITS CORRELATED WITH THE CITRONELLE FORMATION.

LOCATION.

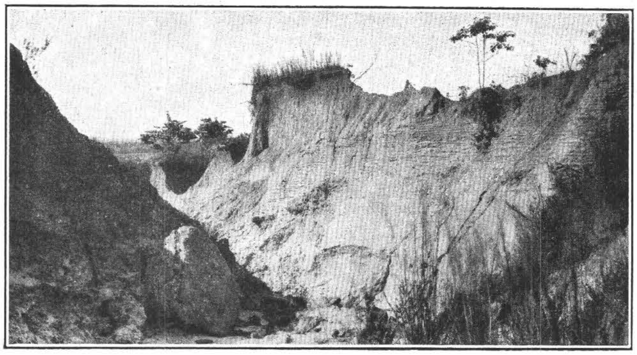
In discussing the constitution of the "Lafayette," Hilgard [2] says:

> There are within the State two distinct regions of occurrence in which this material [gravel] appears in force. One of these extends along the eastern edge of the alluvium of the Mississippi River, occupying, in northern Mississippi, parts of the counties of De Soto, Panola, Yalobusha, Carroll, Holmes, and Yazoo, gradually diminishing as the territory of the fossiliferous Eocene is approached and giving out almost entirely in the greater portion of Warren County. Then, below Vicksburg, it extends inland in a southeast direction and is found in numerous cuts on the New Orleans, Jackson & Great Northern Railroad down to the Louisiana line.
>
> The other region of occurrence of the pebble bed begins at the north on the Tennessee River, in East Tishomingo, and extends along the waters of Big Bear Creek to the eastern head of the Tombigbee, reaching the latter stream by way of Hurricane and Bull Mountain creeks, in Itawamba County. It then extends southward on the eastern side of the Tombigbee and is continued into Alabama, meeting the great pebble beds of the Warrior, which bear the city of Tuscaloosa.

Further study has confirmed the generalization that most of the gravel of the "Lafayette" borders the largest streams. In Mississippi it is found (1) in a belt of counties adjoining the Mississippi bottoms and extending from Memphis to Vicksburg, where the belt broadens and swings east across the State, and (2) in the northeastern counties of the State and a belt extending southward along the Tombigbee. The question naturally arises: Is it not possible that the gravel has been misinterpreted and that it is in part Cretaceous and Tertiary, be-

[1] Unpublished notes.

[2] Hilgard, E. W., Report on the geology and agriculture of Mississippi, pp. 11-12, 1860.



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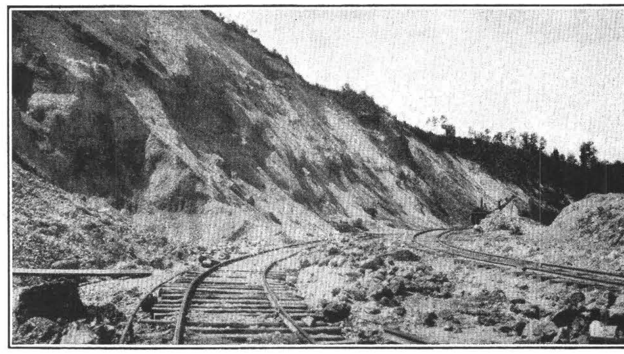

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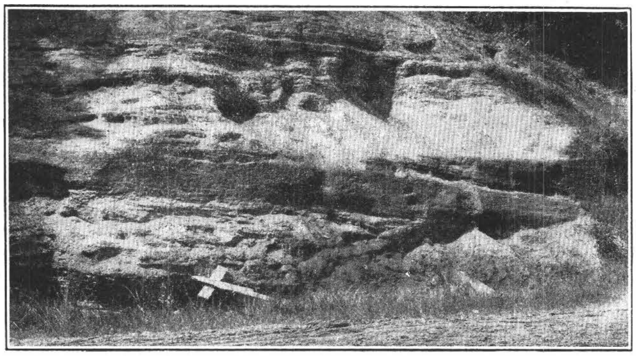

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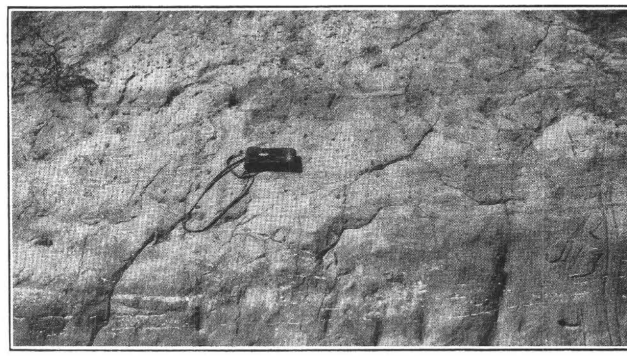

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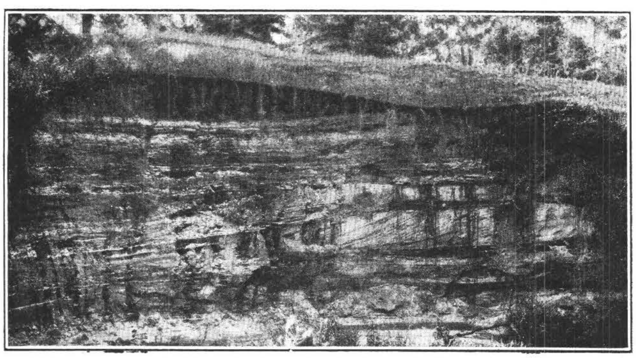

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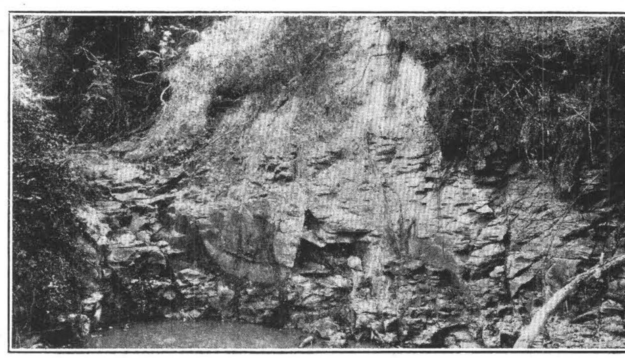

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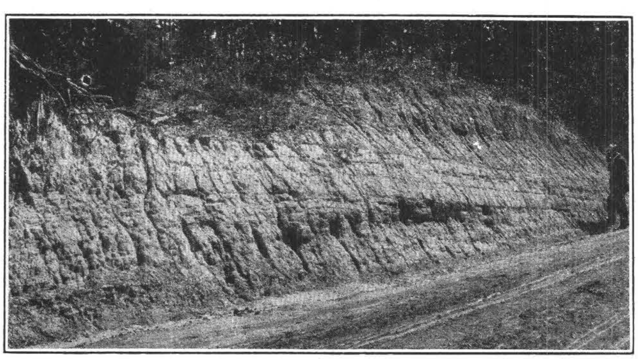

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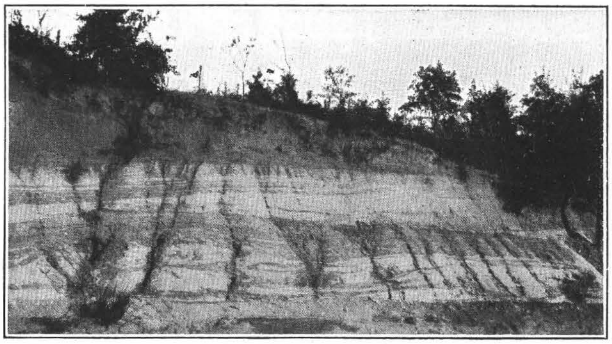
H.

STRATIFICATION AND GENERAL APPEARANCE OF MASSIVE, CROSS-BEDDED, AND LAMINATED MATERIAL FORMERLY INCLUDED IN THE "LAFAYETTE FORMATION," NOW INTERPRETED AS BELONGING WITH VARIOUS FORMATIONS UNDERLYING MISSISSIPPI.

A, Thin wavy-bedded silty sand with embedded fragments of iron-cemented sandstone 5 miles east of Batesville. *B*, Indistinctly cross-bedded gravel 5 miles southeast of Iuka. *C*, Cross-bedded sand, shale, and pebbles of Eutaw formation half a mile south of Iuka. *D*, Indistinctly cross-bedded sand of Eutaw formation (?), with clay pebbles and streaks, 1 mile east of Iuka; altitude 600 feet. *E*, Cross-bedded silty sand of Wilcox group at Baileys Spring, 1 mile southeast of square, Oxford. *F*, Massive purple clay of Wilcox group in bottom of Isom Ravine, Oxford. *G*, Thin, hard, evenly bedded white sandy clay 6½ miles southeast of Oxford. *H*, Doubly cross-bedded sand of Wilcox group half a mile north of Oxford.



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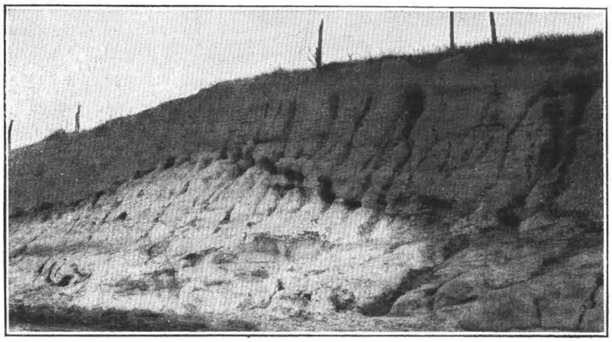

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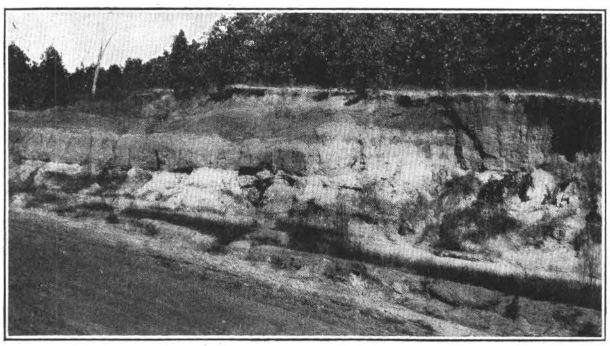

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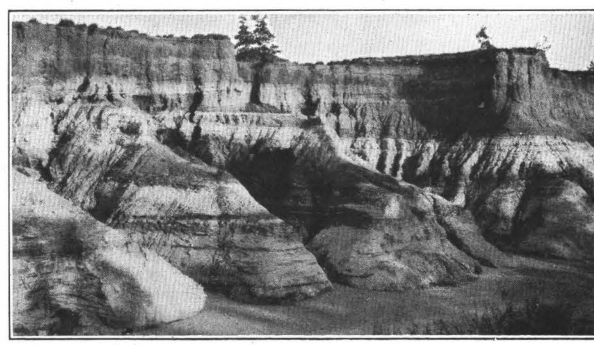

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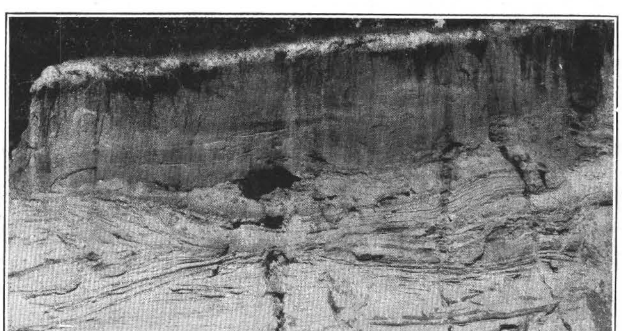

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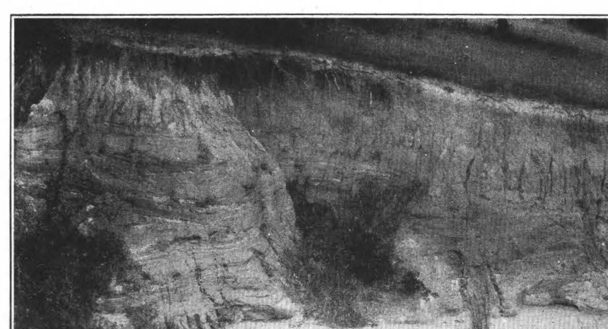
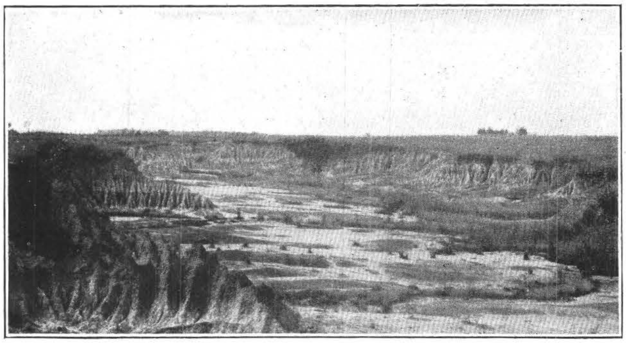


H.

STRATIFICATION AND GENERAL APPEARANCE OF MATERIAL FORMERLY REGARDED AS "LAFAYETTE FORMATION" AT AND NEAR OXFORD, THE TYPE LOCALITY, NOW REGARDED AS BELONGING TO THE WILCOX GROUP.

A, Uneven interfingering beds of clay and sand three-fourths of a mile north of Oxford. *B*, "Jumbled" clay balls and lenses 4 miles west of Oxford. *C*, Intraformational unconformity between stratified reddish sand and white clay half a mile east of Oxford. *D*, Somewhat indistinct, uneven interfingering beds of clay and sand three-fourths of a mile north of Oxford. *E*, Heavy beds of sand and clay 3 miles west of Oxford. *F*, Sharply defined interfingering beds of white clay and red sand 1 mile north of Oxford. *G*, Peculiar stratification of silty sand on east side of Fourmile Creek 2 miles east of Oxford. *H*, Irregular stratification of sand 1 mile south of Oxford.



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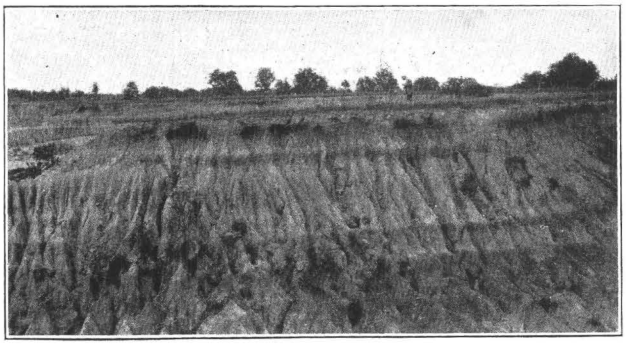

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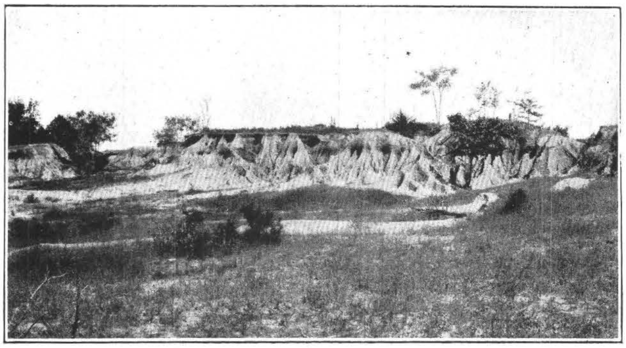

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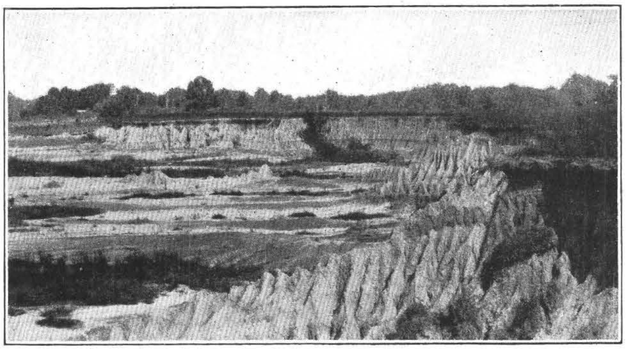

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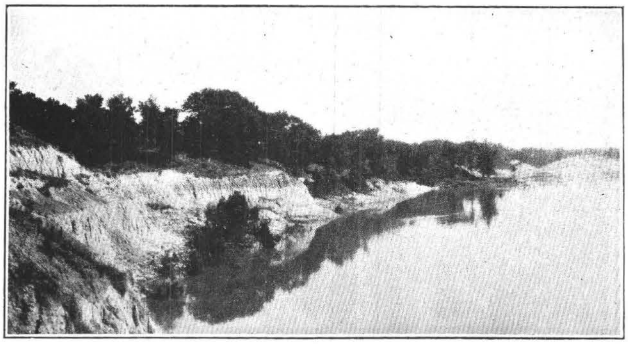

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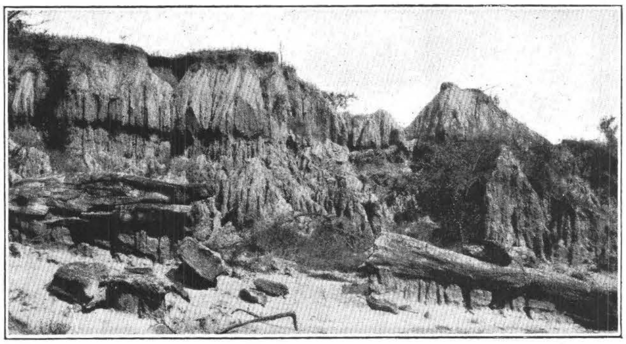

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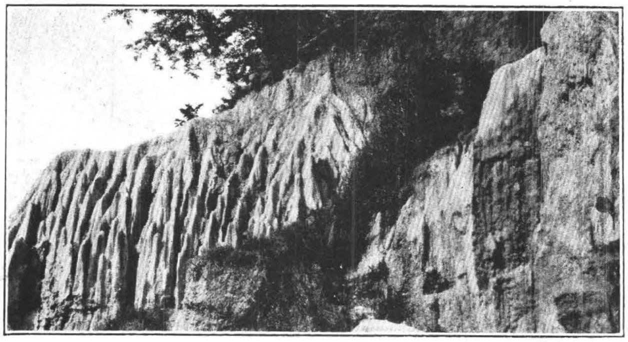

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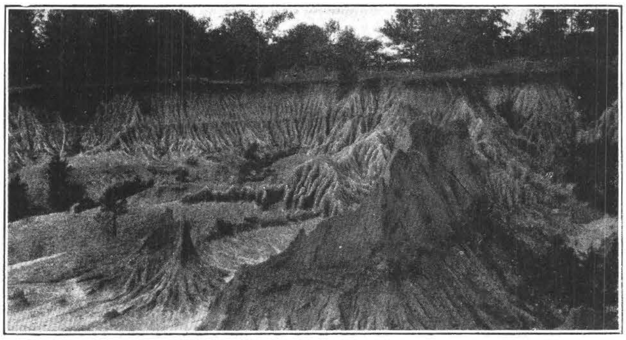
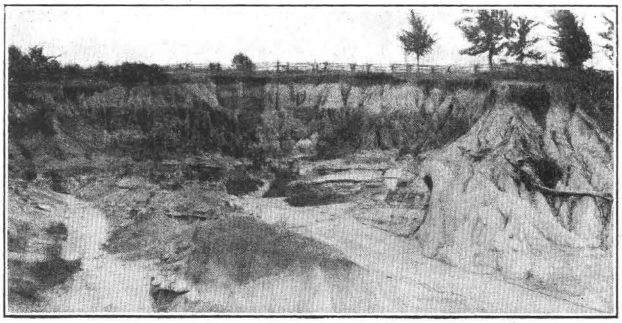


H.

STRATIFICATION AND GENERAL APPEARANCE OF PLIOCENE AND EARLY PLEISTOCENE TERRACE DEPOSITS, MOST OF WHICH HAVE BEEN CLASSIFIED AS "LAFAYETTE FORMATION."

The strata seem to range generally from 5 to 10 feet in thickness and to be comparatively persistent and yet lenticular, and these seem to be diagnostic features. *A*, 3½ miles east of Batesville, Miss. *B*, 3 miles east of Batesville, Miss. *C*, 6½ miles southeast of Oxford, Miss. *D*, 3½ miles east of Batesville, Miss. *E*, Part of type exposure of Port Hudson formation at Port Hickey, La., probably early Pleistocene but shows same general form of stratification as Pliocene terrace deposits. *F*, West end of main part of petrified forest 3 miles southwest of Flora, Miss. *G*, Detail from *E*, illustrating buttress form of weathering common in sandy clay deposited by Mississippi River. *H*, 8½ miles west of Grenada, Miss.



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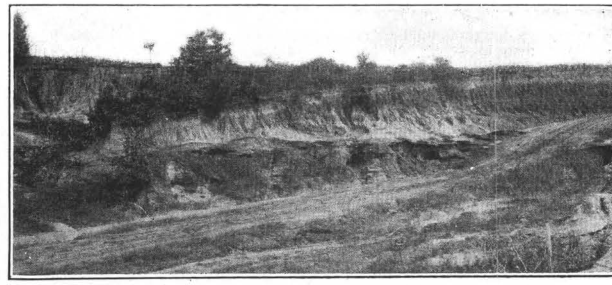

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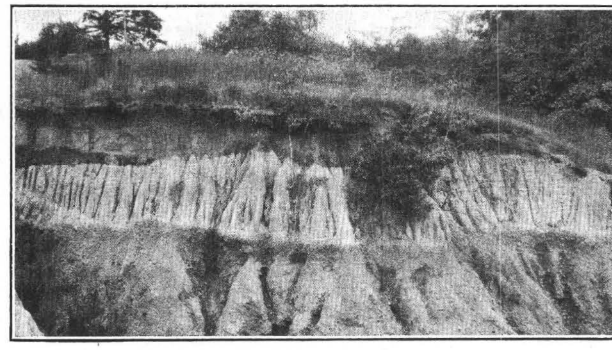

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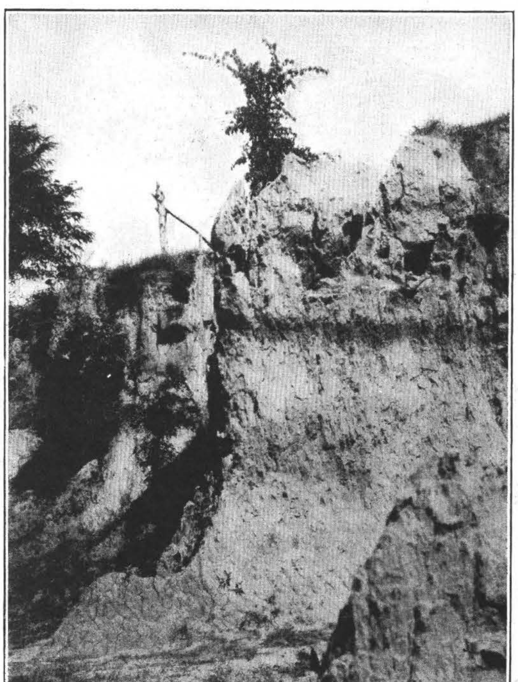

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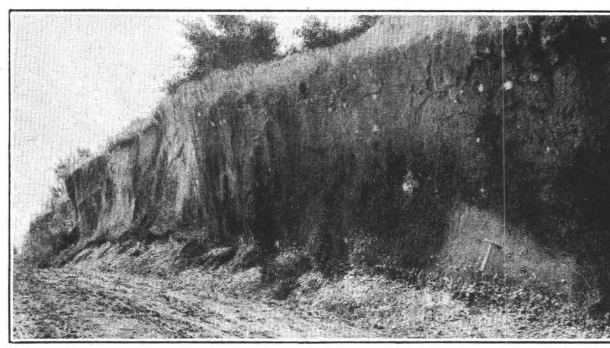

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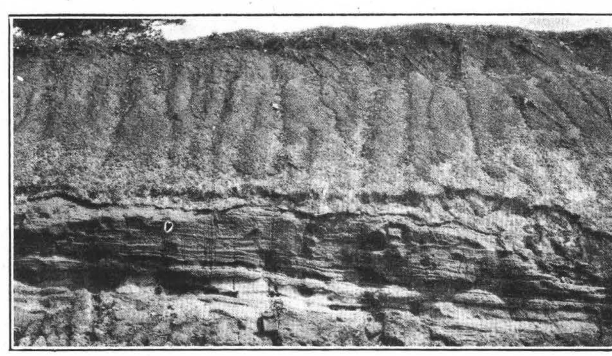


G.

STRATIGRAPHIC RELATIONS OF PLIOCENE TERRACE DEPOSITS.

A, Terrace deposit resting on strata of Wilcox group and overlain by 2 feet of loess 4½ miles east of Batesville, Miss. *B*, Terrace deposit resting on strata of Wilcox group and overlain by 2 feet of loess 5 miles northeast of Sardis, Miss. *C*, Reworked terrace gravel on deformed and eroded edges of Tuscaloosa formation, Cottondale, Ala. *D*, Eastern edge of terrace deposit resting on strata of Wilcox group and overlain by loess 2½ miles north of Batesville, Miss. *E*, Terrace deposit overlain by loess, with well-preserved old soil between, 15 miles east of Yazoo City, Miss. *F*, Terrace deposit overlain by loess 1½ miles south of Edwards, Miss.; apparent gradation from one to the other probably due to creep. *G*, Terrace deposit, perhaps somewhat shifted and reworked, resting on Tuscaloosa formation, Tuscaloosa, Ala.

longing in underlying formations, and in part a terrace deposit or a series of terrace deposits along the Mississippi and Tombigbee and perhaps other streams, thus differing markedly from and having little relation to the "Lafayette" of most of the broad regions between these rivers? The gravel exposed in the pits east of Iuka, for example, is evidently neither a Quaternary terrace deposit nor a mantle formation corresponding to descriptions of the "Lafayette," for it dips under Cretaceous strata and belongs in that system, as was inferred by L. C. Johnson[1] as long ago as 1887. Other gravels have been found to belong at other places in the Cretaceous and Tertiary systems.

The attempt to answer this question was begun by making a traverse westward from Oxford, Miss., in company with the State geologist, Dr. E. N. Lowe. The gravel area was entered about 9 miles east of Batesville. West of this point not only the deposits but also the surface features differ more or less markedly from those to the east, although the general altitude is not much lower. As discussed more fully under "Physiographic record," the principal difference in surface features is that to the east there are no extensive flat upland areas, whereas to the west the slightly lower interstream areas are commonly flat-topped, and from many points it is evident that several have almost exactly the same height, though different groups have different heights, suggesting several terraces.

Similar examinations were then made west of Holly Springs and near Grenada, Durant, Canton, Jackson, Vicksburg, Natchez, and Fort Adams, Miss., and St. Francisville and Baton Rouge, La. The same gravels were followed eastward across the State to the great deposits at Weathersby, Montrose, and other places, which Matson[2] has included in the Citronelle formation. The gravels in Tishomingo County, in the northeast corner of the State, and those along the Tombigbee and its branches, particularly in and near Greene County, Ala., were then examined. In some districts the evidence that the deposits are remnants of terraces is so strong as to be thoroughly convincing. Elsewhere, especially where the underlying rocks are limestone or clay, as near the junction of the Warrior and Tombigbee, the gravel remnants are small, far apart, and discordant in height. In the writer's opinion the discordance is due to the facts that the deposits are remnants of several terraces which stood at different heights, and that the underlying materials have suffered more or less erosion while they were capped with considerable bodies of gravel, which have thus been let down, with more or less lateral shifting. Some of the gravel, however, belongs in Cretaceous and Tertiary formations.

Although the terrace deposits are somewhat difficult to recognize, because they are not well preserved and because only a very small fraction of the region of their occurrence—the western part of Mississippi—has been topographically mapped, sufficient data have been gathered to warrant the conclusion that some of the material formerly included in the "Lafayette formation" is in reality several terrace deposits. These deposits differ markedly from the "Lafayette" of most of the area under discussion, in being dissimilar to the underlying formations, in containing elements that could not have been derived from the weathering of those formations, in having a sharp lower limit, and in lying at concordant altitudes. To illustrate, nearly all the material called Lafayette formation in Lafayette County, Miss., the type locality, falls in that part now interpreted as belonging in the underlying formation. It consists of reddish silty sand and clay, such as could readily have been formed by the weathering of the underlying Wilcox deposits, and it grades downward into those deposits. But in Panola County, immediately to the west, there are extensive deposits of gravel lying at concordant and somewhat lower altitudes and having sharply defined bases. These deposits could not have been produced by the weathering of the underlying formation and are evidently terrace deposits of the Mississippi Valley. Some of them have been so profoundly eroded that they are now scarcely recognizable as terraces, but their terrace origin is shown by the facts that the eroded remnants are, so far as determined, of concordant heights, that the material is rather sharply distinct from the other material formerly referred to the Lafayette but

[1] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 115-116, 1887.

[2] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pl. 38, 1916.

now regarded as belonging with the underlying formations, and that they occupy a belt along the side of the Mississippi Valley.

NUMBER AND NAMES.

The reasons for believing that the terrace-deposit portion of the "Lafayette" represents several distinct terraces are largely found in differences in altitude, which are discussed under "Physiographic record." No reasons for subdivision have yet been found in the nature of the materials, and apparently differences in degree of weathering or dissection are not sufficiently marked to be usable as criteria. The deposits along the Mississippi seem to lie at four different heights above the river bottom, and it is inferred that they are remnants of four terraces. In addition, there are also two or more lower terraces which are assigned to the Pleistocene, and these are considerably less gravelly. Exact and reliable determinations of altitude are scarce, however, as the deposits have been worn down and dissected considerably, and much gravel has crept or been washed down over the slopes of the valleys that streams have sunk into them. Hence inferences concerning the number of terrace deposits are uncertain and will probably remain so for many years, though the number of principal developments may be determined. In order to make reference to them easier, it has seemed desirable to name the four apparently well-developed terrace deposits, and Mr. Matson [1] and the writer have agreed to call them Brookhaven, Sardis, Canton, and Loxley, in order from oldest to youngest, each deposit being extensively developed and well preserved yet abundantly exposed at or near the place for which it is named. Brookhaven is in the southern part of Mississippi, 60 miles east of Natchez; Sardis is in the northern part, 50 miles south of Memphis; Canton is in the southern part, 25 miles north of Jackson; and Loxley is in Baldwin County, southern Alabama.

CONSTITUTION.

Although the terrace deposits are such as are ordinarily called gravel, the bulk of the material is sand through which pebbles are irregularly distributed. In some places the pebbles are contiguous, but they are rarely fitted so closely together that the interstitial sand and clay is reduced to a minimum. Generally the pebbles occur in irregular and poorly defined lenses having a wide range in size. In many places pebbles are scarce and the material is more or less clayey. The terrace deposits are comparatively poorly sorted, as illustrated by the following mechanical analyses.

[1] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, p. 180, 1916.

Sample 1 was taken from the Sardis terrace 5 miles east of Batesville, and sample 2 from the Canton terrace 3 miles west of Canton. Each sample weighed about a pound and was taken from what seemed to be a single layer lying about 8 feet below the surface. The percentages of the coarser constituents were determined with wire screens; of the finer, with a microscope.

Mechanical analyses of samples of Pliocene terrace materials from Mississippi.

Size of grains in millimeters.	Approximate percentage.	
	1	2
16.000 –11.312	0.1	0
11.312 – 8.000	.1	0
8.000 – 5.656	.3	0
5.656 – 4.000	.5	0
4.000 – 2.828	1	.1
2.828 – 2.000	1.5	.1
2.000 – 1.414	2	.3
1.414 – 1.000	2.5	.5
1.000 – .707	3	.5
.707 – .500	3	1
.500 – .3535	3	1
.3535 – .250	3.5	1
.250 – .177	6	2
.177 – .125	8	2
.125 – .0884	13	3
.0884 – .0625	11	4
.0625 – .0442	11	6
.0442 – .0312	7.5	8
.0312 – .0221	6.5	8.5
.0221 – .0156	5	10
.0156 – .0110	4	11
.0110 – .00781	2.5	9
.00781– .00552	1.5	9
.00552– .00391	1	8
.00391– .00276	.5	6
.00276– .00195	.3	5
.00195	.2	3
	98.5	99

Samples of various surficial materials from Mississippi were sent to the Bureau of Soils, United States Department of Agriculture, with the request that they be analyzed according to the standardized method of that bureau. The results are valuable for comparative studies of terrace deposits and other surficial materials.

Analyses of surficial materials from Mississippi.

[Made by Bureau of Soils, U. S. Dept. Agr.]

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Recent alluvium.								
32	Mississippi River silt from bank of canal 3 miles northwest of Vicksburg, Miss.	0. 0	0. 0	0. 0	0. 1	0. 6	34. 9	65. 1	100. 7
38	Mississippi River silt from foot of bluff, Natchez, Miss.	. 0	. 3	. 2	. 6	13. 6	49. 1	35. 9	99. 7
1	Alluvium of Tennessee River at Riverton, Ala.	. 6	1. 9	4. 2	39. 1	15. 9	24. 1	14. 8	100. 6
724	Composite of 20 specimens of surface soil from Delay, Miss	. 6	1. 5	. 4	2. 6	8. 8	62. 8	22. 3	99. 9
	Pleistocene alluvium.								
41	Second bottom loam at west end of wagon bridge, Tuscaloosa, Ala	. 0	. 0	. 1	2. 1	4. 5	66. 6	26. 2	99. 5
36	Clay from thin lamina in upper part of Natchez formation, Natchez, Miss.	. 0	. 0	. 1	3. 2	12. 8	46. 8	37. 2	100. 1
37	Sand from thin lamina at top of Natchez formation, Natchez, Miss	. 0	. 3	1. 0	19. 1	26. 7	39. 4	13. 5	100. 0
54	Pseudoloess 4 inches below the surface, half a mile east of Kokomo, Miss.	. 0	. 6	2. 5	48. 0	9. 6	30. 6	8. 1	99. 4
	True loess.								
941	Loess 2 feet below surface near Edwards, Miss.	. 0	. 0	. 1	. 2	3. 7	88. 1	8. 1	100. 2
942	Loess 4 feet below surface near Edwards, Miss.	. 0	. 0	. 0	. 0	4. 2	82. 0	13. 4	99. 6
943	Loess 5¼ feet below surface near Edwards, Miss	. 0	. 1	. 1	. 3	4. 8	83. 4	10. 5	99. 2
944	Loess 5½ feet below surface near Edwards, Miss.	. 0	. 0	. 1	. 2	4. 6	83. 9	11. 9	100. 7
945	Loess 6 feet below surface near Edwards, Miss.	. 0	. 0	. 1	. 2	3. 2	85. 0	10. 7	99. 2
946	"Brown loam" 2 feet below surface near Edwards, Miss.	. 0	. 1	. 2	. 3	1. 5	84. 0	14. 8	100. 9
725	Loess 6 feet below surface 1 mile southwest of Flora, Miss.	. 0	. 0	. 0	. 2	4. 8	81. 6	12. 6	99. 2
727	Loess 20 feet below surface at south edge of Natchez, Miss. (contains fragments of shells).	. 1	. 1	. 0	. 2	5. 6	86. 9	6. 3	99. 2
731	Loess 8 to 10 feet below surface at Yazoo City, Miss. (contains fragments of shells).	. 3	. 4	. 1	. 2	9. 6	83. 3	5. 8	99. 7
732	Loess 12 feet below surface at Yazoo City, Miss. (contains fragments of shells).	. 1	. 1	. 0	. 2	6. 2	88. 2	4. 2	99. 0
734	Loess 30 feet below surface at Yazoo City, Miss.	. 0	. 0	. 1	. 2	8. 4	87. 2	3. 8	99. 7
26	Loess 4 feet below surface 3⅓ miles west of Grenada, Miss	. 0	. 0	. 0	. 5	10. 4	75. 9	12. 6	99. 4
29	Basal ¼ inch of loess at Yazoo City, Miss.	. 0	. 5	. 3	1. 2	9. 4	80. 3	7. 7	99. 4
34	"Brown loam" near Edwards, Miss.	. 0	. 0	. 0	. 2	5. 9	77. 2	16. 5	99. 8
35	Loess or "brown loam" 4 feet below surface 2 miles east of Chichester, near Edwards, Miss	. 0	. 0	. 1	. 5	5. 8	81. 5	11. 6	99. 5
39	Fossil-bearing loess, Natchez, Miss., from the loess clinging to several hundred fossils (contains fragments of shells).	. 7	1. 2	. 9	4. 9	10. 8	76. 0	5. 5	100. 0
40	Loess 2 feet above base of formation at Natchez, Miss. (contains fragments of shells)	. 1	. 1	. 1	. 2	9. 2	83. 2	7. 1	100. 0
49	Loess 3 miles east-southeast of Yazoo City, Miss	. 0	. 0	. 0	. 3	5. 5	80. 7	13. 1	99. 6
50	Loess (?) 10½ miles east of Yazoo City, Miss	. 0	. 0	. 0	. 4	8. 3	74. 0	16. 4	99. 1
51	Loess 16 miles west-southwest of Canton, Miss.	. 0	. 0	. 0	. 4	6. 0	82. 0	10. 9	99. 3

Analyses of surficial materials from Mississippi—Continued.

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Quasiloess.								
11	Upper 2 feet of "brown loam" 8 miles northwest of Oxford, Miss	0.0	1.9	3.7	6.1	5.9	69.1	13.1	99.8
13	"Brown loam" 18 inches below the surface 1 mile southwest of Oxford, Miss.	.0	.2	.1	.5	4.0	72.6	22.6	100.0
15	"Brown loam" 2½ feet below the surface 2 miles southeast of Oxford, Miss	.0	1.4	1.8	4.5	4.0	71.4	16.7	99.8
17	"Brown loam" 2 feet below surface ½ mile east of Oxford, Miss	.0	.4	.4	1.7	5.5	76.2	15.0	99.2
	Mixed loess, colluvium, residuum, and terrace deposits.								
7	"Brown loam" from a groove cut from top to base in a vertical face in the head of a ravine 3 miles northwest of Oxford, Miss	.0	.1	.2	1.0	5.1	74.4	18.2	99.0
9	"Brown loam" from a groove cut from top to bottom (5 feet) in a vertical cliff 8 miles northwest of Oxford, Miss	.0	.7	.7	2.5	7.5	72.0	16.4	99.8
16	"Brown loam" 2 feet below the surface at south edge of Oxford, Miss. (probably not true loess)	.0	.4	.5	2.1	6.6	72.1	18.1	99.8
24	Mixed loess 10 feet below the surface 2½ miles north of Batesville, Miss	.2	3.6	2.2	1.8	10.1	71.9	9.2	99.0
43	Loess (?) 2 feet below surface of divide 3 miles west of Holly Springs, Miss	.0	.2	.1	.3	3.0	71.1	25.0	99.7
46	Loess (?) 4 feet below the surface 1 mile south of Sardis, Miss	.0	.0	.1	.5	8.1	73.6	16.8	99.1
48	Loess (?) 16 miles west of Yazoo City, Miss	.0	.1	.1	.6	10.7	65.0	23.3	99.8
726	Material down to 4 feet below surface 3 miles west of Grenada, Miss	.0	.1	.1	.6	4.3	78.1	16.2	99.4
728	Material down to 2 feet below surface 1½ miles south of Oxford, Miss	.0	.4	.4	1.8	3.5	73.0	20.1	99.2
729	Material 2 to 4 feet below surface (mostly colluvium), same locality as 728	.5	7.6	5.9	18.4	5.1	44.9	16.9	99.3
	Washed loess.								
33	Loess or loess wash, Vicksburg, Miss	.0	.1	.1	.4	9.3	85.4	4.8	100.1
	Recent colluvium.								
12	"Wash creep" ½ mile south of station at Oxford, Miss. (composite of 20 small handfuls	.4	4.9	5.7	17.6	9.4	50.7	11.3	100.0
	Old colluvium.								
4	Sandy silt containing pebbles ½ mile west of station at Iuka, Miss. (composite of 20 small handfuls)	.0	.4	1.6	39.6	11.5	20.0	27.0	100.1
10	"Brown loam" (?) from top of exposure below schoolhouse, at Oxford, Miss. (May belong just below "brown loam")	.0	1.1	1.7	5.4	5.4	56.1	29.3	99.0
42	Washed loam 8 feet below the surface 10 miles southeast of Corinth, Miss	.0	5.0	14.1	45.8	3.2	24.8	6.8	99.7
	Pliocene sea-terrace deposits.								
30	Clay conglomerate 6½ miles east of Pinola, Miss	5.0	9.3	7.2	18.7	16.8	19.5	22.9	99.4
52	Lafayette (?) from groove 8 feet high, 6 inches wide, and 1 inch deep, cut in cliff in gully in northeastern part of Brandon, Miss	2.0	31.0	23.0	21.3	1.2	1.4	19.7	99.6
53	"Buttress clay," Woodville, Miss	.0	.1	.3	65.5	3.4	13.8	16.6	99.7

Analyses of surficial materials from Mississippi—Continued.

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Pliocene stream-terrace deposits.								
27	Ancient stream silt (?) 10½ miles west-southwest of Grenada, Miss.	0.4	2.1	1.7	7.1	12.0	64.6	11.1	99.0
28	Laminated loess or ancient stream silt 30 feet below the surface at Yazoo City, Miss.	.3	1.1	.5	1.4	11.2	79.9	5.6	100.0
45	Loess (like silt) 6 feet below the surface 7 miles southeast of Vidalia, Miss.	.3	3.5	4.1	11.4	5.5	63.0	11.6	99.4
47	Terrace deposit (?) 6 miles north of Sardis, Miss.	.0	.6	3.1	22.4	13.3	30.2	30.1	99.7
	Residuum of Miocene deposits.								
31	Clay from Grand Gulf formation ¾ mile east of Pinola, Miss.	.0	.0	.0	.9	5.1	65.8	27.5	99.3
	Residuum of Eocene deposits.								
8	Wilcox or Lafayette formation 10 to 20 feet below the surface ½ mile east of Oxford, Miss.	6.0	60.0	16.0	15.7	1.1	.8	.6	100.2
14	Wilcox or Lafayette formation from thin sand lamina ⅔ mile north of station at Oxford, Miss.	.0	.0	.1	2.8	20.6	42.7	33.5	99.7
18	Clay lens in Wilcox formation 1½ miles south of Oxford, Miss. A layer of iron ore has been concentrated on top of clay	.0	.0	.0	.1	2.8	58.7	37.7	99.3
19	Leaf-bearing clay at Oxford, Miss.	.0	.0	.0	.4	12.9	48.4	37.7	99.4
20	Wilcox or Lafayette formation 4 to 16 feet below the surface 1½ miles south of Oxford, Miss.	.6	4.4	4.4	68.2	4.2	9.2	8.5	99.5
21	Purple clay from Wilcox formation at Oxford, Miss.	.0	1.0	2.5	7.6	6.0	43.6	38.3	99.0
22	Clay from Lafayette or Wilcox formation at schoolhouse, Oxford, Miss.	.0	.0	.0	.6	1.0	49.6	47.8	99.0
23	Sand from Wilcox formation 10 to 20 feet below the surface 1½ miles south of Oxford, Miss.	.0	.4	1.5	81.9	5.4	5.8	4.2	99.2
25	Sand from Wilcox formation 4 miles east of Grenada, Miss. This apparently iron-free sand is interbedded with iron-bearing sand.	.0	.7	8.1	90.1	.5	.1	.0	99.5
947	Residuum 3 feet below surface near Oxford, Miss.	.2	2.4	6.0	29.0	7.0	41.7	14.6	100.9
948	Residuum 6 feet below surface near Oxford, Miss.	.0	.9	2.2	11.3	6.2	70.2	9.5	100.3
	Residuum of Cretaceous deposits.								
2	Clay balls in sand 6 feet below surface 1 mile east of Iuka, Miss.	.0	.1	2.0	12.4	6.1	39.9	39.3	99.8
3	Sand surrounding clay balls 6 feet below surface 1 mile east of Iuka, Miss.	.0	1.0	8.3	70.3	1.2	3.9	15.7	100.4
5	Sand 5 miles south of Iuka, Miss.	.1	.6	1.0	48.0	31.0	10.1	8.9	99.7
6	Sand containing small masses of white clay 4½ miles east-southeast of Iuka, Miss. (Is the clay the residuum of limestone pebbles?)	.0	.1	1.3	60.0	7.2	6.0	25.5	100.1

The pebbles of the terrace deposits are mostly of subangular chert, though well-rounded quartz pebbles are common. On the other hand, among the sand grains quartz predominates, and both quartz and chert are less well rounded. Quartzite, sandstone, and some other rocks are represented among the pebbles, but limestone seems to be lacking throughout the extent of the deposits. Many pebbles of all rocks, even quartz, are ready to fall to pieces so long have they been exposed to the weather. The chert pebbles have evidently come from the areas of Paleozoic rocks bordering the Mississippi embayment, particularly central Tennessee and Kentucky and the Ozark province, for many of them contain identifiable Paleozoic fossils. Most of the quartz pebbles may have come indirectly from the Piedmont province, which extends northeastward from northeastern Alabama, but if so they probably started long ago and in the meantime have been incorporated in one, if not several, Paleozoic and younger formations, for though very resistant they are well rounded and hence have been subjected to much wear, and no transporting agent is known to have carried material from the Piedmont province to central and northern Mississippi since middle Tertiary time. The large streams have been flowing southward across this line instead of westward along it, and if the "Lafayette" is not the product of marine invasion no shore-line transportation has been operative along this course since Miocene, if indeed since Oligocene, time.

On the whole, the lower part of each terrace deposit is more gravelly than the upper part. In many places the upper few feet is sandy clay, free from pebbles, and separated rather sharply from the underlying more gravelly portion. Generally, however, the gravel lenses become smaller, less numerous, and more sandy toward the top.

As is common with the Coastal Plain formations, the terrace deposits are more or less deeply stained with iron and are here and there cemented into sandstone and conglomerate.

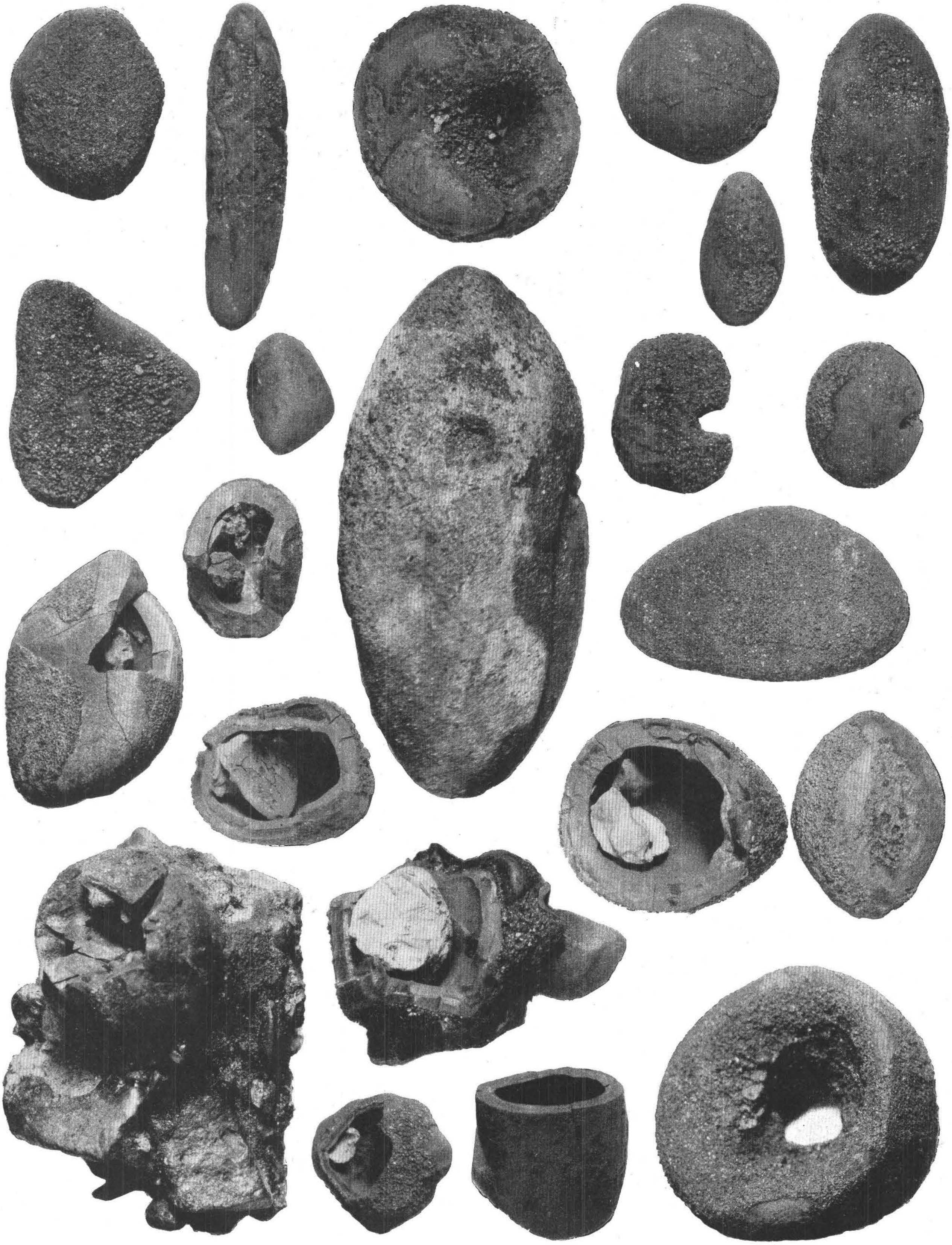
HOLLOW PEBBLES OF IRON OXIDE.

In some places—for example, near high-water mark in the bluff of the Mississippi at Natchez—iron compounds seem to have partly replaced the lime carbonate of limestone pebbles, for although here, as elsewhere in the terrace deposits, limestone pebbles are lacking, there are many hollow and fragile pebbles of iron oxide which contain a little clay. They are similar to some of the pebbles known as Klappersteine, aetites, or eagle stones. (See Pl. L.) These pebbles must have been more durable at the time of their transportation, for although they have outwardly the form of pebbles they could not have been hollow when they were formed, else the shells of individual pebbles would vary in thickness, many would be worn through, and fragments would be abundant. The clay in the interior appears to be indistinguishable from the residue of limestone after the lime carbonate has been dissolved with acid, though both materials show considerable variation.

The nature of the chemical processes involved in the replacement is not obvious. The facts (1) that in other regions layers of iron ore are common at the tops of such limestones as are overlain by marcasitic shale, (2) that in many places the contact between iron ore and limestone does not lie along a bedding plane, its position indicating that the ore is not an original bed, and (3) that fossils consisting partly of iron ore and partly of limestone are not uncommon show that the replacement of lime carbonate by some iron compound takes place rather readily under certain conditions that are common in nature. The fact that in some places the ore at such contacts is in the form of carbonate suggests that ground water saturated with iron carbonate may on reaching some lime carbonate effect replacement because of a greater solubility of the lime carbonate in water containing a moderate amount of carbon dioxide.

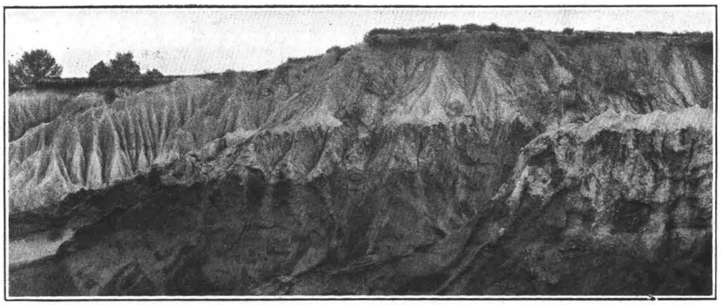
STRATIFICATION.

Although the Wilcox and other sandy Coastal Plain formations seem to show every possible variety of stratification, the terrace deposits are commonly distinguishable from them by differences in stratification alone. The strata of the terrace deposits are comparatively thick and persistent, they are commonly separated from one another by a gradation layer several inches thick, and few of them can be followed more than half a mile because, as a rule, they pinch out or become indistinct. The contrast in stratification is well shown in Plates XLVI–XLIX and LI, and its significance is believed to be that the



HOLLOW PEBBLES OF IRON OXIDE (KLAPPERSTEINE), POSSIBLY PRODUCED BY REPLACEMENT OF LIMESTONE PEBBLES.

Each pebble contains a little clay, and some have a little iron carbonate, suggesting that iron carbonate was the replacing compound and that it has since changed to the oxide.



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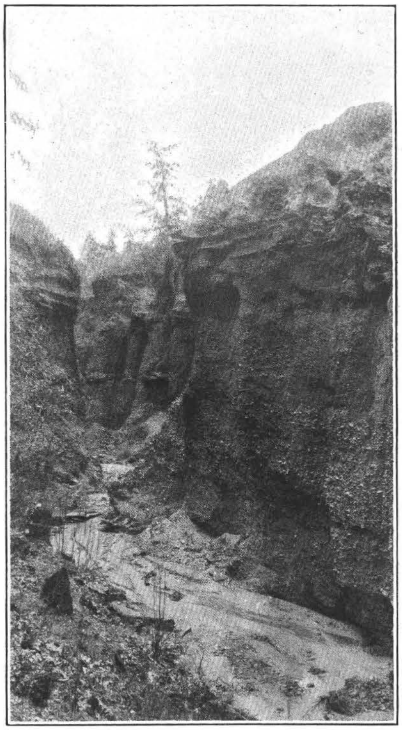

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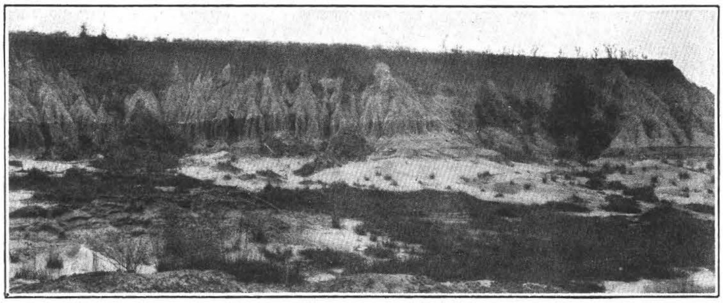

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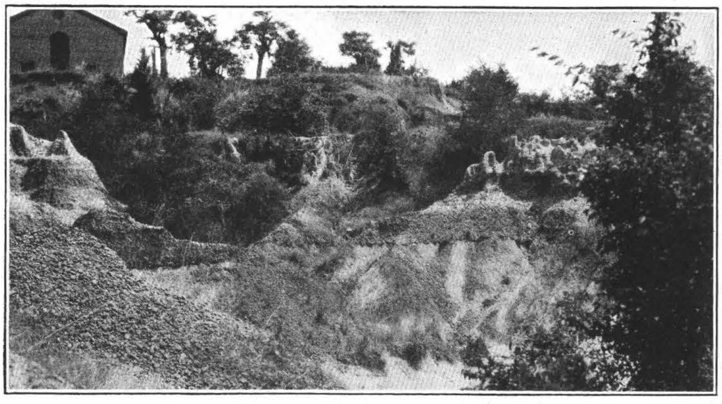

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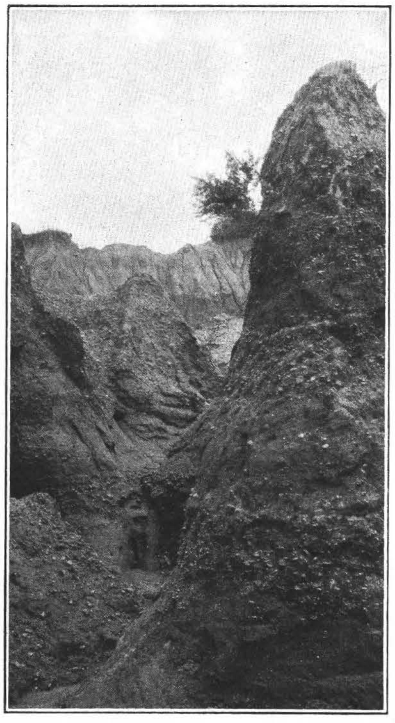


F.

UNEVEN BEDDING AND GRAVELLY PORTIONS OF PLIOCENE TERRACE DEPOSITS.

A, Evenly stratified red gravel 2 miles north of Batesville, Miss. *B*, Uneven bedding planes 9 miles west of Holly Springs, Miss.; red (dark) material Wilcox group. *C*, Gravel in pit on campus at University, Ala. *D*, Undulating bedding plane with old soil 3 miles east of Batesville, Miss. *E*, Gravel and clay at Rocky Springs, Miss. *F*, Gravel resting upon Wilcox group 7½ miles southeast of Byhalia, Miss.

terrace deposits were made by a single large stream, whereas the Wilcox and other formations were laid down by many small streams.

STRATIGRAPHIC RELATIONS.

The terrace deposits rest unconformably on rocks ranging in age from Cretaceous to Miocene or younger. In some places where the underlying formation is sandy and the terrace deposit not pebbly, it is difficult to recognize the unconformity, but there can be no doubt of its presence. Plate XLIX, *A*, *B*, *D*, *G*, shows the common appearance of the basal contact.

The chief material overlying the terrace deposits is loess, which is thickest on the bluffs of the Mississippi and gradually thins to the east. It also varies considerably along the bluffs, being 50 to 75 feet thick at Vicksburg and Natchez and scarcely half as thick west of Grenada. The contact at the base of the loess is undoubtedly unconformable everywhere and is in places marked by an ancient soil, as shown in Plate XLIX, *E*. However, as shown in Plate XLIX, *F*, in many places one formation seems to grade into the other. Most of this gradation is believed to be due to creep. At Natchez a thin layer of terrace gravel is overlain unconformably by a heavy deposit of river sand, which is apparently of early Pleistocene age, for it contains very deeply weathered pebbles from Canada. The formation which it represents has been so severely eroded that though a somewhat careful search has been made no other remnants of it have been found.

The stratigraphic relations of the terrace deposits therefore indicate that they are considerably younger than any other Tertiary deposit of the region and considerably older than the loess and probably also than the early Pleistocene gravel at Natchez.

FOSSILS.

Diligent search for fossils that might aid in the determination of age and in the interpretation of the terrace deposits has been made by the writer and several others, but almost none have been found. Silicified shells in pebbles are common but serve only to show that the material is post-Paleozoic. Petrified wood is not at all rare, but it has been considered of little value in this study, for it might have been taken from some older formation and reburied in the terrace deposits. The writer, however, found some large logs that could scarcely have been reworked—they are not only too large but are broken into sections which retain their natural position and orientation. Thin sections of some of this petrified wood have been cut and submitted to F. H. Knowlton, who says:

> One specimen is a conifer, probably *Sequoia*, and the other a dicotyledon, perhaps *Quercus*. It is not possible to fix the age, though I think it is probably Tertiary, but beyond this I would not venture an opinion.

AGE AND CORRELATION.

The assignment of the terrace deposits to the Pliocene is based on the absence of igneous pebbles in them, their extremely weathered and dissected condition, their position topographically above the Natchez terrace, which contains pebbles of glacial origin and is believed to be of early Pleistocene age, and the fact that they may be traced almost continuously into great deposits in the southern part of the State, some of which are unquestionably Pliocene.[1] The terrace deposits are certainly younger than Oligocene, for they overlie formations of that age, and they are older than any of the loess, which is Pleistocene. Their appearance and relations indicate that they are much younger than the Oligocene formations and yet much older than the loess.

UPLAND SURFICIAL MATERIALS.

CLASSIFICATION AND TERMINOLOGY.

For some purposes it is desirable to classify the material near the surface of the earth according to the extent and nature of its modification by weathering and other erosive processes. In the region under discussion the upland surficial deposits seem to fall naturally into the principal divisions named below, from above downward. For convenience these will be called layers, though most of them have not been laid down as true strata.

1. The surface soil, about a foot thick, containing more or less organic matter and other matter that has been modified by organic agencies.
2. A discontinuous but ubiquitous layer from 1 foot to 15 feet or more in thickness, consist-

[1] Matson, G. C., op. cit.

ing of material from the outcropping edges of underlying formations which has been washed down slopes by sheet floods and small rills.

3. A layer from 1 foot to 4 or 5 feet thick, consisting of surface portions of underlying formations which have crept a few or many feet down slopes. Both Nos. 2 and 3 are as a rule scarce or altogether lacking on the crests of divides.

4. A layer of material in place, from 1 foot to 5 feet in thickness and very deeply weathered.

5. A much less but still deeply weathered layer extending from No. 4 down to the lowest dry-season position of the ground-water surface. In other words, this division includes all the material below No. 4 which is subject to alternate wetting and drying and as a consequence exhibits certain peculiarities, particularly as regards its content of iron oxide. It may be subdivided into two parts at the ordinary position of ground water and is often found at two horizons because of perched ground water.

6. Below the dry-season ground-water table the Coastal Plain strata are practically a unit as regards weathering and consist largely of unconsolidated sand and clay many hundred feet thick, resting upon a floor of hard Paleozoic rocks. This division is scarcely surficial, and yet it seems to fall under the name regolith, which was proposed for unconsolidated surficial deposits.

The terms in use for surficial materials and also those proposed but not yet current are only in part satisfactory for the materials listed above.

Layer 1 is commonly called "soil," but many writers use this word in a broader sense to include this layer, the underlying subsoil, and varying amounts of lower unconsolidated material.

For layer 2 the descriptive word "colluvial" would be used by some geologists, but this term is an adjective and it has been used for deposits of other kinds. Merrill[1] restricts it to "talus and cliff débris," a definition that would exclude layer 2. On the other hand, Hilgard[2] uses it in a much broader sense for the product of "rolling or sliding down, washing of rains, sweeping of wind, etc." He does not mention cliff débris, though he speaks of landslides and creep and says that "colluvial soils form a large portion of rolling and hilly uplands." On the whole, other authorities seem inclined to use the term in a broad sense more or less similar to Hilgard's usage, but most authors of geologic textbooks do not use it at all. The adjective "pluvial" (from pluvius, rain) has been used for such deposits, but there is no corresponding noun, and, furthermore, rain ceases to be rain after it reaches the surface of the earth.

Layer 3 is the result of a process for which the word "creep" is generally used, but there seems to be no corresponding noun for the product.

Layer 4, produced by the weathering of underlying beds in place, might be called residuum, but it is not exactly formed in place by rock decay and left as a residue after the leaching out of the more soluble products, for materials so extensively oxidized as those of most of the formations underlying uplands in Mississippi can scarcely be said to decay further, and these materials consist generally of about equally insoluble substances—mainly quartz, clay substance, and iron oxide—and hence they are subject to little change in constitution through the carrying away of more soluble parts. Furthermore, layer 5, the layer between the subsoil and the ground-water table, though differing in important respects from layer 4, is almost as truly residual. "Eluvium" also is not sufficiently definite and restricted.

The great mass of material below layer 5, comprising all the unconsolidated deposits below the dry-season water table, is somewhat peculiar to areas of Cretaceous and Tertiary deposits in this and other parts of the Coastal Plain, for in few other places does a great thickness of largely unconsolidated material perpetually saturated with water rest upon a floor of hard rock. For this material there seems to be no distinctive name. It might be called "regolith," a name proposed by Merrill[3] for the "entire mantle of unconsolidated material" resting upon "solid rock," but this term would include all the other members in the list, for though here and there the Coastal Plain strata are cemented they are on the whole comparatively unconsolidated.

Other more or less generally current terms seem still less applicable to the surficial mate-

[1] Merrill, G. P., A treatise on rocks, rock weathering, and soils, p. 319, 1897; new ed., p. 307, 1906.

[2] Hilgard, E. W., Soils, p. 12, New York, 1906.

[3] Merrill, G. P., op. cit., new ed., p. 287.

rials in Mississippi and adjoining States than those already mentioned. "Saprolite," proposed by Becker [1] for "thoroughly decomposed earthy but untransported material," would include layers 4 and 5 and perhaps also a part of layers 6 and 1. As Merrill [2] remarks, it is also objectionable on other grounds. "Geest," proposed by Deluc [3] and indorsed by Eaton, Beck, McGee,[4] and others, for decayed rock in place, as opposed to alluvium, has been used in a variety of senses, and in each it seems to include more than one of the Mississippi deposits. "Local drift"[5] and "meteoric drift"[6] would indicate layers 1 to 5 but were especially intended for residual material, for which the word "drift" seems inappropriate.

TEMPORARY DEFINITIONS.

Although most of the terms available seem objectionable on one score or another, it is undesirable to burden geologic literature with additional terms, at least until careful and somewhat extended consideration can be given to the invention of new ones. For the present report the existing terminology may perhaps be made to serve if temporary definitions are given and two terms introduced which, though new, are closely allied to two already in use.

For layer 1 the word "soil" will be used in this report, the application of the term being thus restricted to that surficial material which contains much plant and plant-modified matter. The Latin word "humus" (soil) might be used in making a technical term, such as "humulite," especially as this layer generally contains much humus.

Layers 2 and 3, which together have sometimes been called a colluvial deposit, deserve a substantive appellation, and for this purpose "colluvium," corresponding to "alluvium," seems so natural that its apparent novelty is remarkable. The writer and perhaps others have used it orally for many years. This new term will be used in a broad sense as similar as possible to that given to the adjective form by Hilgard and others. It thus becomes a generic or class name, and no doubt at a later date the two species here referred to as layers 2 and 3, and perhaps others, will be set off and named. It seems necessary even now to recognize the two species, and for these the Anglo-Saxon words "wash"[7] and "creep" will be used temporarily, though it is recognized that both words are in some respects objectionable. Layer 2 is perhaps the least well washed of all aqueous deposits, and "wash" has many other meanings. "Pluvialite" seems at present not quite satisfactory, even though the ancient Romans used "pluvialis" for "produced by rain." It would seem better to limit "pluvial" to the product of true rain, including accumulations of soil particles through the beating of rain, and to classify deposits made by little rills and other water running down hillsides as of stream origin. Not only in origin but in character such deposits are more similar to stream deposits than to material moved by rain beat. However, they should not be classed with alluvium, and Hilgard's criticism of Shaler for so doing seems well taken. The Latin word "rivulus" (a rivulet) would thus seem to furnish a better foundation than "pluvius" (rain), "pluvialis" (produced by rain), or "nimbus" (pouring rain). "Creep" has been used by several authorities for the process by which layer 3 is formed, but no name seens to have been given to the result. "Creep" is not altogether satisfactory as a noun, but it may suffice until a better term is invented—perhaps "repite," from the Latin "repo," to creep. The Latin "gravitas" (weight) may be found useful as the basis for a generic term to include both the products of slow creep and landslides which gravitate down hill slopes.

For layers 4 and 5 "upper residuum" and "lower residuum" may be used temporarily, though "residuum" is misleading except as it indicates rough homology with the untransported product of weathering in other regions, where, in the process of erosion, a mere soluble part of the rock is carried away and a less soluble part thus concentrated at the surface.

A name for layer 6 can perhaps be dispensed with in this report. One seems to be needed that will mean unweathered, except for the

[1] Becker, G. F., Reconnaissance of the gold fields of the southern Appalachians: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 3, p. 289, 1895.

[2] Merrill, G. P. op. cit., new ed., p. 287.

[3] Deluc, J. A., Abrégé géologique, p. 121, Paris, 1816.

[4] McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, p. 279, 1891.

[5] Broadhead, G. C., Missouri Geol. Survey Rept., 1873-74, p. 64, 1874.

[6] Kinahan, G. H., Irish drift, subgroup meteoric drift: Royal Geol. Soc. Ireland Jour., new ser., vol. 4, pt. 3, pp. 115-121, 1877.

[7] See, for example, Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and the Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 254, 1898.

weathering before and during deposition, and signify that the deposits are comparatively uncemented, and another would be useful for the underlying Paleozoic rocks, which are both unweathered and cemented. It will be noticed that layers 1 to 5, inclusive, lie in the belt of weathering, a part of the zone of katamorphism[1] and those below in the belt cementation. Van Hise says: "The zone of katamorphism is divisible into two belts—(1) an upper belt of weathering and (2) a lower belt of cementation. The belts are delimited by the level of ground water."

POSSIBILITY THAT SOME RECORD OF PLIOCENE TIME MAY BE LEFT IN THE COLLUVIUM OR RESIDUUM.

If throughout the broad area of uplands occupying the central and northern parts of Mississippi east of the practically single row of counties in which the Mississippi bluffs and Pliocene terraces occur the "Lafayette" consists in reality only of the outcropping portions of several underlying formations, the sedimentary record of Pliocene time would seem to be lacking in this area, for all parts of it have been visited by geologists, and no Pliocene deposit other than the "Lafayette" has ever been found. However, in a geologic sense the Pliocene epoch was not very long ago, and the questions arise: (1) May there not have been made in this region in that epoch some deposit of which, though now mostly worn away, some remnants are left on or just below the surface? (2) Even if no Pliocene deposit was made, may not the colluvium or the residuum contain material from other formations or display some other feature due to Pliocene events?

COLLUVIUM.

GENERAL NATURE.

The material lying from 1 foot to 10 feet or so below the surface of central and northern Mississippi is generally massive reddish or buff, more or less sandy clay, having at least the general appearance of such material as would be expected to develop through the weathering of underlying more or less sandy strata. The upper part, which, especially in the western half of the region, is less sandy, has been called "the yellow loam"[2] or "the brown loam."[3] Some if not all of the lower part has been regarded as "Lafayette" or Columbia. However, several inconspicuous but nevertheless definite characteristics show that this lower part is neither residuum nor a sea or stream deposit. It is not residuum, for it contains elements not found in the immediately underlying strata, and it commonly has a sharply defined base. It is not a stream or sea deposit, for it mantles the surface at all altitudes and slopes, it is comparatively unsorted, it contains fragments of soft iron-cemented sandstone that show no wear, and it partakes from place to place of the nature of the underlying material. Its features indicate that it has been produced by rain wash, modified perhaps from time to time by climatic changes, and hence it falls under the class name colluvium. Its general features are well shown in Plates LII and LIII and its possible origin suggested in Plate LIV.

The upper part, comprising much of what has been included in the brown or yellow loam, is believed to be partly eolian and related to the loess and partly much weathered colluvium and other surficial material.

PEBBLES AND BOULDERS.

DISTRIBUTION AND LITHOLOGY.

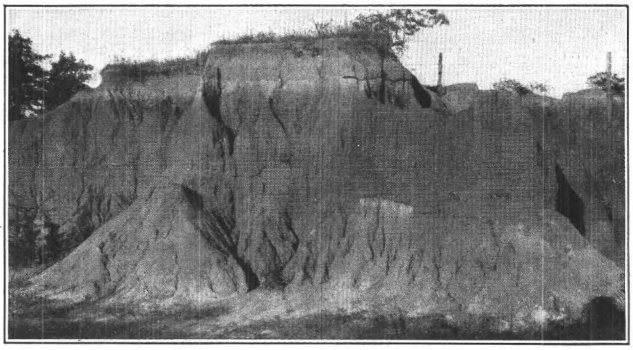
The study of the colluvium was begun at Oxford, where after a search of a few hours pebbles were found that seemed considerably larger than any occurring in the underlying Wilcox. In a few days many such pebbles were found, some being so large as to be more appropriately called boulders, whereas in the Wilcox no pebbles over half an inch in diameter were found, and few more than a quarter of an inch. On a later field trip an estimate of the average number of exotic pebbles and boulders present on a unit area in northern Mississippi indicated between 20 and 100 to the acre.

The suspicion then arose that the pebbles and boulders had come from some very high gravel deposit, practically unmodified remnants of which might be found in some part of Lafayette County or in the adjoining region. A careful search, however, was without result. Instead, more pebbles and boulders were

[1] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 162-163, 1904.

[2] Hilgard, E. W., Geology and agriculture of Mississippi, p. 197, 1860.

[3] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 393, 1891.



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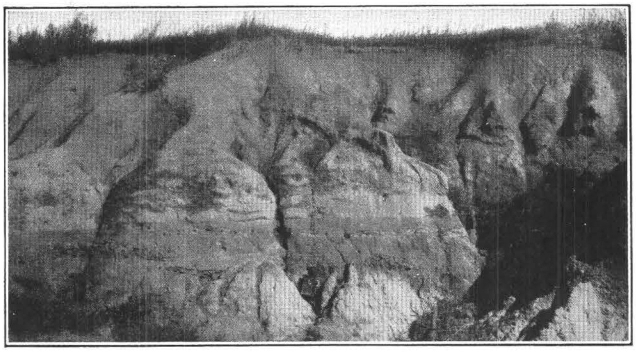

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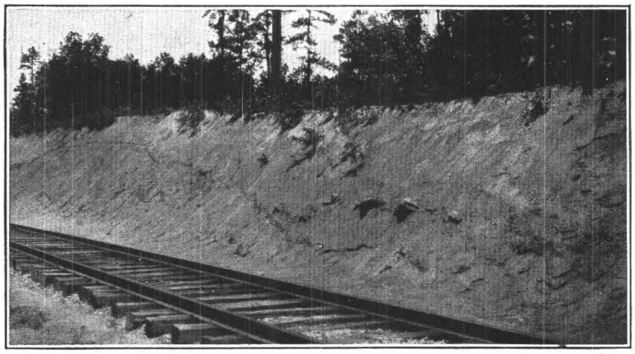

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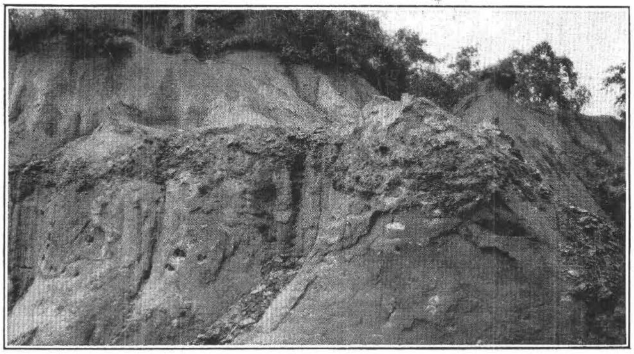

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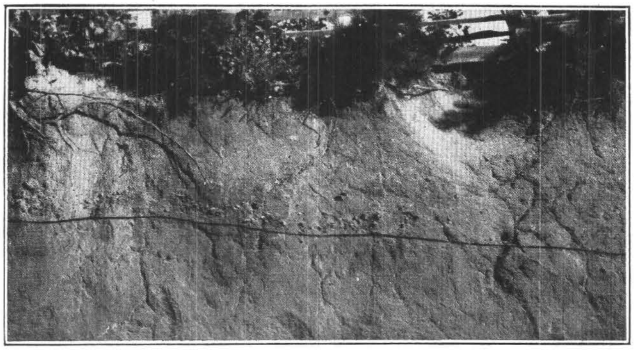

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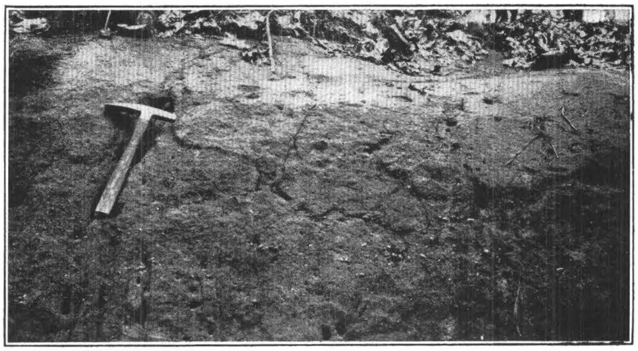

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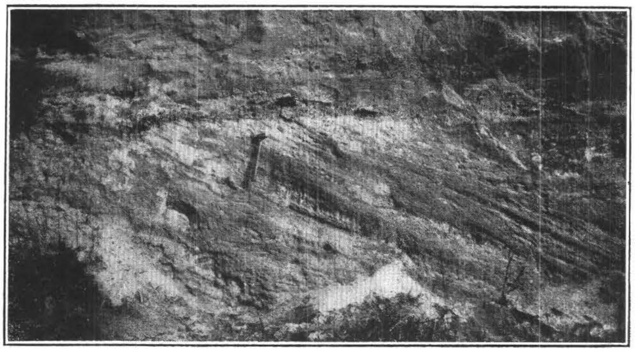

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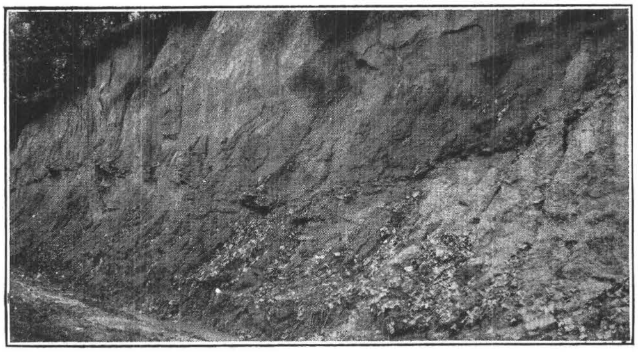
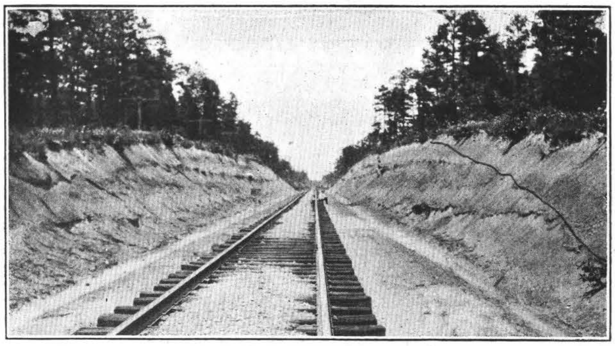


H.

TYPICAL EXPOSURES OF COLLUVIUM.

The colluvium shows little or no stratification and contains quartz pebbles and other elements commonly lacking in underlying formations, also angular fragments of iron-cemented sandstone. *A*, Colluvium about 2 feet thick, overlain by 2 feet of loess and underlain by Wilcox group, with an old soil at top, half a mile north of station at Oxford, Miss. *B*, Colluvium with fragments of iron-cemented sandstone at base, south edge of Oxford, Miss. *C*, Colluvium, from 5 to 15 feet thick, resting on Eutaw formation about 2 miles northwest of Leedy, Miss. *D*, Layer of iron-cemented sandstone fragments and concretions at base of colluvium 10 miles northwest of Holly Springs, Miss. *E*, Distribution of pebbles in subsoil 1½ miles east of Iuka, Miss. Base of colluvium indicated by black line. *F*, Distribution of pebbles in subsoil near top of Red Hill, southeast of Jackson, Miss. *G*, Colluvium resting on Citronelle formation 1 mile south of Lamberts, Ala. *H*, Colluvium, largely red sand with layer of iron-cemented sandstone fragments at base, 4 miles northeast of Holly Springs, Miss.



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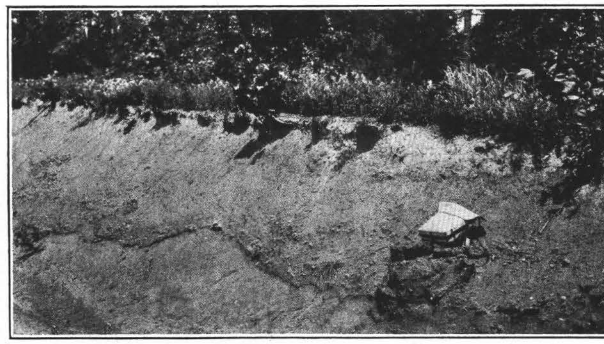

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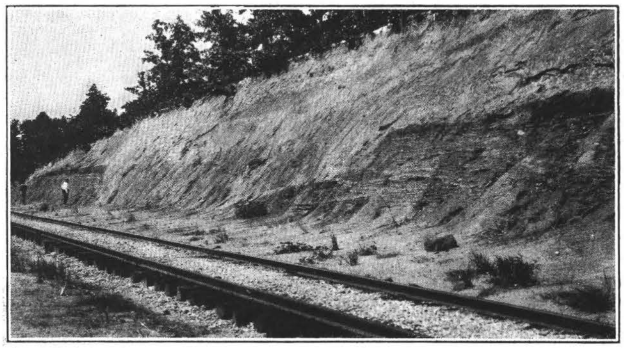

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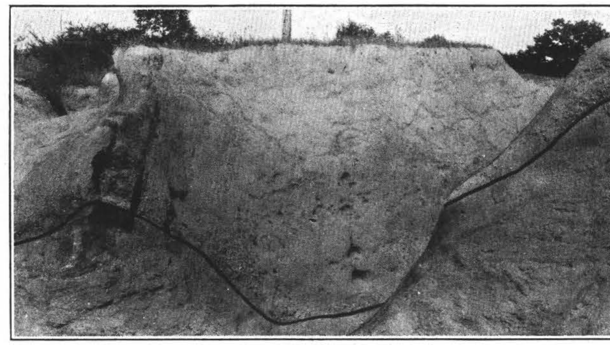

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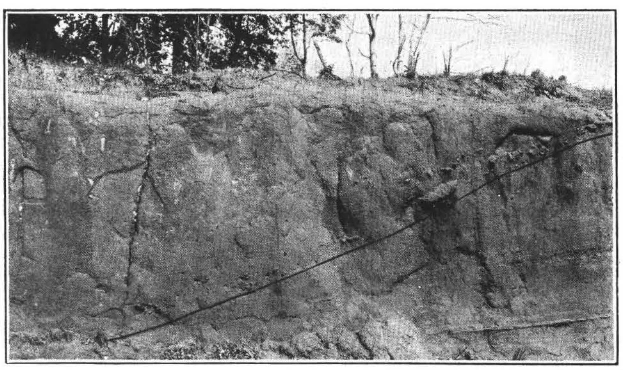

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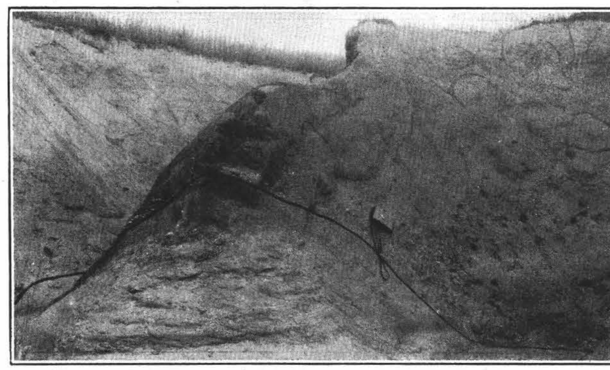

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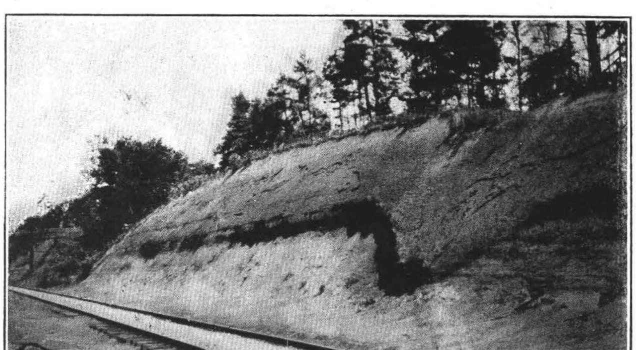

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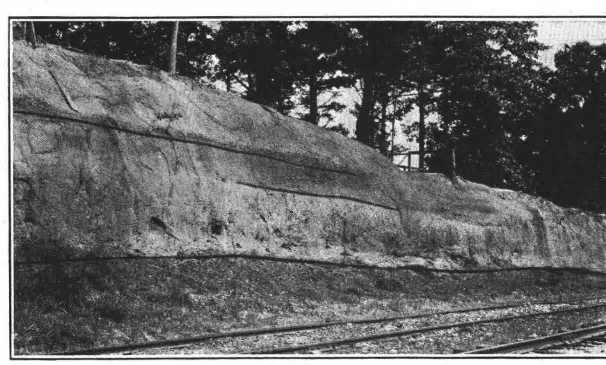
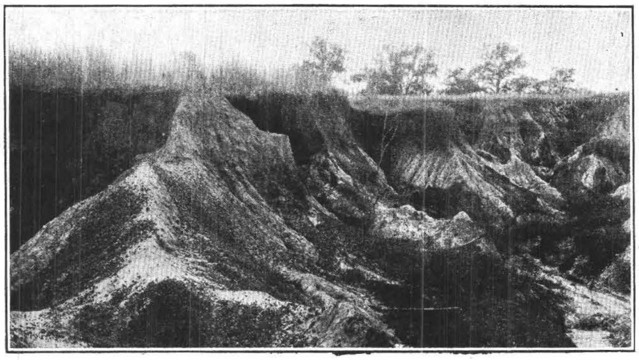


H.

EXPOSURES SUGGESTIVE OF ORIGIN OF COLLUVIUM, SHOWING PARTICULARLY THAT IT COMMONLY FILLS HOLLOWS AND IS IN SOME PLACES THOUGH RARELY DOUBLE.

Base of colluvium indicated in places by black line. *A* and *B*, Panorama of colluvium 10 miles southeast of Corinth, Miss. The concretionary mass beneath the collecting bag throws light on the origin of the surficial deposit, for it contains many Eutaw fossils, is very fragile, and has evidently been let down from the concretionary layer seen in the distance at a stratigraphic position about 10 feet higher. The concretion is of a kind characteristic of this layer. The associated pebbles, however, are not common, if indeed such pebbles occur at all in the underlying Eutaw formation, and hence the conclusion seems unavoidable that the coarser parts of overlying strata have been concentrated downward in the development of the surficial formation and that none of the material has been transported very far. *C*, Small valley filled with colluvium 8 miles southeast of Corinth. *D*, Colluvium with very uneven base 1 mile west of Iuka. *E*, Colluvium with angular fragments of iron-cemented sandstone at base, Fourmile Creek, 2 miles east of Oxford. *F*, Colluvium with uneven base half a mile west of Iuka. *G*, Gully filled with colluvium 7¼ miles southeast of Corinth. (Photograph by L. W. Stephenson.) *H*, Double (?) colluvium half a mile west of Iuka. Upper 8 or 10 feet is from railway cut; below are two layers, each several feet thick, with quartz pebbles at base.



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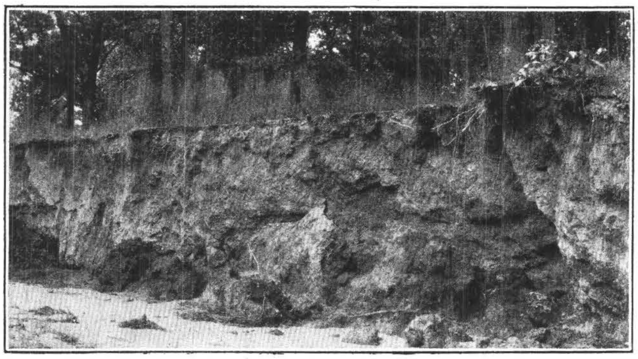

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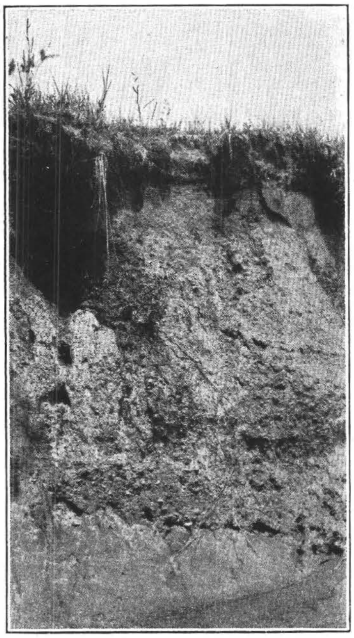

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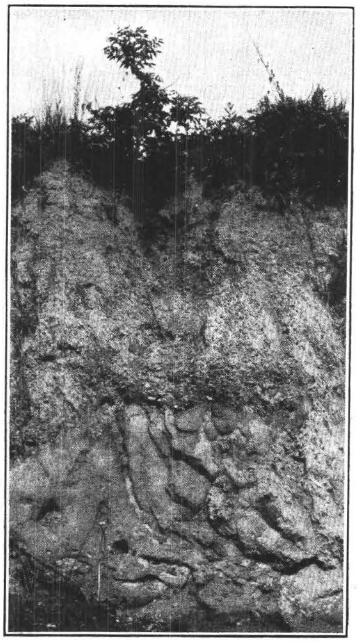

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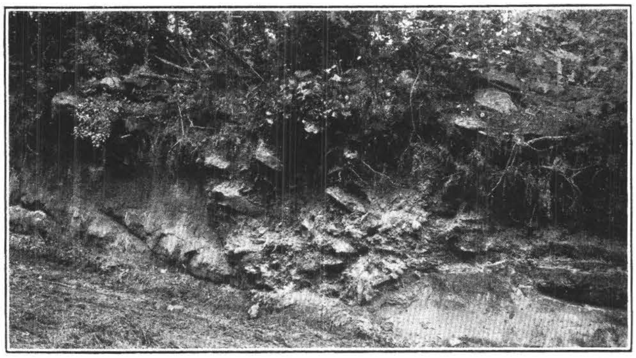

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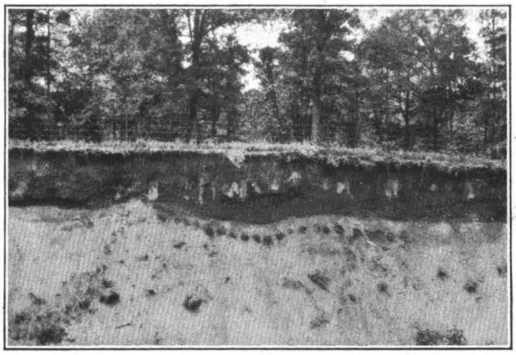
F.

RECENTLY FORMED DEPOSITS OF KNOWN ORIGIN AND HISTORY, SOMEWHAT RESEMBLING THE OLDER COLLUVIUM BUT STILL DIFFERING RATHER MARKEDLY.

A, Exposure 7 miles northeast of Canton, showing coarse material left behind in a wash; perhaps the old colluvium was formed in part by the burial of a residual accumulation of this kind. *B*, Product of creep half a mile south of Oxford. *C*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia. *D*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia, somewhat similar to the old colluvium. *E*, Small filled gully 5½ miles east of Grenada. *F*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia.



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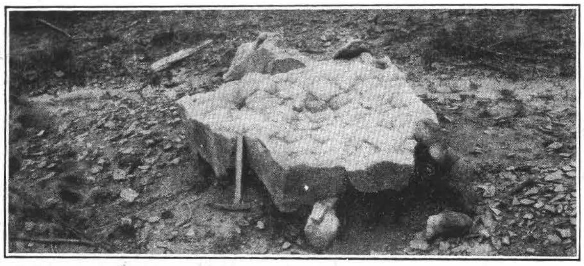

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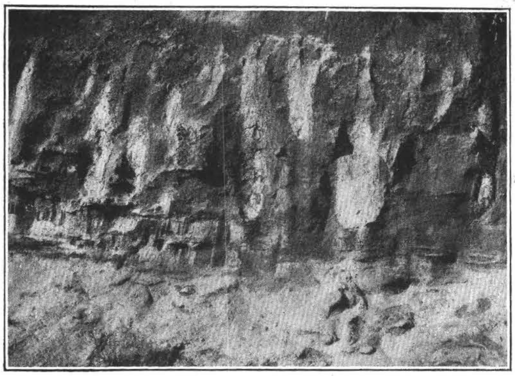

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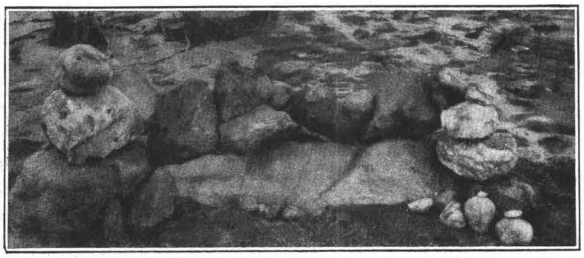

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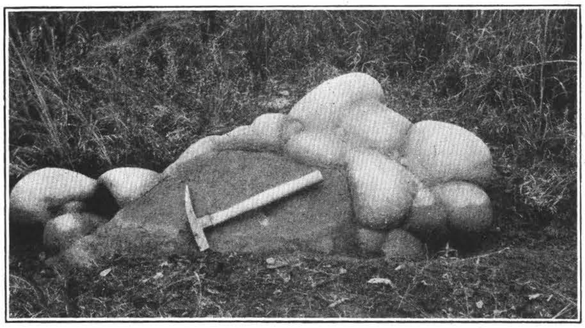

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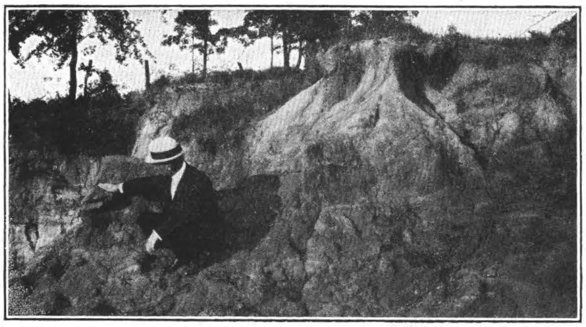

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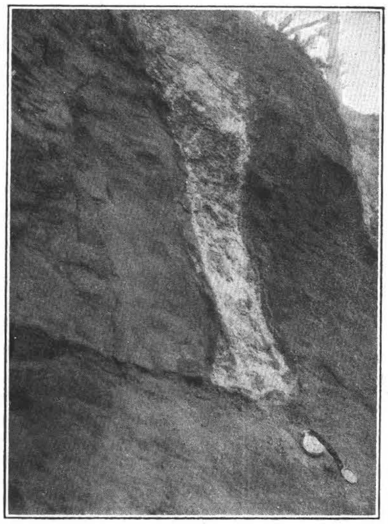


H.

REMARKABLE POCKET-LIKE FEATURES, SUGGESTING FILLED BURROWS OR POTHOLES, AND PEBBLES AND BOULDERS OF QUARTZ AND QUARTZITE FROM COLLUVIUM.

A, Filled burrows (?) extending below colluvium 3¾ miles southeast of Corinth, Miss. (Photograph by L. W. Stephenson.) *B*, Botryoidal quartzite from colluvium 5½ miles south of Oxford, Miss. *C*, Filled burrows (?) extending below colluvium 4½ miles southeast of Corinth, Miss. (Photograph by L. W. Stephenson.) *D*, Pebbles and blocks of quartz and quartzite from colluvium 1 mile northeast of Buford Mills, Miss. *E*, Filled burrow (?) extending below colluvium 1½ miles southeast of Washington, Ark. (Photograph by G. D. Harris.) *F*, Botryoidal quartzite from colluvium 5½ miles south of Oxford, Miss. *G*, Quartzite in place in colluvium three-fourths of a mile north of Oxford, Miss.; the quartzite is so much weathered that it is about to fall to pieces. *H*, Near view of one of the filled burrows (?) just northwest of Strickland, Miss. (Photograph by L, W. Stephenson.)

found, every one lying at or near the surface, without regard to altitude or physiographic relations. The pebbles and boulders not only differ from any in the underlying Wilcox, but they differ among themselves, falling naturally into several groups. Lithologically they may be classified as iron-cemented sandstone or sandy iron oxide, quartz, quartzite, and chert. All the pebbles are of very resistant materials, and yet most of them are deeply weathered. Their features are illustrated in Plate LV.

The fragments of iron-cemented sandstone show all degrees of rounding, ranging from pieces that are almost entirely angular to some that are nearly spherical, and it is generally difficult to determine whether the rounding is due to wear or to concretionary or some other cementation.

The quartz pebbles are nearly white and are well rounded, but many show more or less deep solution pits and some, particularly the larger ones, have many cracks, probably made by changes in temperature extending over a long period of time. Many of them have one or two flat faces, indicating that they have been broken by this process of insolation.

The quartzite pebbles and boulders display a wide range in form. Some look so much like the quartz pebbles that a close examination is necessary to distinguish them. On the whole they are larger, more angular, and more of a cream or brownish color. The most striking features they display are the huge size of such blocks as those 5½ miles south of Oxford, one of which is over 8 feet across, and the botryoidal form of some of the same blocks and others elsewhere, as illustrated in Plate LV, *B*, *D*, *F*. Another feature, which, though more obscure, is fully as significant with reference to the origin of some of the quartzite, is the presence of grains of certain minerals, particularly graphite, which are characteristic of the metamorphic region of northern Georgia and farther north.

Except the boulders nothing has so far been found in the residuum that promises to throw light on the Pliocene history of the region, though here and there the clay and sand portions seem to differ essentially from the underlying materials.

SOURCE.

The fact that all the pebbles and boulders are within a few feet of the surface and are much larger than any found in underlying formations indicates that they came from some other formation, and they are sufficiently numerous and observations on the size of pebbles in the underlying strata are sufficiently abundant to put this inference beyond question. The large size and angularity of such quartzite blocks as those shown in Plate LV, *B*, makes the conclusion that they are less than a mile from their place of formation practically unavoidable, but on the other hand the presence of graphite in fairly well rounded quartzite boulders 1 to 5 inches in diameter points clearly to a source in the area of metamorphic rocks 200 miles to the east. Obviously, then, the quartzite is of two varieties. Some was formed in the Coastal Plain by the cementation of sand grains with silica without the help of high temperature and pressure. Such quartzites have been found at numerous places in the Mississippi embayment, particularly in the Claiborne group, the northernmost outcrop of which is at Grenada. Being similar in certain peculiar features they may also be similar in conditions of development and perhaps also in age to the abundant quartzite blocks scattered over some parts of the Dakota plains and the region to the west. On the other hand, some of the quartzite must have been subjected to high pressure and fairly high temperature, else it would not contain delicate flakes of graphite. Such flakes could scarcely have been taken by water, wind, or any other agent from some other rock and incorporated in the sand of this rock at the time of its deposition without the delicate cleavage folia being broken up if not ground to powder or floated, because of their lightness, far out among finer deposits.

HISTORY.

Past cycles.—Although something can be determined concerning the original source of the pebbles and boulders, their history is largely problematic. The quartz and some of the quartzite pebbles and boulders evidently started in the region of metamorphic rocks 200 miles and more to the east. At many places the quartz and quartzite boulders are certainly larger than any in the formations which underlie these places, and they seem larger than those known to be in place anywhere else in the region. The large quartzite blocks and probably the iron-cemented sandstone also were formed near by, for such sandstone occurs abundantly in many formations in the region particularly near the surface and some of the quartzite blocks are too large and too angular to have been transported far. The chert pebbles had their source in a region of Paleozoic limestone; probably most of them came from central Tennessee. In any event the pebbles and boulders are evidently remnants of strata now worn away, for they are not concretions or other forms originating in their present positions. The question then arises, Did those strata belong to a single formation that covered all or practically all the region, or did they belong to several formations, some or all of which are still represented by more or less continuous deposits? It seems improbable, if not unbelievable, that they are the sole remnants of a single formation, for the removal of a formation from an area of 10,000 or 20,000 square miles would ordinarily proceed by its complete removal from some parts of the area before it had scarcely been dissected in other parts. The removal of 99.9 per cent or more from all parts of the area before all had been carried away from any part seems altogether beyond possibility, though if possible for any formation it would be so for one consisting of sand and silt containing scattered boulders. If the boulders had been let down from a single formation they should show some relation to altitude and surface features. They should be most abundant near their source and in the bottoms of washes and gullies.

The second hypothesis, that the boulders have come from several different formations, seems to accord with all known facts and principles. The original landward portion of any coastal-plain deposit, whether marine or subaerial, is likely to be coarser than the seaward portion, and as the beds off-lap one another the landward portion of each formation is exposed from the beginning of deposition, though the seaward portion is buried and protected from erosion. Hence it is not at all unlikely that the eroded landward portions of formations now present in the region once contained pebbles larger than any now found in them. If the blocks of stone too large to be moved by streams, rills, and rain wash were so numerous as to form a thick bed, they would act as a resistant stratum which in the course of erosion would come to cap the highest hills. But if they were scattered here and there in a matrix of sand and clay this finer material would be worn away from above, around, and below them, and they would be let down, with more or less lateral shifting, until by long exposure to the weather they would be broken to pieces small enough to be carried away.

Little has been determined concerning the long gaps between the times when the pebbles were integral parts of their parent rocks and the time or times when they reached their present positions, probably before the Pliocene epoch. The quartz pebbles may have passed through several cycles of weathering, transportation, and deposition. Probably they have traveled far, and to this their rounding is no doubt partly due. On the other hand, their long travel is due partly to their rounded form. Some of the quartzite may have had a similar varied history. The large, angular quartzite blocks, however, and the iron sandstones have never formed parts of any strata except those in which their cementation was accomplished and those in which they now lie. They seem to be similar in origin to the "graywethers" or "sarcen stones" of the English chalk downs, except that these are believed to be relics of formations not now present in the region. Some of the chert pebbles, particularly the smaller ones, may have been taken from their parent limestones long ago, dropped in a Coastal Plain formation, and perhaps later taken up and redeposited once or many times, but it seems probable that most of them came directly from the Appalachian province comparatively late in geologic time, during one of the more recent epochs of uplift of that province.

Present cycle.—The questions then arise, When and under what conditions were the pebbles moved from their places in the last formation of which they formed a part to their present positions, and how far did they travel? These questions are more germane to the present discussion, for it is believed that their answers afford data on the Pliocene history.

The data bearing on them are also more abundant and less inscrutable. The distribution of the pebbles, their stratigraphic relations, and certain general inferences concerning rate of erosion seem to throw light on the Pliocene history of this region.

The fact that the pebbles and boulders are nowhere concentrated into gravel beds or lenses but are widely and rather evenly scattered, particularly over the smoother middle and high portions of the surface, suggests that their lowering began, if indeed most of it did not occur, at a time when the region was lower and smoother than now, for if they had been let down by the erosion of their matrix while the country was rough they would have shown a tendency to move away from divides and down slopes, accumulating here and there in the bottoms of gullies. A similar argument indicates that their downward movement has not been great—at least not many hundred feet.

Their apparently close genetic relationship and the fact that they rest upon Coastal Plain formations ranging from middle or early Cretaceous to Oligocene indicates that they came to their present positions not longer ago than middle Tertiary time.

It seems much more likely that the pebbles came to approximately their present positions in Pliocene time than in any other epoch. If pebbles and boulders had been scattered over the surface of Mississippi in any epoch preceding the Pliocene, it seems very improbable that most of them would still remain near their original position, for in the opinion of the writer the assumption is well warranted that the uplands of central and northern Mississippi have been worn down more than 100 feet in Pliocene and Quaternary time. The present rate of erosion is probably about a foot in 10,000 years.

The pebbles and boulders have certainly been let down many feet, for they are found only in the colluvium. If they had been lowered much less than 100 feet, one might reasonably expect to find here and there remnants of the beds from which they came, but no such remnants have been found. They have not been let down many hundred feet, however, for they are somewhat evenly distributed and are almost as common on divides as anywhere else. On sharp-crested and steep-sided ridges and knobs they are scarce or lacking, but on rounded divides they seem as common as anywhere else. No beds known to be of Quaternary age have been so extensively eroded. Hence it is inferred that the beds from which the pebbles and boulders came were worn away, in part at least, in Pliocene time, and the somewhat even distribution of the pebbles and boulders suggests that the region lay lower in that epoch than it does now.

Just how the colluvium was formed is not yet clear. The distinctly greater abundance of coarse material at the base and the great extent of the deposit can apparently be explained best by climatic change, for ordinarily in the wash of soil down a slope there is little chance for such sorting. It would therefore appear that the basal coarse material was accumulated under different conditions from those which existed while the upper, finer part was being formed.

The general history of little hillside gullies in the region to-day seems to consist of (1) cutting of the gully, (2) deposition of gravelly and sandy silt in its bottom, (3) gradual obliteration of the gully by wash of fine material from above and the sides. This process being observed, the resulting deposit was carefully compared with the older colluvium, but it was found to differ markedly on the whole, though perhaps not in any single essential respect. The principal difference is that the basal coarse layer is much more irregularly developed in the present-day colluvium. This may be accounted for by the fact that owing to the activities of man in clearing forests and pasturing, etc., washing proceeds more rapidly than formerly, with results that differ not only in extent but in kind; but this seems scarcely an adequate explanation, and hence the writer is inclined to accept the hypothesis of climatic change.

On the other hand, objections may be raised to this hypothesis. The greatest climatic changes since middle Tertiary time have been those of the glacial epoch, and it might be reasonably assumed that the colluvium was produced by them, but if so it should be possible to find several deposits of colluvium of different ages and in many places one deposit superimposed upon or cutting another, whereas in only a few places, as in the railroad cut half a mile west of the depot at Iuka (see Pl. LIII, *H*), has one colluvial deposit been found above another. In any case many of the pebbles and boulders seem to date back to Pliocene time, though they may not have reached their present positions in that epoch.

Except the pebbles and their arrangement little that promises to throw light on the Pliocene history of the region has so far been found in the colluvium, though here and there the clay and sand portions seem to differ from underlying materials. One of its very remarkable features consists of forms that resemble filled burrows or potholes and extend down into underlying material. Harris[1] reproduces a photograph (see Pl. LV, *E*) showing one of these burrows, which he ascribes to a Cretaceous reptile, a Cretaceous age being assumed because the supposed burrow is in Cretaceous strata on a hillside and higher strata crop out near by. But the writer has found a great many of them, and all are connected with the colluvium. The best examples of them have been found by L. W. Stephenson in new cuts along the Illinois Central Railroad 5 to 10 miles southeast of Corinth, Miss., and pictures of some of these are shown in Plate LV. To judge by the present rate of erosion these burrows would seem to be of late Pliocene or early Pleistocene age.

RESIDUUM.

GENERAL NATURE.

Below the material which has been moved down slopes a greater or less distance by some agency, or at the surface in places where such material is lacking, lie strata of different ages that are in almost the exact position in which they were deposited and yet have been subjected to the somewhat effective weathering process of frequent wetting and drying. (See Pl. LVI.) They consist for the most part of irregularly bedded sand or clay or mixtures of the two. The upper few feet of this member, here called the upper residuum, commonly has a different appearance from the underlying part. In some places it is buffish gray or dull colored, contrasting with the brighter-hued strata below, but more generally it has red, brown, or black colors due to iron oxide, which here and there constitutes more than half of the deposit. (See Pl. LVII.) Below is a greater thickness of bright-colored and more sharply defined strata, the lower residuum, extending down to the dry-season water table.

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pl. 15, *B*, 1910

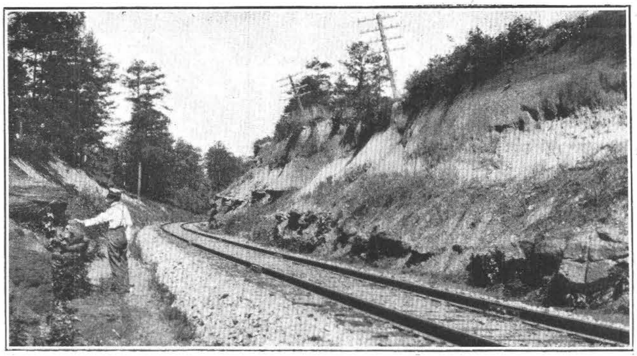
IRON CONTENT.

It seems to have been generally assumed that the iron which is so abundant or at least so conspicuous near the surface in Mississippi was deposited in one form or another along with the sediments with which it is now mingled, except for some shifting by solution and redeposition. For example, Crider[2] says: "The water passing through the Lafayette takes up iron oxide in solution and, being checked by the underlying impervious bed, deposits the iron oxide, thus cementing the sands into a compact mass." It is also assumed that the relative abundance of red color near the surface is due to some chemical change induced by exposure to the weather. Thus Berry, in the quotation given on page 130, ascribes the redness of the surficial material to dehydration of ferric oxide. Hilgard,[3] on the other hand, says that the color is due to "hydrated peroxide of iron or orange-yellow ocher." So far as the writer can determine many of the more or less reddish tints displayed may be due to either hydrous or nonhydrous iron oxide, and not only limonite and hematite may be present but perhaps turgite or other oxides and also iron compounds that are not red, such as the carbonate, sulphate, and sulphide.

If the iron has been subject to solution and redeposition and to change in constitution, it is reasonable to suspect that these processes would have been affected by any change in climate or altitude, by any burial beneath stream or sea sediments, and perhaps by faunal or floral changes. If so, the question presents itself, May not some Pliocene events have been thus recorded and the record preserved? Although the iron compounds seem to have been modified more than other portions of the residuum, perhaps other materials may also contain scraps of Pliocene history. A search has not yet brought to light any considerable record of this sort. Evidently one reason is that such records are more obscure than might be expected, and another is that the greater part of any record that was made has been effaced by erosion. The principal effect of such changes as those mentioned would have been felt within 50 feet of the surface, and the writer believes that most of the region has

[2] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 46, 1906.

[3] Hilgard, E. W., op. cit., p. 7.



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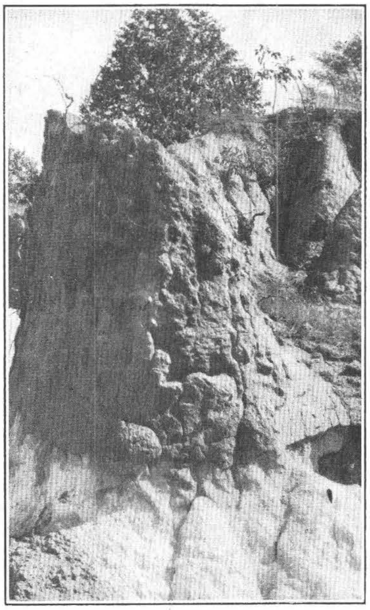

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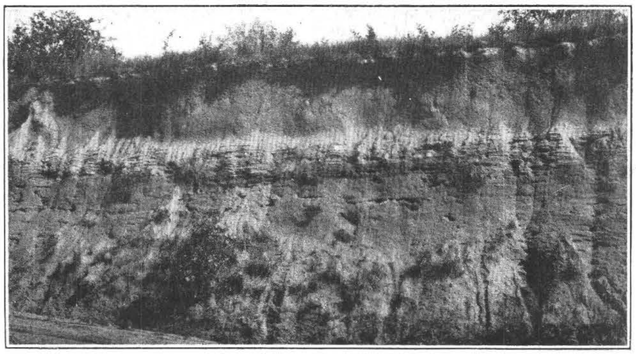

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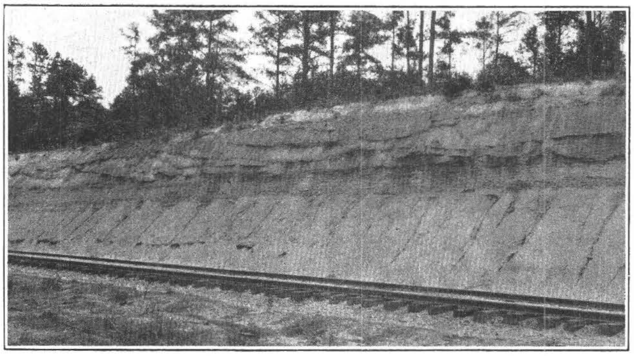

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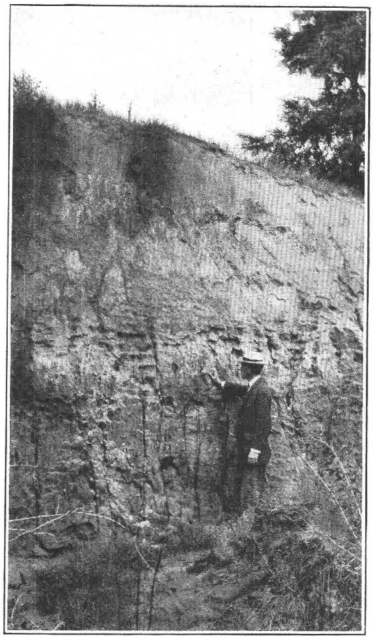

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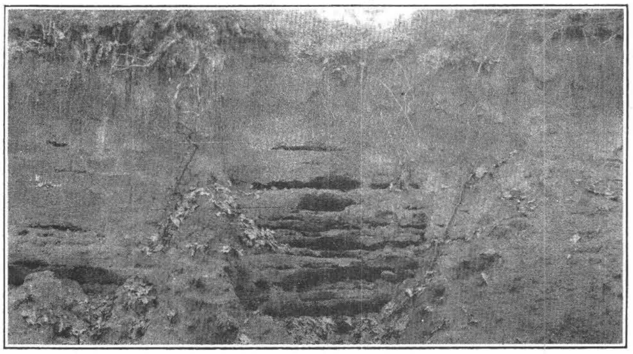
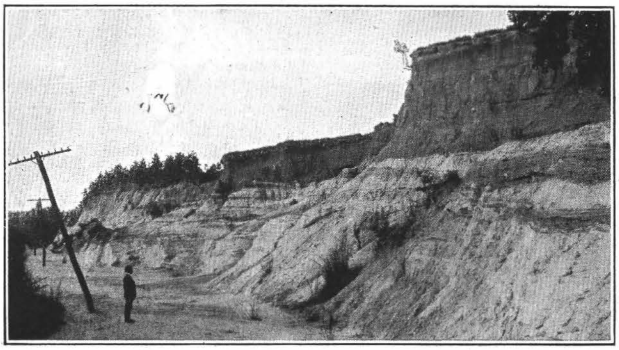


F.

RESIDUUM OR MATERIAL IN PLACE BUT MODIFIED SOMEWHAT BY WEATHERING, THOUGH LITTLE IF ANY PART HAS BEEN REMOVED.

Dr. E. A. Smith believes that much of the iron cementation shown in railway cuts has occurred since the cuts were made, but some is apparently much older, perhaps Pliocene. The residuum seems to contain material brought to it in solution and in the form of minute particles by the way of pores, from strata removed in the Pliocene and other epochs. *A*, Tuscaloosa formation 5 miles east of Tuscaloosa, Ala. *B*, Wilcox group 2 miles east of Holly Springs, Miss. *C*, Wilcox group at Oxford, Miss. *D*, Eutaw formation about 1¾ miles northwest of Leedy, Miss. *E*, Wilcox group 6½ miles east of Sardis, Miss. *F*, Wilcox group 13 miles east of Holly Springs, Miss.



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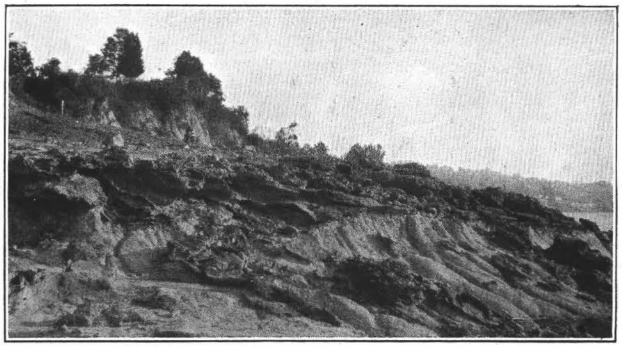

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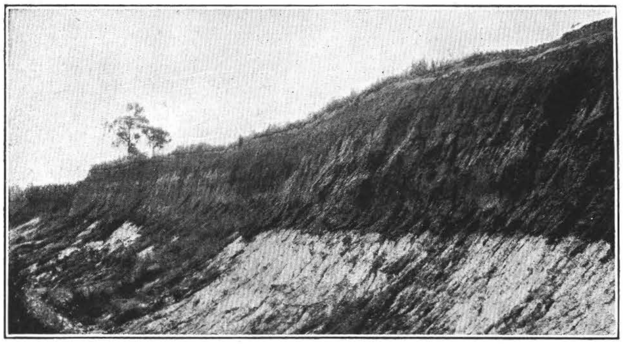

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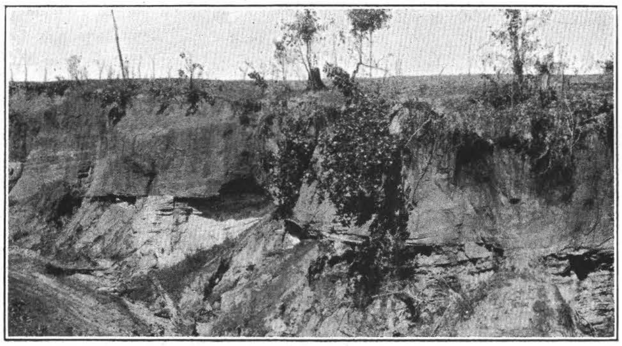

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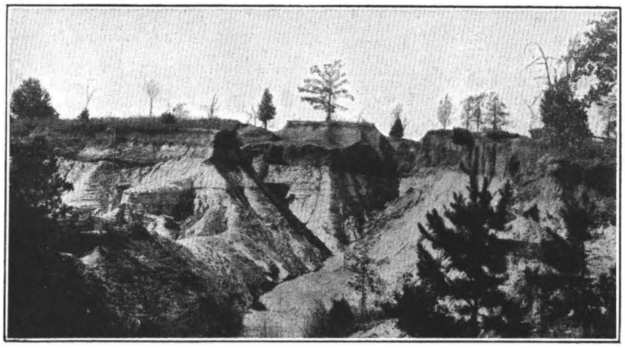

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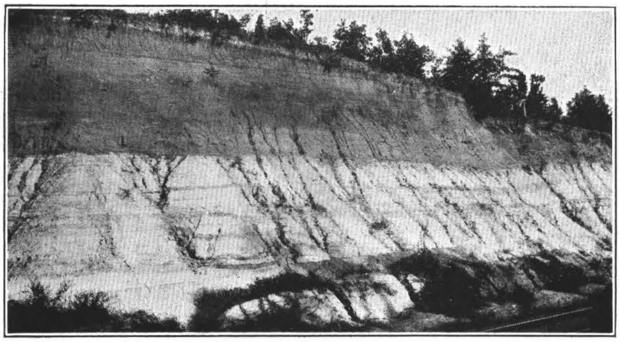

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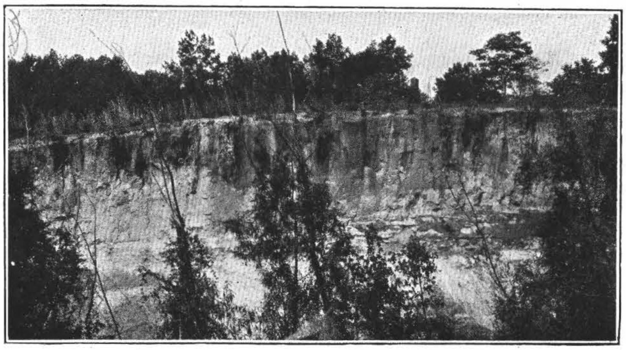

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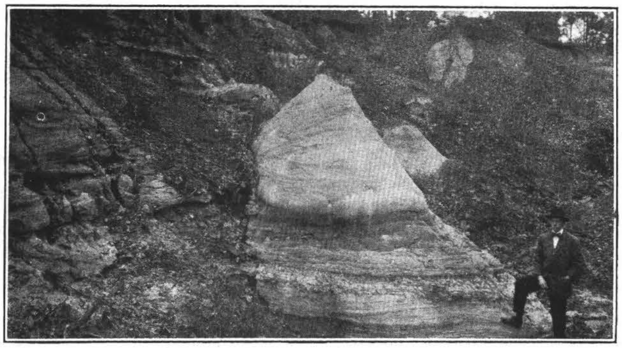


H.

VIEWS ILLUSTRATING REDDENING AND PROBABLE CONCENTRATION OF IRON COMPOUNDS NEAR THE SURFACE.

A, One mile north of station at Oxford, Miss. *B*, Gravel composed of hollow pebbles of iron oxide 1 mile north of wharf at Natchez, Miss. (See Pl. L.) *C*, Red sand with much iron oxide over impervious white clay, Grand Junction, Tenn. *D*, West side of Fourmile Creek, 2 miles east of Oxford, Miss. *E*, One mile south-southeast of Oxford, Miss.; upper part of white material is impervious clay and basal part of overlying red sand is more than half iron oxide. *F*, Three-fourths of a mile north of Oxford, Miss. *G*, Three-fourths of a mile south of Oxford, Miss. *H*, 4½ miles south of Oxford, Miss.; sand is white under clay lens showing in upper part of view but reddened to each side.

been reduced more than that amount since Pliocene time, and an additional, probably still greater, amount during Pleistocene time.

However, other facts point to the inference that the fundamental assumptions above mentioned need some modification.

It seems probable that the iron was not deposited along with the sediments where it is now found, but that it has been moved and concentrated not only through solution and redeposition but also mechanically. The basis of these inferences may be briefly stated. Much of the iron oxide is in the form of minute discrete grains, which are commonly less than a thousandth of a millimeter in diameter, and some are less than a ten-thousandth. Many of them are thus smaller than the pores of sand and other surficial material and must be carried about by percolating water. The main movement is naturally downward, for the downward movement of water after a rain is more rapid and more effective in washing than the upward and lateral movements due to capillarity and hydraulic gradient. As a result and also because the comparatively impervious bed acts as a strainer the iron is concentrated at the base of a porous layer and the top of an impervious layer.

The accumulation of iron oxide at the top of a clay layer, as illustrated by the quotation from Crider on page 146, has been ascribed to transfer in solution, but the assigned reason for precipitation of the iron seems inadequate. Only two possible causes suggest themselves, and both seem probably ineffective. First, the impervious bed is generally different in chemical constitution from the pervious bed, and something in it may cause a precipitation of the iron, but there is little reason for assuming that such a reaction occurs, particularly as the iron is concentrated only at the top of the impervious bed. Second, it is conceivable that the iron oxide is slowly being precipitated from ground water all the time, and the reason why more of it accumulates at the top of clay beds than elsewhere is that water is more nearly perpetual at such positions than elsewhere. But if this is so, it would seem that iron should accumulate at and below the water table and that the sand above should be robbed of its iron content. In many places there seems to be a concentration of iron at the top of the water table, and many iron crusts may be interpreted as marking a present or former position of the ground-water surface, but these crusts are comparatively thin instead of characterizing the saturated zone or its upper part as a whole, evidently more of the iron-rich sand is related to impervious beds than to present or former positions of the water table, and the arrangement can be much better explained by a mechanical process of downward concentration, the minute particles of iron being swept downward by rain water as it sinks into the ground and accumulating at the top of the ground water, where the rain water is stopped or its velocity greatly checked.

It should be remarked, however, that a large part of the iron oxide is very irregularly distributed, in an unaccountable manner, and much of it has evidently been affected by solution and reprecipitation, for some of it fills pores completely as a practically impervious mass and some of it coats sand grains, adhering to them closely. The iron oxide is thus found in two principal forms—as a compact mass clinging to sand grains and filling pores and as loose particles scattered through the pores. Many specimens of what seems to be deeply iron-stained red sand are easily cleaned by washing in water, and under the microscope the iron oxide is seen to consist of separate particles. The iron thus seems to be transferred both mechanically and in solution, and there is reason for believing that the dominant process is a downward mechanical concentration, followed by a slight rearrangement and compacting by solution and redeposition.

In some places, particularly where erosion is proceeding rapidly, the material most enriched with iron lies at the surface, the iron having come from material eroded away. In a railway cut half a mile south of the station at Oxford about 5 feet of colluvium overlying 10 feet of sandy Wilcox strata is exposed. A series of samples were taken at this place and submitted to Chase Palmer, of the United States Geological Survey, with the request that the percentage of total iron in each be determined. The results show a concentration of iron at the present surface and a similar concentration at the old surface which existed before the colluvium was laid down.

Percentage of metallic iron in colluvium and residuum half a mile southwest of station, Oxford, Miss.

[Chase Palmer, analyst.]

	Per cent.
Colluvium:	
1 foot below surface	3.85
2 feet below surface	3.08
3 feet below surface	2.58
4 feet below surface	2.06
Residuum:	
6 feet below surface	3.18
8 feet below surface	2.85
10 feet below surface	1.93
12 feet below surface	1.31
14 feet below surface	.89

BEARING ON PLIOCENE HISTORY OF REGION.

If the process of downward concentration of iron is now operative it has presumably been in progress for ages, though perhaps modified from time to time by climatic changes. If the surface of central and northern Mississippi has been lowered by erosion 100, 200, or 300 feet since the beginning of the Pliocene epoch, and the process of concentration has been active during this time, some iron from strata worn away in Pliocene time is probably present in the region to-day. But the search for some record of climatic and other changes in the iron deposits has thus far been fruitless. Iron-rich layers and lenses lie at many positions, which so far seem quite discordant, and much of the iron-cemented sand does not follow the bedding but cuts across it at various angles.

PHYSIOGRAPHIC RECORD.

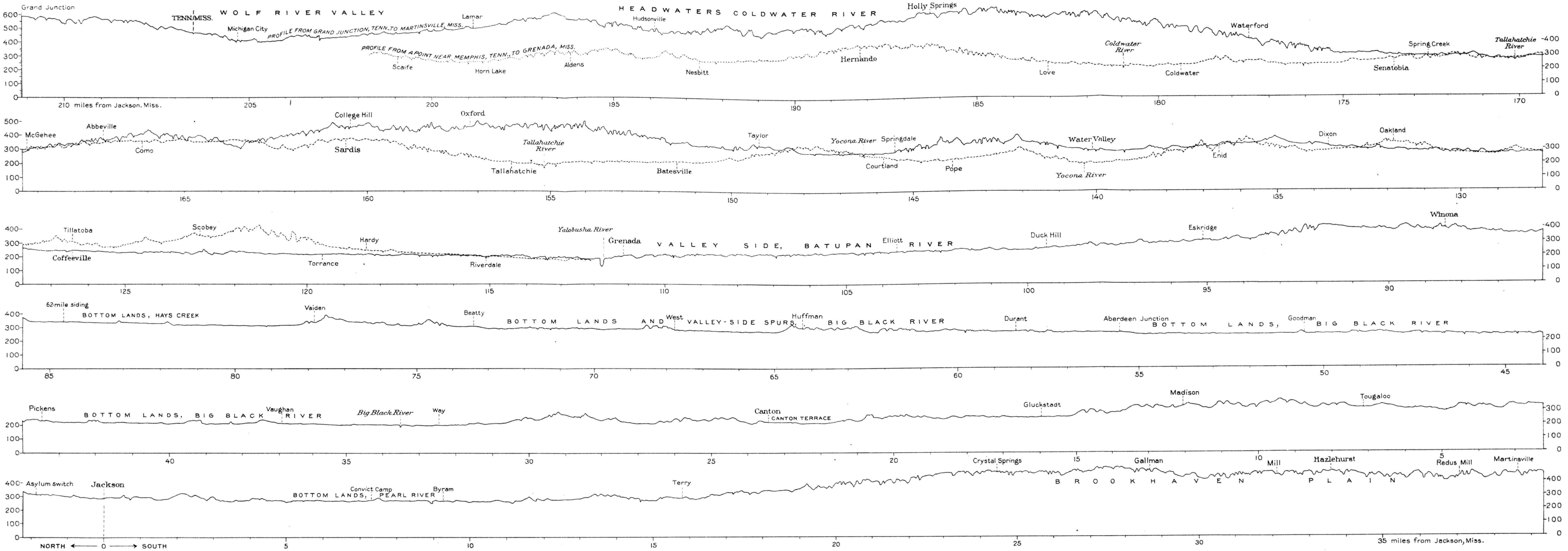
NATURE OF DATA.

In order to decipher the physiographic history of a region it is necessary first of all to have knowledge concerning areas that are approximately flat or that lie at accordant altitudes, for such features, whether large or small, may mark periods of erosion, producing extensive or incipient peneplains; of erosion and sedimentation, particularly in connection with stream terraces; or of sedimentation essentially alone, such as produces the surfaces of many sea, lake, and even stream deposits. Second, the investigator must know the arrangement of drainage lines. Third, he must know to some extent how readily the rocks underlying different parts of the region yield to erosion. Fourth, he can often use certain other facts concerning the nature of the sedimentary strata of the region and adjoining areas to which silt, sand, and gravel may have been swept from the region under study.

As detailed topographic maps have not been made for most of Mississippi, full and exact data regarding the surface features, such as are necessary for their interpretation, are comparatively meager. The literature concerning Mississippi seems to contain no descriptions of peneplains and little reference to terraces. The drainage lines are well shown on many maps of the State, but they appear in greatest detail on the General Land Office map, upon which most commercial maps are based. Information of other sorts is still comparatively scarce, though it has been considerably augmented by the present study.

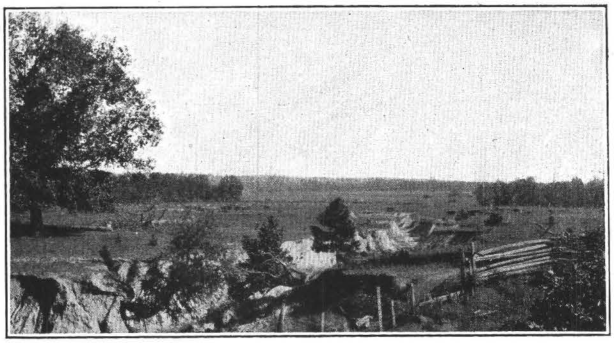
The basis of the inferences set forth in this report consists of published maps and descriptions of the region; unpublished topographic and physiographic observations of other geologists, particularly Dr. E. N. Lowe, State geologist, and members of the section of Coastal Plain investigations of the United States Geological Survey; results of spirit leveling, the profiles, generously furnished by many railroads (see Pl. LVIII), being of especial value; and notes on the appearance of the surface, made by the writer as he traveled by rail and buggy throughout the region, these notes being correlated with points of known altitude by the help of barometric readings between such points.

As good topographic maps are not available, it was necessary to use a barometer constantly, and although the readings of this instrument are subject to unknown and variable corrections, still, by using all possible means of checking, results of some value were obtained. The checks consisted of established bench marks, Weather Bureau records of air pressure for the times during which the barometer was used, the general average diurnal variation in air pressure, previous barometer readings, and occasional sights with a hand or spirit level. The appearance of the surface to the unaided eye, although scarcely usable in checking even a barometer, was nevertheless recorded, especially where appearances and barometer readings were discordant. Part of the time a barograph was used to record the air pressure for the day at a single point, generally in a hotel, and the barometer readings were modified to accord with those of the barograph.

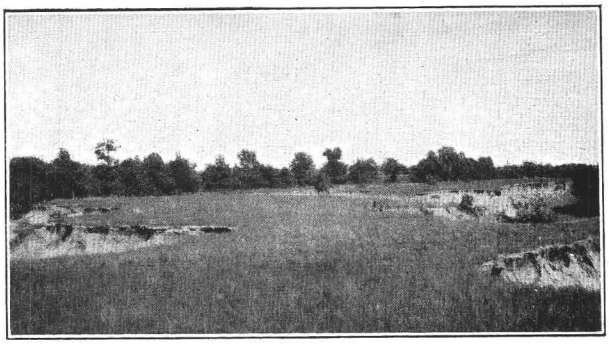


PROFILES ALONG ILLINOIS CENTRAL RAILROAD FROM GRAND JUNCTION, TENN., THROUGH JACKSON TO MARTINSVILLE, MISS., AND FROM A POINT NEAR MEMPHIS, TENN., TO GRENADA, MISS.

Profiles show surface features before cuts and fills were made.
Figures along bottoms of profiles show distances north and south from Jackson, Miss.
Vertical scale exaggerated about 20 times.



A.



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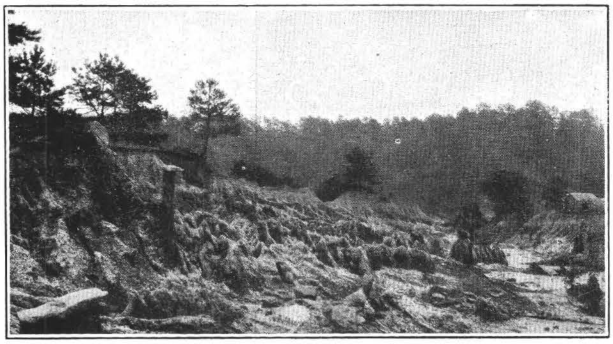

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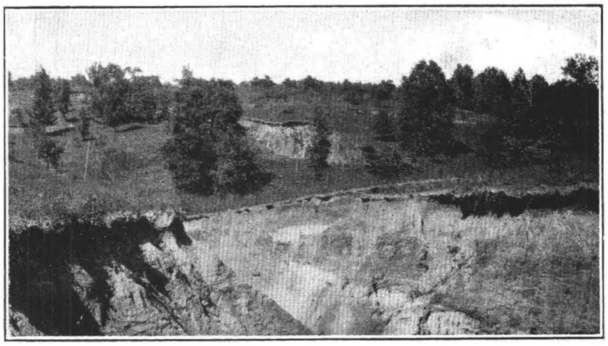

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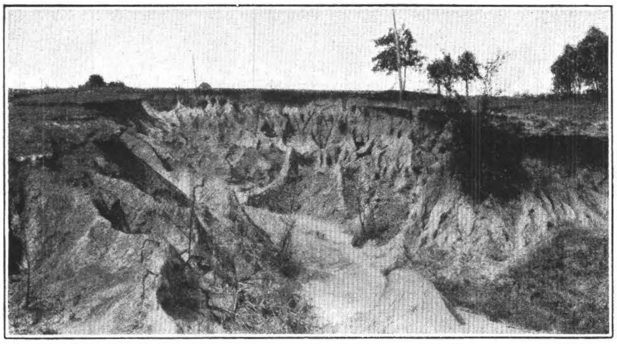

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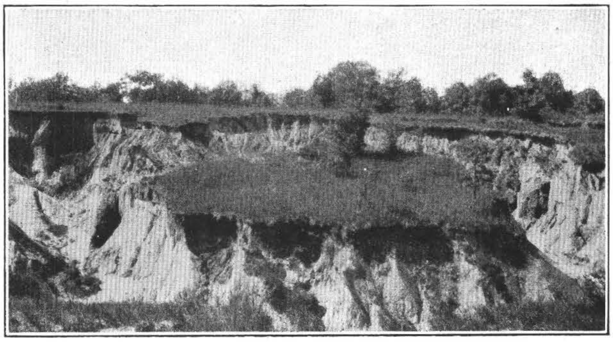

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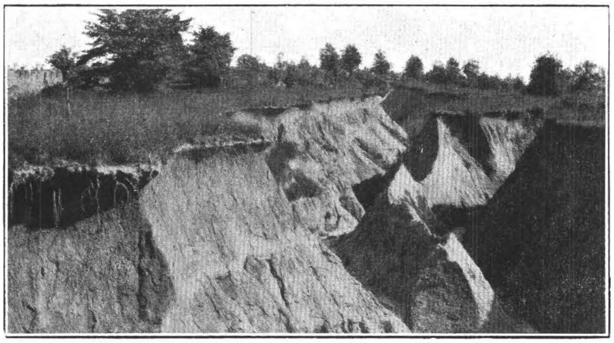

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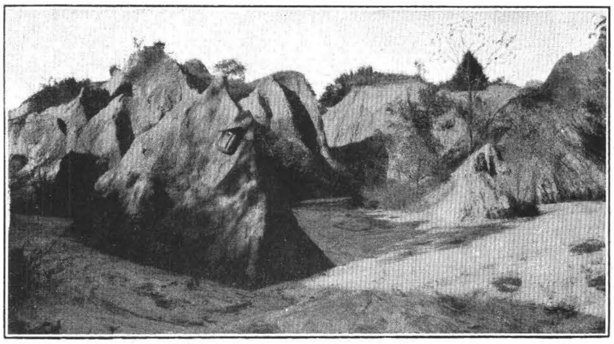
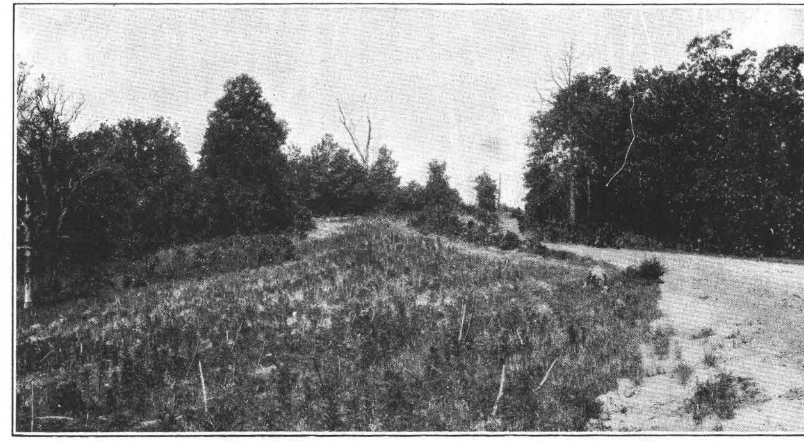


H.

VIEWS ILLUSTRATING OCCURRENCE AND MODE OF DEVELOPMENT AND THE EXCELLENT EXPOSURES AFFORDED BY OLD FIELD GULLIES.

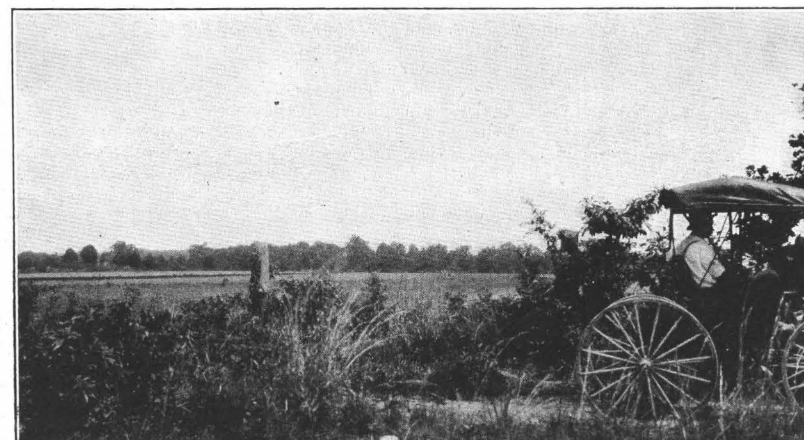
Such gullies may have played an important part in the Pliocene erosion of the region, though they were no doubt much less numerous than to-day. The part played by the sod in resisting erosion is well shown. Many of the gullies have rounded instead of V-shaped heads and evidently grow neither through erosion by water flowing into their heads nor through softening of materials by underground water issuing as a seepage, but only because of the fact that the rain which falls into them finds erosion easier than that which falls on sodded areas. *A*, Recent colluvium on border of flood plain $1\frac{1}{4}$ miles south of Delay. *B*, 8 miles south-southeast of Yazoo City. *C*, 5 miles west of Grenada. *D*, 12 miles east of Batesville. *E*, 7 miles west of Oxford. *F*, 12 miles west of Oxford. *G*, 15 miles east of Batesville. *H*, At Oxford; shows filling after deep erosion.

A.



B.

C.



D.

VIEWS ILLUSTRATING PENEPLAINS AND MONADNOCKS.

A and *B*, Peneplain with monadnock in distance 6 miles east of Holly Springs; the road on the right follows an even-crested divide, whose top was once a part of the peneplain. *C*, Thackers Mountain, a monadnock, from a point 5½ miles south of Oxford. *D*, Flat plain at altitude of 600 feet (barometric) on Ripley road, 11 miles east of Holly Springs.

GENERAL SURFACE CONFIGURATION OF THE REGION.

The surface features of northern and central Mississippi are those of comparatively rough elevated coastal plain, sculptured for the most part in only slightly consolidated sand and clay, the layers of which are nearly flat but lenticular and commonly ill defined. The altitude ranges from about 800 feet above sea level at the tops of some of the higher hills in the northeastern part of the State to about 100 feet on Mississippi River at Vicksburg, in the southwest corner of the area here discussed. The profile in Plate LVIII shows some of these features.

The areas underlain by sand are mostly rough, and some of them are almost rugged. The areas of clay and limestone are less extensive and smoother; some parts, as for example the uplands north of West Point, being strikingly flat and prairie-like. A part of the flat country around West Point, however, is made up of terrace tops. The principal areas of clay and limestone are along the east and south sides of the region. The divides in these areas are lower than in the sand areas; on the other hand, the valley bottoms seem somewhat higher. Old field gullies are common in most parts of the State, and their general form is illustrated in Plate LIX.

The physiographic record of Pliocene time in Mississippi seems to fall into three principal divisions. One is found in the upland surface forms, another in high terraces along Mississippi River, and a third in the arrangement of drainage lines.

UPLANDS.

MONADNOCKS.

Several more or less distinct stages in erosion are recorded in the surface features. The most striking and most legible part of this record consists of isolated monadnock-like hills which rise above the general upland where the underlying material is sand, for sand seems to be much more favorable to their preservation than limestone or clay. Several of these hills are to be seen in the vicinity of Iuka; one is 3 miles southwest of the town and another 5 miles northwest. Blue Mountain, south of Ripley, and parts of the Pontotoc Ridge also belong in this class. A striking isolated hill known as Thackers Mountain stands on the west side of the Illinois Central Railroad 5 miles southwest of Oxford, and another, somewhat lower, known as Summerville Mountain, is 9 miles west-northwest of Oxford. These hills are not capped with gravel or other material differing from the country rock, though as a rule each one has a layer of sand firmly cemented by iron at or near its top.

The question then arises whether any or all of these striking isolated hills have been formed in one and the same cycle of erosion. Apparently the two in Lafayette County were not formed in the same cycle, for one, Thackers Mountain, rises above a high divide, whereas the other, Summerville Mountain, is on the side of the broad valley of Toby Tuby Creek, and its crest is scarcely so high as the divide between this stream and Clear Creek, the next stream to the southwest. According to barometer readings, it is also considerably lower than the divide between Tallahatchie River and Yocona River, the major drainage lines to the northwest and southeast.

Most of the isolated hills, however, stand on high uplands and their tops show more or less concordance in height. Those in the northeast corner of the State reach about 800 feet above the sea; those in the Pontotoc Ridge country, east of New Albany, about 700 feet; and Thackers Mountain about 600 feet. In Choctaw County hills that are perhaps similar in history have crests at about 650 feet, suggesting that if they are of the same age the area including Choctaw County has been uplifted, for it is no more favorably situated with reference to drainage lines than the area to the north. The similarity in height of these isolated hills is not very close, however, the high hills in any county commonly showing a discordance of 100 feet or more.

The fact that no such large masses of hard rock seem to be present anywhere in the region, except on the tops of scattered hills, suggests that their formation was started by conditions different from those of to-day. If other such masses were present in the earth and were sharply defined and not close together, no doubt in the progress of a single cycle of erosion they would come to cap isolated hills, but unless the strata were horizontal and the hard masses occurred in only one layer the hills would be discordant in height. As a matter of fact, strata belonging at the horizons of the iron-cemented hill caps are well exposed at many places and are within reach of wells in extensive areas, but no such large, hard, and sharply defined masses have been found except on hilltops. Hence it must apparently be inferred that the formation of the hard masses began on a peneplain now marked by the tops of most of these hills and that instead of disintegrating with exposure to the weather the masses that now cap the hills have become more and more consolidated. The processes of underground mechanical concentration of iron oxide outlined on page 147 seem in accord with this inference. It seems possible if not probable that the hard masses began to develop in little hollows on a smoothish surface and then after uplift and during dissection the hard masses caused hills to develop where there had been hollows. Had there been no peneplain there might have been no such isolated hills.

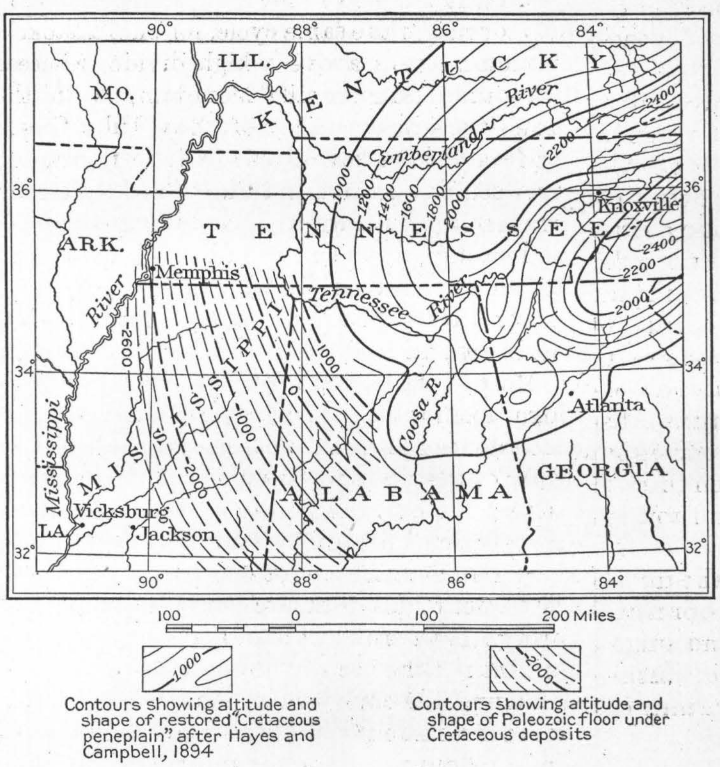


FIGURE 22.—Diagram showing the slope of the Cretaceous peneplain, according to Hayes and Campbell, and the slope of the Paleozoic floor beneath the Cretaceous deposits of Mississippi, which has been considered as being equivalent to this peneplain. The contours showing the Cretaceous surface are copied directly from an illustration in the pioneer description of peneplains of the southern Appalachians, which may be regarded as a first approximation and a representation of a hypothesis of the authors. Some believe that no peneplain of the Appalachians would, if restored, have the form of that here represented, but there is general agreement (1) that peneplains are represented in the Appalachian province, (2) that they slope outward from a central region at an angle no greater than that represented here, and (3) that in a belt around the margin of the province the slope decreases outward.

In any case their rough accordance of summits suggests a peneplain. On the other hand, the hard caps are not being softened by weather and even seem to be due in part to the forms of the hills, as well as the forms of the hills to the hard caps.

EVENNESS AND CONCORDANCE IN HEIGHT OF LOWER CRESTS.

Throughout a large part of the region the divide crests are so nearly even that more and better wagon roads are to be found on them than at any other topographic position. This is well shown in Plate LX, which shows also in the distance two low monadnocks. The evenness, however, though commonly a striking feature, is throughout most of the region only relative.

Generally the divides in any area are not only even crested but somewhat similar in height, the differences in altitude being as a rule only 50 to 100 feet. At many places, however, the average altitude of the divid seeems to increase rather abruptly by 50 or 100 feet, and the increase can scarcely be explained by the presence of harder rock. In some places the rise is so abrupt as to be unquestionable, but more commonly there is room for doubt as to the existence of any significant boundary of a physiographic feature.

The scarcity of exact data as to altitude, the uncertainties of the barometer, and the common lack of definition of the surface features make the unraveling of the upland erosional record very difficult. At hundreds of places it is evident that more of the upland surface lies at one, two, three, or even four altitudes than at any intervening positions, and that the difference is not due altogether to differences in hardness of rock nor to a combination of such differences and some other cause. But satisactory proof that any particular feature records a change in the rate or nature of erosion is difficult to obtain, and the correlation of features that probably record stages of erosion is fully as difficult.

However, after several months of study the writer has become convinced that several stages of erosion are recorded in the uplands and that these stages can be proved when detailed topographic maps are made. The data collected suggest that surfaces of concordant height stand at four different main positions. One position is represented by the tops of most of the monadnock-like hills. A second is represented by the comparatively even-crested high divides of the Pontotoc Ridge and some other less conspicuous features, particularly in a belt extending north-northeastward from the headwaters of Pearl River to Tishomingo County. A third, which is at present by far the most extensively represented, is that of most of the divides of the region. A fourth is represented by the tops of innumerable shoulders or benches, which are broadest near Mississippi River and on the more yielding formations.

Shoulders on spurs and benches on hillsides which are accordant in altitude but not sufficiently so to be terrace remnants and which bear no terrace deposits are common at still lower positions, but they are even more difficult of correlation and interpretation. Any single one might be due to a resistant bed or to some unknown cause. However, after traversing many valleys the writer has become convinced that below the four upland flats referred to above, two or more changes in rate and nature of erosion are recorded in features that are not stream or sea-cut terraces.

RELATION OF PHYSIOGRAPHIC FEATURES TO THOSE OF THE APPALACHIAN PROVINCE.

GENERAL CHARACTER OF SURFACE ALONG BORDER.

In the northeast corner of Mississippi and adjoining parts of Tennessee and Alabama opportunity is afforded for tracing the peneplains of the Coastal Plain northeastward into the Appalachian province, where three peneplains have been mapped and described and have become widely known. Fortunately several quadrangles in this critical border area have been mapped topographically.

According to Hayes,[1] the region lying northeast of the northeast corner of Mississippi, including much of central Tennessee and northeastern Alabama, belongs in the Highland Rim portion of the Interior Lowlands division of the southern Appalachian province. (See figs. 22 and 23.) Later studies have not led to any essential revision of this classification. Hayes and Campbell[2] describe two peneplains in this region. The older and higher or "Cretaceous peneplain" slopes westward and southwestward from 2,000 feet above sea level in Warren County, Tenn., 60 miles southeast of Nashville, to 1,000 feet above sea level within 100 miles, or at the rate of about 10 feet to the mile. The second or Tertiary peneplain is represented on Plate VI of the report cited, reproduced in part in figure 22,

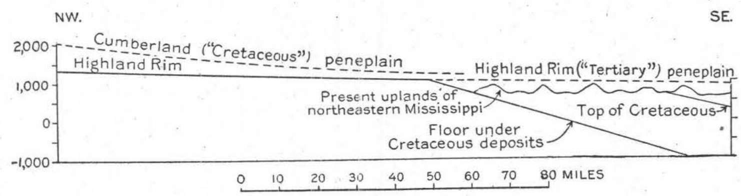


FIGURE 23.—Diagrammatic profile to show relations of upland surface features of Mississippi to the peneplains in a portion of Tennessee to the northeast, described in the text. This profile indicates that the peneplains of the Appalachian province are much younger than the floor beneath the Cretaceous sediments, and apparently the older of the two plains represented is younger than the floor under the Tertiary. This representation of the Appalachian peneplains seems subject to amendment of two principal sorts. First, the restored Cumberland peneplain may be warped up over the Nashville uplift, which falls in the left center of the figure; and, if so, the apparent discordance between it and the floor under the Cretaceous would be reduced. Second, there is strong indication that more than two peneplains are represented in this region, and each has a general slope less than those represented, and, if so, the discordance would be increased.

as having a westward and southwestward slope in the same region from 800 to 600 feet in 60 miles, or $3\frac{1}{3}$ feet to the mile. Hayes[3] a little later described three peneplains under the names Cumberland, Highland Rim, and Coosa, of which the first two apparently correspond to the Cretaceous and Tertiary, though he does not say so explicitly. The conclusions concerning these peneplains have received wide acceptance, and it would be out of place to discuss their status in a report on Mississippi.

In the vicinity of Iuka, in the northeast corner of Mississippi, the divide tops average perhaps 650 feet above the sea and are thus

[1] Hayes, C. W., Physiography of the Chattanooga district: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pl. 2, 1899.

[2] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, pls. 5, 6, May, 1894.

[3] Hayes, C. W., op. cit.

not far from alignment with the slope of the Tertiary peneplain above referred to. As a matter of fact, however, between 10 and 25 miles to the northeast the divides of to-day rise somewhat abruptly to 1,050 feet, and farther northeast the rise is again very slight. Thus the divides in south-central Tennessee fail to accord with the described slope of the Tertiary or Highland Rim peneplain. To the west they hold their altitude or decline very gently to 600 feet at the border of the somewhat lower area of Mississippi River terraces 25 miles east of Memphis. To the south they decline 350 feet within 80 miles, the altitude of those near West Point being only about 300 feet. The decline is not regular but is relatively steep to the belt underlain by the nonresistant Selma chalk. For example, the divide on which Guntown, 35 miles southwest of Iuka, is built has an altitude of about 350 feet. This same belt of weak rocks is, however, over 500 feet high west of Iuka, suggesting two stages of erosion. South-southwest of Iuka, along the main divide between Mississippi and Tombigbee rivers, and southward to the latitude of Natchez, or fully 250 miles, the surface ranges from 450 to 600 feet in altitude, showing from place to place a response to varying rock hardness and perhaps recording substages in erosion and slight warping. In other words, the uplands of Mississippi seem to show remnants of several plains, all of which are nearly horizontal and lie below the uplands of the adjoining Interior Lowlands subdivision of the Appalachian province and most of which, at least, have not sufficient northeastward rise to meet the "Tertiary peneplain" of Tennessee, unless they have undergone a somewhat sharp upwarp, so as to rise 400 feet in 25 miles.

HIGHLAND RIM PENEPLAIN.

Not only would the upwarp first referred to be called for if the general uplands of Mississippi are to be correlated with the Tertiary peneplain, as described, or with the Highland Rim, as it exists to-day, but also a downwarp a little farther to the northeast, for the slope of the "Tertiary peneplain" is only one-third as great as this rise, and the crests of the present divides in the vicinity of Waynesboro, Tenn., 40 miles northeast of Iuka, Miss., are still more nearly horizontal and 400 feet higher than most of the divides of northeastern Mississippi. Hence the assumption that the uplands of Mississippi are not of the same age as those of the adjoining portion of the Appalachian province seems warranted, and this assumption is verified by the fact that the divides near Waynesboro show some degree of accordance with the tops of the monadnocks near Iuka, suggesting that these two groups of features may be equivalent in age and may owe their difference in size and form to the difference in underlying materials.

East and south of Waynesboro, Tenn., there are some rather large and flat upland areas that are no doubt remnants of the plain which Hayes called the Highland Rim peneplain, and apparently considered identical with the Tertiary peneplain that he and Campbell had described three years before. One remnant is a flattish divide area of about 40 square miles, from 1 to 5 miles wide and about 22 miles long, all of which is between 1,000 and 1,080 feet above sea level. The crest of the north end of this divide averages about 1,065 feet above sea level and that of the south end about 1,005 feet; in other words, the divide slopes southwestward at the rate of about 3 feet to the mile for 20 miles.

In Mississippi, 45 miles southwest of this area, is a monadnock whose top is almost 800 feet above the sea. If the divide south of Waynesboro, with its slope of 3 feet to the mile, were extended to this hill it would lie 870 feet above the sea. As, if other considerations balance, the smaller the remnant of a peneplain the lower is its altitude, it may be that the two crests are to be correlated, and this possibility is strengthened by one or two remnants of intermediate height—for example, one 3 miles southeast of Riverton, Ala., whose top is 850 feet above the sea. It is also only natural that the peneplain should be found to slope continuously in a southwesterly direction toward the sea and the master drainage line.

In view of the presence of a large stream (the Tennessee) in this region, it is remarkable that the distance between the remnants described is not greater. They are so close together and so similar in altitude that it must be inferred either that they are all remnants of the same surface or that the larger and relatively higher ones near Waynesboro belong to a somewhat older surface.

If a broader area is considered it is found that the flat near Waynesboro extends interruptedly northeastward 40 miles, or nearly to Columbia, holding the same altitude of a little over 1,000 feet; indeed, it may be carried to Duck River Ridge, 10 or 12 miles north of Columbia, whose crest is also between 1,000 and 1,050 feet above the sea. East of this ridge the surface rises gradually for at least 15 miles, to a point where it reaches 1,150 feet, and it seems to have a general eastward rise beyond that point. However, in the Hollow Springs quadrangle, 40 miles east of Columbia, where it is well developed and preserved, it has a southeastward slope from 1,200 or 1,300 feet to about 1,100 feet within 15 miles. To the north the old flat is interrupted by the Nashville Basin, the bottom of which Hayes [1] correlated with a peneplain in Georgia that he called the Coosa.

From these facts it is evident that the Highland Rim is so high and so nearly horizontal that if projected south-southwestward it would intersect nothing in northeastern Mississippi but would lie slightly above the tops of the monadnocks in that region. If extended still farther it would likewise lie just above the tops of the highest hills in Union and other counties, and at Thackers Mountain (600 feet), 70 miles southwest of the 800-foot hill near Iuka, it would lie at 660 feet. Other intermediate hills, however, suggest that the slope of 3 feet to the mile is slightly reduced in Mississippi, so that at Thackers Mountain the position of the old plain is perhaps 700 feet above the sea, this hill, like others of the monadnocks, having been worn down 100 feet or so more than the larger remnants in Tennessee.

Still farther south the old plain seems to be traceable in the tops of the highest hills as far as the latitude of Jackson, a short distance south of which it is apparently covered by strata of Pliocene age, at an altitude of about 470 feet. However, as the Pliocene overlaps somewhat it is possible that this old surface lies below the Miocene. The tracing is a little uncertain because of the lack of topographic maps, the poor preservation of the features representing the old plain, and the comparatively slight difference in height between this plain and younger and lower upland plains; but two features relieve a large part of the uncertainty. One is the comparatively strong contrast in form between the monadnock-like remnants of the old surface and the much broader remnants of younger plains, and the other is the apparently uniform response to erosion by the numerous ferruginous sand members of several formations. If no error has been made in tracing, the average slope of the old surface in Mississippi is 2 feet to the mile for 200 miles. Owing to warping, however, the slope is not regular but apparently ranges from 3 feet to the mile to horizontality, or even a slight reversed slope here and there.

[1] Hayes, C. W., op. cit., pl. 2.

COOSA PENEPLAIN.

If the old surface represented by the tops of monadnocks in Mississippi is the Highland Rim peneplain, one would expect to find remnants of the younger Coosa peneplain in some of the lower hilltops. Correlation is somewhat uncertain, because the distance from the Mississippi region to known remnants of this surface is greater than to the type region of the Highland Rim peneplain. It seems possible that the Coosa plain is compound and that its members are equivalent to the two or three upland plains of Mississippi that lie lower than the tops of the monadnocks.

According to Hayes [2] peneplains may be correlated by continuous tracing, by noting similarities in degree of dissection, by observing coincidence of projected plains, and by determining recent drainage changes. To this list may be added observations of relation to other peneplains. Apparently the Coosa peneplain can not be traced continuously into Mississippi. Its degree of dissection would presumably be different in the region under consideration from that in the type locality, because the underlying materials are very different and also because of a different arrangement of principal drainage lines. The regions are too far apart to use coincidence of projected plains as a criterion, and no recent drainage changes seem to help in correlation.

In Mississippi the next to the oldest peneplain of which remnants are preserved lies about 100 feet below the tops of the widely spaced monadnocks, and if they have been worn down 100 feet more than larger remnants its position is about 200 feet lower than that of the Highland Rim. On the other hand, it lies from 100 to several hundred feet above the present valley bottoms, which have ap-

[2] Hayes, C. W., op. cit., p. 25.

proximately adjusted gradients, and it is maturely dissected. It thus resembles the Coosa peneplain in being next below the Highland Rim peneplain, in lying considerably above present graded valley floors, in being much dissected, and in being the principal if not the only peneplain between the Highland Rim and the present valley floors. It differs from the Coosa plain in being somewhat more dissected and in being apparently one of about three that are younger than the Highland Rim. The greater dissection may be explained by more yielding materials. The Coosa plain is decidedly undulating if not rough, and it seems possible if not probable that it will be found to be compound. If so, its divisions may correspond with plains later than the Highland Rim lying lower than the tops of monadnocks in northern Mississippi.

Thus it seems possible to determine the probable age of certain peneplains in Mississippi from evidence found within the State, and this forms a basis for revising and clarifying ideas concerning the age of Appalachian peneplains. It is recognized, however, that the data are not conclusive.

WARPING OF PENEPLAINS.

The peneplains of northern and central Mississippi lie nearly horizontal, and yet all of them have suffered some warping; originally each had no doubt a slight general inclination in some direction between west and south. Their present slopes are in the same quadrant, but the directions of slope of some have apparently been shifted a little, and the amount of slope of some has been increased and of some diminished. In general, the younger the plain the gentler is its present inclination, and a considerable part of the deformation seems to have taken place in Pliocene time.

The Paleozoic floor slopes about 30 feet to the mile; the plain at the base of the Tertiary about 20 feet to the mile; the slope of one at the top of the Eocene and others buried in the Eocene is no doubt considerably less than 20 feet to the mile. Thus the slope of successive buried plains gradually decreases toward the top of the geologic time scale. The slope of the top of the Oligocene averages only about 2 feet to the mile, and still younger peneplains seem to have average slopes of less than 2 feet to the mile.

Next to the general southwestward tilting of the plains and the fact that the older the plain the greater the slope, the most striking feature of their warped form consists in the decidedly steeper average slope of the older plains south of a belt of counties in the latitude of Vicksburg. The downward bend does not follow a sharp line but is irregularly developed. On the whole, its course trends east-southeastward from Jackson. For the older plains it inclines more to the southeast, and for the younger plains to the east. The slopes of the plains continue to increase southward, and at the present coast even some of the Pliocene buried plains are tilted as much as 25 feet to the mile.

Not only do the plains slope steeply in the south end of the State, but in the central part they seem to have been warped in the opposite direction, so that north of Jackson their original gentle seaward and riverward slope has been reduced to zero or a reversed slope. So far it has not been possible to determine the details of the warping. Some features suggest that a principal axis of uplift runs from Natchez to the northeast corner of the State, and another from Mobile northeastward, and other features suggest an east-west axis through Vicksburg and another through Natchez. Perhaps the warping has followed all these lines at the same time or at different times. Determination must await the preparation of topographic maps. In any case the evidence that some of this warping occurred in Pliocene time seems convincing, for both peneplains and quasipeneplains, including those which slope down into Pliocene deposits, seem to be warped upward around Jackson, and features of terraces and the drainage confirm the inference.

TERRACES.

GENERAL FEATURES.

The presence of several ancient and high gravel terraces, principally along the Mississippi, the deep erosion of these terraces, and some other reasons for regarding them as Pliocene have been referred to under "Sedimentary record." Apparently there are four main Pliocene terraces. All of them are now discontinuous, but on account of the facts that the terrace remnants are parts of ancient valley floors which were evenly graded, and that they have not since suffered very great deformation, they can be classified and correlated roughly, and if topographic maps were available they could no doubt be traced with a good degree of certainty.

The scattered remnants of the terraces were followed southward from Illinois through Tennessee, Kentucky, and western Mississippi to Vicksburg, where they were found to broaden and swing abruptly to the east across the State and continue into Alabama. After a conference with G. C. Matson,[1] who had been working on the late Tertiary deposits of the Gulf coast, it was decided to name the four main terraces as described below and illustrated in figure 24.

BROOKHAVEN TERRACE.

The Brookhaven terrace is broad and well preserved around Brookhaven, where it now lies nearly 500 feet above the sea. On the north it rises gradually for 35 miles to the southern parts of Hinds and Rankin counties, where, notwithstanding the fact that it has been severely eroded, its scattered remnants still reach 550 feet above the sea. That this terrace or some similar gravel-formed surface must have once extended 20 or 30 miles still farther north is indicated by the gravelly soil and subsoil of the higher knobs in that belt. These knobs are all lower than the remnants of the terrace south of Jackson, apparently for two reasons—the easy erodibility of the Vicksburg and Jackson formations, which underlie this district, and the fact that the horizon of the original surface of the terrace is lower because of warping than in the vicinity of Star and other places south of Jackson. The warping is inferred from the position of several plains and terraces but particularly from that of the younger terraces, which are fairly well preserved west and northwest of Jackson.

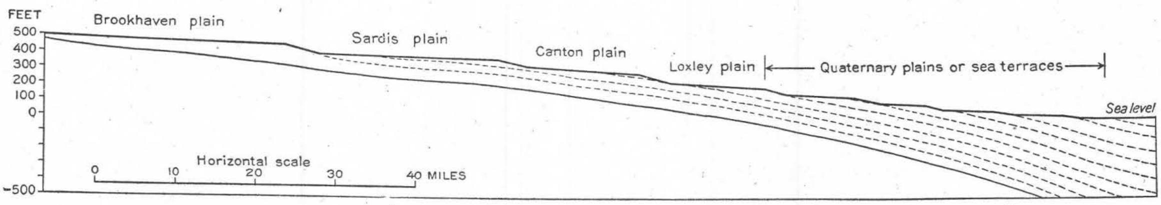


FIGURE 24.—Diagrammatic cross section of Pliocene deposits and profile of Pliocene terraces in the south end of Mississippi.

Thus the Brookhaven terrace, or plain, as Matson has called its seaward portion, is fully 60 miles wide and rises northward from about 450 feet to more than 550 feet, perhaps to 600 feet, and then declines to some unknown altitude greater than 450 but probably not more than 500 feet. It has been so severely deformed and eroded that present information is not sufficient to justify a statement that it is not compound. Relative to lower terraces, it is much broader in the east-west coast belt than along the Mississippi in the central and northern parts of the State, and this may be due simply to a difference in resistance of underlying materials, but differences in the process of development may also have played a part, and differences in destructive processes have almost certainly had a notable effect.

North of Vicksburg and Jackson, for the width of a county or two, no remnants of the Brookhaven terrace are now known, though pebbles let down from the deposit forming it are numerous in many places. North of Yazoo County, however, where the underlying formations are the more sandy and resistant Claiborne and Wilcox, scattered remnants of the Brookhaven terrace are found as far north as Memphis. They seem to decline very gradually to the north, or upstream, from about 460 to about 430 feet above sea level.

SARDIS TERRACE.

The Sardis terrace is somewhat better preserved than the Brookhaven but is still so badly eroded that in the lack of exact topographic data the identification of many of the supposed remnants is somewhat doubtful. It seems to be practically horizontal and from 2 to 10 miles wide from Sardis, where it lies nearly 400 feet above the sea, to Durant. Between Durant and Vicksburg, where no part of the Brookhaven terrace remains, there

[1] Matson, G. C., op. cit., pp. 180–186.

are a few remnants of the Sardis terrace. A few miles southeast of Vicksburg the terrace lies a little more than 400 feet above the sea, and east of Natchez it reaches nearly 450 feet, is 30 to 40 miles wide, and is fairly well preserved. To the east it becomes narrower and slopes to the east and south.

CANTON TERRACE.

In the vicinity of Canton, Miss., there are some very broad, rather flat, upland areas, underlain by sandy clay with gravel here and there, at an altitude of somewhat less than 300 feet above the sea, evidently remnants of a terrace. To the north the terrace seems to be nearly horizontal or to rise very gently to the Tennessee line. To the south the remnants rise to an altitude of about 370 to 380 feet at a point east of Natchez. Along the Mississippi this terrace ranges generally from 1 mile to 10 miles in width, though here and there it seems to have been cut away by the lateral swing of the river. Unlike the older terraces, it seems to be fairly well developed along some of the larger tributaries, particularly the Big Black.

LOXLEY TERRACE.

The Loxley terrace lies generally 40 to 80 feet below the Canton terrace, and its general slope is slightly greater, or more nearly like that of the present flood plains of the Mississippi and other large rivers. In the northern part of the State it lies 275 to 300 feet above the sea, or 100 feet above the present flood plain. To the south it declines gradually at about the same rate as the present flood plain to Yazoo City, where its surface buried under the loess is about 250 feet above the sea. From Yazoo City to Vicksburg it seems to be about horizontal and thus its distance above the present stream increases. Farther south its altitude increases somewhat rapidly downstream to more than 300 feet at a point east of Natchez. Apparently a terrace equivalent in age was well developed and is fairly well preserved on Pearl, Big Black, Yalobusha, and Tallahatchie rivers and on the Tombigbee, in the eastern part of the State. The terrace rises up each one of these streams, though its height above the present flood plain gradually decreases upstream—in other words, on these streams the terrace has a downstream slope which is more gentle than that of the present flood plain. However, the divergence of the two is not uniform.

WARPING OF TERRACES.

Although many of the terrace tops are undoubtedly parts of ancient flood plains, most of them differ in gradient from the present flood plains of the same streams. On the whole they have a more gentle slope, but in some parts of the State they seem to slope upstream instead of down, and these upstream slopes can be accounted for only by deformation.

The Brookhaven terrace seems to be warped upward as much as 200 feet just south of Jackson, where its position reaches 550 feet. Indeed, it seems to slope away from this district in all directions, but most steeply to the west and south. Fifty miles to the northeast it is 60 or 70 feet lower. To the east, near the Alabama line, it is over 100 feet lower, and according to Matson [1] this slope continues across Alabama. Apparently, however, another and smaller upwarp is located north of Mobile. Fifty miles south of Jackson the terrace is more than 75 feet lower. To the west also it declines to about 380 feet in Louisiana.

The site of maximum uplift of the later terraces seems to be successively farther and farther southwest toward Natchez, and the amount of uplift less and less. Perhaps, however, the actual amounts of uplift of each terrace did not differ greatly, but, the effect being cumulative, the oldest terrace now shows the greatest deformation. The resulting slopes have been still further modified by an uplift of the earliest Pleistocene terrace in the vicinity of Natchez.[2]

DRAINAGE MODIFICATIONS.

MISSISSIPPI RIVER.

During Pliocene time the Mississippi or some other large stream followed the general course of the present Mississippi, in the region under discussion, as can be inferred from the remnants of its old deposits and valley floors which are preserved in the form of terraces. Nevertheless the stream differed in several noteworthy respects from the Mississippi of to-day.

[1] Matson, G. C., op. cit., p. 180.

[2] Shaw, E. W., The mud lumps at the mouths of the Mississippi: U. S. Geol. Survey Prof. Paper 85, p. 18, 1914.

In early Pliocene time its mouth was far above the site of its present mouths—probably farther north than Natchez, which is 375 miles by water above the mouths—for (1) the general effect of bringing so huge a load of sediment as it carries to the sea is to build the coast forward, whether or not moderate warping is in progress, though in case of rapid downwarping the coast might migrate landward; (2) no Pliocene river deposit is known south of the southwest corner of Mississippi; and (3) a Mississippi River terrace deposit believed to be early Pliocene spreads eastward across the State 100 miles north of Natchez, indicating either a seashore at this latitude or the northern boundary of a great and continuous area of land sedimentation, for the deposit caps the highest divides, and its landward edge, though now much frayed, was apparently once straight or gently sinuous.

The volume of the Mississippi was evidently much smaller in the Pliocene epoch than now, for an extensive area is known to have been added to the northern part of its basin by the glaciers of Pleistocene time, and certain topographic features in the upper half of its basin including the youthful form of its valley, seem to indicate that this added area is considerably larger than has generally been supposed. The coarseness of the Pliocene deposits of the river may also be an indication of lesser volume. If its volume was less its gradient was presumably steeper, as the coarse deposits also suggest; and if the gradient was steeper the inferred deformation which has brought the deposits in places to a horizontal attitude or even given them an upstream slope was greater than if the slope had been as gentle as at present. However, the gradient of the lower half of the Mississippi is not extremely gentle to-day, for the lower Amazon, the lower Nile, and even the lower Ohio have gradients as slight or slighter.

The breadth of the Mississippi Valley was apparently not so great in Pliocene time as to-day, for the terrace remnants of its Pliocene valley floor are small and have evidently been severely worn by lateral swings of the river. In very few places are all four of the main Pliocene terraces represented, and in some places all have been worn away.

In one or several parts of the Pleistocene epoch the Mississippi flowed on the west side of its valley, at times whipping against the bluff at Little Rock, and the Ohio joined it at some point below Helena, Ark., perhaps south of Greenville, Miss., Crowleys Ridge being the divide between the two rivers. It appears probable that a similar arrangement existed in Pliocene time, but direct evidence is lacking.

PEARL RIVER.

The course of Pearl River lies for the most part in the region of the coastal Pliocene deposits, and although precise data concerning the form of the valley and the profile of the stream are scant it is evident that some anomalous features are displayed in the vicinity of Jackson. These features seem to be explained by the upwarps at Jackson and to the southwest. In the first place its course has a peculiar westward bend at Jackson and its main tributaries come from the east, suggesting that one or more of its main western tributaries have been captured and diverted by the Big Black. Second, the smaller southern tributaries of the Big Black are pushing the divide close over to the Pearl, whose channel is from 50 to 100 feet higher than that of the Big Black. Third, in the vicinity of Jackson the Pearl has a low gradient, a very meandering channel, and a swampy flood plain, whereas the Big Black and also sections of the Pearl above and below this part have a higher gradient, a more direct course, and a less swampy flood plain. In the vicinity of Jackson the Pearl has the appearance of an aggrading stream, which is disproportionately small compared with its valley, yet it is 250 to 300 feet above sea level and the distance that its water has to travel in getting to the sea is 100 miles shorter than that traveled by the water of the Big Black.

These facts suggest that the headwaters of the Big Black were once the western headwaters of the Pearl. Whether the diversion took place near Canton or at some place farther upstream has not been ascertained. The remarkable width of the Canton terrace and the much lower general altitude and more subdued surface features around Canton, compared with the region around Jackson, shown on the Jackson topographic map, suggests that the stream capture may have occurred in that vicinity, and that the time was late Pliocene or later.

BIG BLACK RIVER.

In addition to the apparent enlargement of its drainage basin one other feature of the Big Black seems worthy of mention in a paper on the Pliocene history of the region. The divide between the Tennessee and the headwaters of Big Black, Yalobusha, Yocona, and Tallahatchie rivers is well over toward the Tennessee, the middle and upper portions of which are much more nearly in line with one of these Mississippi rivers than with the lower course of the Tennessee. On account of this and other considerations Hayes and Campbell[1] have inferred, and many geologists have accepted the inference, that the Tennessee once had a southwesterly course across Mississippi. They believe that "at the close of the Cretaceous cycle of erosion" a small river flowed westward across northern Alabama and emptied into the sea in the northeast corner of Mississippi; that one or more of the head branches of this stream then captured some eastern Tennessee drainage that had been going to Mobile Bay; that upon the withdrawal of the sea this stream followed the course of the Big Black to the Mississippi. The northward diversion of the Tennessee in the northeast corner of Mississippi is described as having occurred in the early part of "the present cycle," after "the Lafayette depression," which "occupied the closing epoch of the Tertiary cycle."[2]

Although many details of the history of the Tennessee as set forth by Hayes and Campbell appear to need modification, numerous facts seem to support the more essential parts of their postulate. The Tennessee surely did not flow down the course of the Big Black in Pliocene time, for no high terraces seem to be left along the Big Black as a record, and there is no abandoned valley between the two streams. Certainly the Tennessee did not flow near Iuka and Tupelo, as shown in their figures. For similar reasons it seems also certain the Tennessee did not flow down the Yalobusha, Yocona, or Tallahatchie valleys in the Pliocene epoch.

That it did not flow down the Tombigbee, however, or even that it did not follow one of the other valleys mentioned, in some earlier epoch, is not clear. The Eocene deposits of Mississippi seem to be largely stream laid and to indicate that when they were laid down many small streams (or distributaries of a few large ones) with shifting channels flowed in general southwesterly courses across Mississippi. Presumably the Eocene sediments of Mississippi came from the adjoining portion of the Appalachian province, which includes the middle and upper parts of the present basin of the Tennessee and adjacent territory. There is hence reason for assuming that the drainage of most of the Tennessee basin in Eocene time, and perhaps also in Oligocene time, went southwestward across western Alabama and Mississippi. However, the Oligocene Vicksburg limestone and some of the Eocene Jackson marl indirectly indicate that at the time of their deposition sand and silt from the southern part of the Appalachian province was not being deposited in the region of their occurrence (Mississippi and farther east).

TOMBIGBEE RIVER.

Along the Tombigbee there are somewhat extensive high terraces, particularly in the vicinity of West Point, Miss., and to the southeast in Alabama; Bear Creek, a tributary of the Tennessee in the northeast corner of Mississippi, has a strikingly gentle gradient and a broad valley; the divide around the headwaters of the Tombigbee, in the northeast corner of the State, is only 15 or 20 miles from the Tennessee; and northeast of Iuka the Tennessee flows over a rocky shoal in a very narrow valley. These facts suggest that the Tennessee may have emptied down the Tombigbee Valley in Pliocene time, but if so some parts of the old course of the stream have not been found. It seems rather unlikely that Bear Creek occupies a part of the old course, for its valley, though wide, is scarcely wide enough for the Tennessee, and if it was cut by a large stream that is now diverted the diversion must have occurred in Quaternary time, for the valley is broad to its bottom. As Lowe[3] has pointed out, however, the higher part of the divide between the major streams is in some places "a narrow ridge" a few hundred yards wide and perhaps 50 feet high, and it is probable that at a point 4 miles below Paden Mackeys Creek, a tributary of the Tombigbee, is as low as the Tennessee at the

[1] Hayes, C. W., and Campbell, M. R., op. cit.

[2] Idem., p. 119.

[3] Lowe, E. N., A diversion scheme to prevent overflows of the Mississippi and to establish a navigable waterway from Mobile Bay to the Ohio River, p. 5, 1912.

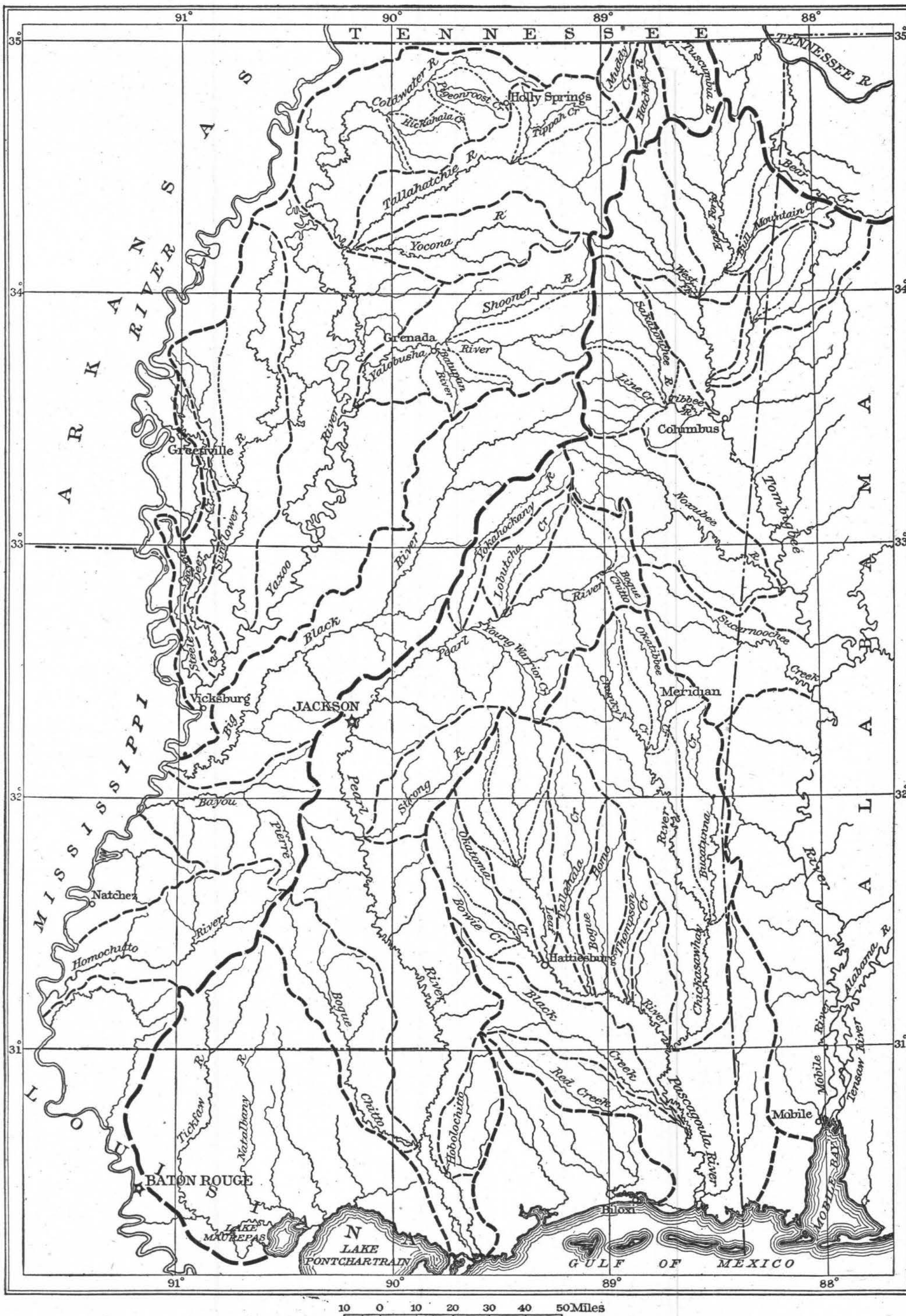


FIGURE 25.—Sketch map showing shapes of drainage basins in Mississippi. Note particularly that the divide between Mississippi and Tennessee rivers is located far to the east, and that the form of the drainage basin of the Pearl strongly suggests that the upper and middle parts of the Big Black basin formerly drained into it.

north boundary of the State. Lowe states that "the total distance * * * from the Tennessee River to an equal elevation on Mackeys Creek is 29 miles," and the crest of the divide is only about 200 feet above low water on the Tennessee and considerably less above high water.

The general shape of the drainage basins of Mississippi, which seems to have been largely acquired in Pliocene time, is indicated in figure 25.

STRUCTURAL RECORD.

What is known of the structural record of Pliocene time in northern and central Mississippi has been largely outlined in the discussion of warped physiographic features. It consists of evidence of uplifts in the southwestern part of the State and perhaps also along a belt extending northeastward to the northeast corner and possibly another uplift whose axis lies in southwestern Alabama, affecting the southeast corner of the State. Stephenson[1] has found evidence of an uplift at Starkville, on the axis that is thought to run northeastward from Jackson, and such an uplift may have occurred, as there seem to have been other movements along this axis in Pliocene time.

The Pliocene uplift along the Memphis-Charleston axis suggested by Shaler,[2] described by McGee,[3] and accepted by Hayes and Campbell,[4] does not seem to have affected either the surface features or the deposits of Mississippi, though it is described as crossing the northern part of the State.

That a surprisingly large amount of deformation of the strata of Mississippi probably occurred in Pliocene or early Pleistocene time is shown by the comparatively much disturbed attitudes of the Pliocene deposits and the surface features that are buried in them or for other reasons are believed to date from the Pliocene epoch.

Hilgard[5] and Crider[6] call attention to a northward dip of Eocene and Oligocene strata between Jackson and Canton. Veatch[7] describes a fault with a downthrow on the north of about 600 feet that extends from Texas through southern Arkansas and northern Louisiana to a point 15 or 20 miles north of Vicksburg and forms a continuation of one in Texas called by Hill[8] the Red River fault and described as having a similar displacement; but later work by Stephenson[9] throws doubt on the existence of this fault in at least a part of its course. Another structural feature, "the Angeline-Caldwell monoclinal flexure," is described by Veatch as extending southwestward from the same point north of Vicksburg.

However, on account of the fact that an uplift of the southwestern part of Mississippi is implied by the physiographic features, the writer recommended that an area around Vicksburg be examined with reference to its possibilities of yielding oil and gas. A survey[10] was made and the hard rocks were found to be bent upward, thus confirming the inferences drawn from surface features. The map showing the structure of the hard rocks gives somewhat more detail than can be inferred from the surface features in the lack of topographic maps, but still it shows less accurately the movements that have affected the rocks, because it includes the effects of pre-Pliocene warping and also those of all later movements together, whereas from the surface features something may be inferred as to the time, place, and effect of each movement.

CONCLUSIONS.

INTERPRETATION OF THE "LAFAYETTE FORMATION."

In the opinion of the writer, the material called "Lafayette formation" in Mississippi is the product neither of Pleistocene icy floods from the north nor of a marine invasion; it is not a Pliocene blanket of waste from the Appalachians gradually spread over the State by streams; and it does not consist altogether

[1] Stephenson, L. W., unpublished notes.

[2] Shaler, N. S., On the causes which have led to the production of Cape Hatteras: Boston Soc. Nat. Hist. Proc., vol. 14, pp. 110-121, 1871.

[3] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 403, 1891.

[4] Hayes, C. W., and Campbell, M. R., op. cit., p. 81.

[5] Hilgard, E. W., Geology and agriculture of Mississippi, p. 128, 1860.

[6] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 34, 1906.

[7] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46: p. 68, pls. 36, 37, 41, 1906.

[8] Hill, R. T., Geography and geology of the Black and Grand prairies, Tex.; U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, p. 384, 1901.

[9] Stephenson, L. W., unpublished notes.

[10] Hopkins, O. B., Structure of the Vicksburg-Jackson area, Miss.: U. S. Geol. Survey Bull. 641, pp. 93-120, 1916 (Bull. 641-D).

of parts of pre-Pliocene formations, with their surface residuum. It is believed to be made up of unrelated or distantly related materials that have been erroneously grouped together and to consist in the main of more or less modified parts of the underlying formations, including some residuum and colluvium, and of terrace deposits of Pliocene and Quaternary age.

DIASTROPHISM.

Position of surface at beginning of epoch.—The facts that the buried portion of the Pliocene surface is of gentle relief and that the tops of monadnocks and other remnants of plains are somewhat concordant in altitude suggest that at the beginning of the Pliocene epoch the surface of Mississippi was smoother than it is to-day. The coarseness of the stream deposits and the nature of the warping of the plains and formations suggest that at that time the surface of central and northern Mississippi, though possibly lower than at present, had a considerable and somewhat regular westward and southward slope toward Mississippi River and the Gulf. However, this surface, though perhaps lower with reference to sea level, was higher with reference to the underlying rocks and possibly with reference to the earth's center; for it has not only suffered local upheaval but has been worn down by erosion and perhaps has sunk a little, owing to general earth shrinkage.

Deformation.—The triangular area of which Jackson, Vicksburg, and Natchez form the corners has certainly been elevated in and perhaps after Pliocene time, and the place of maximum upwarp seems to have shifted southwestward during the epoch, for the deposits and plains are not only warped upward, but the earliest ones are uplifted most and the center of uplift is different for different plains and deposits. In addition there appear to have been a general east-west and a northeast-southwest belt of uplift through Jackson and another region of uplift just east of the southeast corner of the State. The maximum amount of uplift seems to have been at least 200 feet, for a terrace seems to rise in a downstream direction to that extent between Yazoo City and Star. The uplift seems to have been intermittent and to have occurred in four principal stages. The great breadth of the earliest Pliocene terrace and its height compared with the bordering divides suggest that the low relief of the beginning of Pliocene time lasted through perhaps a third or a half of the epoch before the first of the four uplifts occurred. The most pronounced result of all the movements is a great steepening of the seaward slope of strata and plains of all ages in the southern third of the State. Other than the depression of the coast region involved in this steepening, no downwarps are known to have occurred.

EROSION.

Weathering and local transportation.—The work of meteoric waters and of vegetation during the Pliocene epoch was evidently manifold. In addition to the main processes involved in the production of soil rains and consequent rills washed much of the incoherent underlying sand and clay down slopes and dissolved and carried away much mineral matter, both above and below ground; gravity through the aid of wetting and drying and other agencies, including perhaps freezing and thawing, pulled surface material downhill; wetting, aeration, and chemical processes weathered the material lying above ground water and transported iron oxide and other substances, both by solution and mechanically, a greater or less distance; and apparently much iron oxide that lies near the surface to-day has been concentrated downward from strata that were worn away in Pliocene time.

Through transportation and corrasion.—Aside from the probably small amount of mineral matter that has been carried to the sea underground the removal of such matter from Mississippi has evidently been accomplished largely by streams, though no doubt some material has been swept out of the State by wind. The general work of erosion has been the gradual deepening of valleys, though apparently this work has been in places, particularly on the Mississippi, subjected to interruptions during which considerable deposits were laid down. Not only were valleys deepened, however, but divides were reduced both by mechanical and by chemical agencies. To judge by processes now active the amount of material carried away in solution was fully as great as that in suspension if not greater. Hence it must be assumed that all parts of the region that have been exposed since Miocene time have been subjected to a continuous and vigorous process of reduction, perhaps to an extent of 100 tons to the square mile each year.[1] It seems reasonable to assume, therefore, that the surface at the beginning of Pliocene time was at least 100 feet above the highest hills remaining to-day, and that much of it was lowered more than 200 feet in the Pliocene epoch.

At apparently four different times the nature of the erosive processes was so modified that plains began to be formed, though the earliest one or two of these times may have been in the Miocene epoch. It seems possible that the deepening of valleys in Mississippi was checked at times when it was accelerated in adjoining provinces, for at such times in Mississippi through streams would probably be overloaded with material from their upper courses. In any case erosion developed striking monadnock-like hills in certain sandy areas and cemented their tops with iron oxide.

In the northeast corner of Mississippi an opportunity is afforded for tracing the peneplains of the Appalachain province southwestward into the Coastal Plain. A careful study of the surface features in and near this part of the State suggests that the Highland Rim peneplain, so well developed in the adjoining portion of the Appalachain province, is less ancient than has generally been supposed. It does not seem to be older than the beginning of the Pliocene but may be as old as early Miocene. A pre-Cretaceous peneplain, however, is apparently represented by hilltops in and near the northeast corner of Mississippi, but this plain is preserved because for a large part of its existence it was buried beneath the Coastal Plain sediments and has only recently been exposed. There is also indication that a peneplain emerges from between the Cretaceous and Tertiary systems in Mississippi and passes upward toward the northeast but slopes less steeply than the pre-Cretaceous plain, with the result that the two intersect. Both plains no doubt suffered considerable denudation in Pliocene time. The Miocene (?) plain at the tops of the isolated hills rises even more gently to the northeast and intersects the other two plains. The still lower and younger plains are not yet satisfactorily differentiated, but they are nearly horizontal and, like the older ones, rise to the northeast, each successive one more gently than the preceding and each intersecting all the older plains.

If the old surface represented by the tops of monadnocks is not the Highland Rim peneplain, it must be slightly younger, and if so that peneplain must cross it and slope down under slightly older sediments. The lack of any indication of such a relation lends support to the interpretation that the monadnocks are really somewhat reduced remnants of the Highland Rim peneplain. Moreover, if the seaward portion of this peneplain passes under Pliocene sediments, it must have been formed just before Pliocene time, and one part was buried and another carved into monadnocks during Pliocene time.

It seems evident that the present divides, which show a comparatively abrupt rise 10 to 25 miles northeast of Iuka, do not belong to a surface of uniform age and origin, but that the surface farther northeast is the remnant of a plain which was mainly developed upon resistant cherty limestone of Mississippian (St. Louis and Fort Payne) age and which now has a gentle southwesterly slope to a line lying about 25 miles northeast of Iuka. Along this line the Highland Rim peneplain intersects a more steeply sloping and older planed surface which dips under Cretaceous deposits that reach sea level 15 or 20 miles west of Iuka. The accordant crests of Mississippi, with the possible exception of the monadnock tops, evidently belong neither to the Highland Rim peneplain nor to the peneplain finished just before Upper Cretaceous time. However, the surface of the region when it became partly submerged in the Upper Cretaceous sea may have been little or no smoother than it has been at many times before and since.

Drainage modifications.—The drainage modifications seem to have been continuous and very gradual rather than sudden. A portion of the Pearl seems to have been captured by the Big Black; but the other changes seem to have consisted in a gradual shifting of divides, which is suggested by drainage patterns but can not be demonstrated because of lack of topographic data. Perhaps the most striking feature of this class is the short distance between Tennessee River and the divide on the southwest side of its basin in Mississippi.

[1] See particularly data on the Pearl at Jackson given in U. S. Geol. Survey Water-Supply Paper 234, p. 87, 1909.

SEDIMENTATION.

Sedimentation in valleys.—Not only did the streams of Mississippi considerably deepen their valleys in the Pliocene epoch, but at the same time, though not at a uniform rate, they deposited much sand and gravel in their valley bottoms. Apparently, at four stages in particular, the Mississippi received more sand and gravel than it could carry perhaps because of uplifts of the Appalachian or Ozark mountains, and as a consequence it meandered widely, undercutting its valley sides and spreading sand and gravel over its flood plain. Somewhat extensive though much dissected remnants of these deposits are to be found to-day here and there along the valley side. The overloaded condition did not last long, for the deposits do not seem to have been much thicker than the ordinary alluvium along large rivers. Perhaps the four terrace deposits correspond to the four peneplains that are possibly represented in the divides; but it may be that at only two or three times of valley filling were plains perceptibly developed and that the older one or two peneplains are Miocene.

Coastal sedimentation.—Whether at the beginning of Pliocene time the coast was at the northern limit of the Pliocene deposits or whether part or all of these sediments are land deposits are problems that have not been solved, though the balance of evidence seems to favor land deposition. The facts that the northern boundary seems to have been a somewhat regular line, that the deposits cross interstream areas, that they are fairly uniform in composition and extent and resemble the terrace deposits of the Mississippi much more than those of other streams, and that the surface features consist of about four terraces parallel to the coast suggesting in some respects the surfaces of uplifted compound deltas seem to suggest marine conditions. On the other hand, the facts that the terrace fronts are not well-defined escarpments, that sea cliffs and beaches seem to be lacking, that Pliocene land plants grew at least as near the present coast as Perdido Bay, Ala., and perhaps considerably farther south than the present coast, that the stratification and sorting seem to point to stream rather than ocean action, and that nowhere in these deposits do there seem to be marine fossils strongly suggest land deposition.

CLIMATE AND LIFE OF THE EPOCH.

What is known of the plants and animals that lived in Mississippi in Pliocene time is largely set forth in recent papers by Matson and Berry.[1] The only additional organic remains worthy of mention are petrified logs, such as are fairly common in the high terrace deposits of the Mississippi. The climate also seems to have left little record except the products of weathering, which seem to be indistinguishable from those of to-day. Perhaps some of the erosion features were produced by changes in climate, but they seem more reasonably accounted for by deformation.

[1] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pp. 167–192, 1916. Berry, E. W., The flora of the Citronelle formation: Idem, pp. 193–208.

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UNITED STATES GEOLOGICAL SURVEY
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Professional Paper 108—I

STRATIGRAPHY IN SOUTHWESTERN MAINE AND SOUTHEASTERN NEW HAMPSHIRE

BY

FRANK J. KATZ

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STRATIGRAPHY IN SOUTHWESTERN MAINE AND SOUTHEASTERN NEW HAMPSHIRE.

By Frank J. Katz.

INTRODUCTION.

Area.—The region discussed in this paper includes some 1,500 square miles, most of which is in the southwest corner of Maine, in Cumberland and York counties, the remainder being in the adjacent parts of Strafford and Rockingham counties, N. H. The area lies between

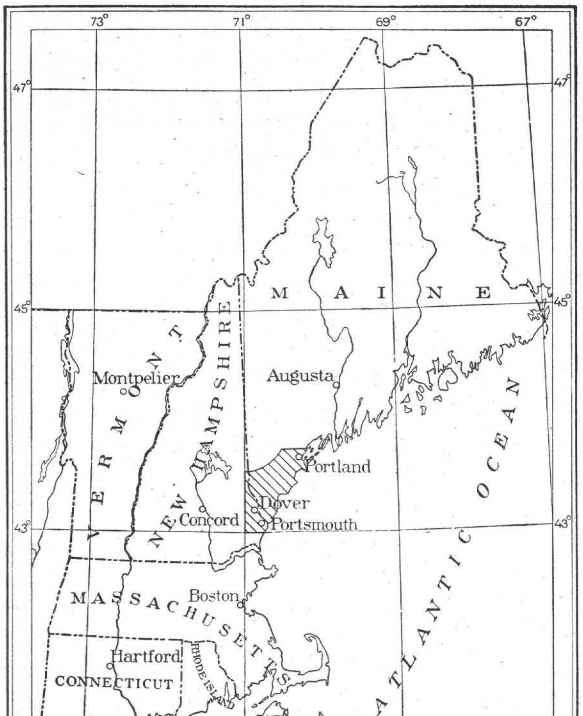


FIGURE 26.—Index map showing area in southwestern Maine and southeastern New Hampshire.

meridians 70° and 71° and parallels 43° and 43° 45′, which inclose the Casco Bay, Portland, Buxton, Newfield, Biddeford, Kennebunkport, Berwick, York, and Dover quadrangles of the United States Geological Survey topographic atlas. (See fig. 26.)

Field work.—The conclusions on this region here set forth are the result of work begun in July, 1911, and still in progress. The field work has included critical study and detailed mapping of about one-third of the area and reconnaissance examination of the remainder. This work was under the direction of Mr. Arthur Keith, who has conferred frequently in the field and office with the writer and whose encouragement and assistance contributed to its progress. Mr. Laurence LaForge, who has long been studying areas in New Hampshire and Massachusetts southwest of the region here considered, has also contributed to the results by field conferences and by critical discussions. The writer gratefully acknowledges indebtedness to both these geologists.

Previous work.—Little geologic work had been done previously in southwestern Maine and the adjacent part of New Hampshire, and there are no published conclusions of present interest except those of Charles H. Hitchcock,[1] which can be briefly summarized as follows:

Hitchcock elaborated the views of his father, Edward Hitchcock, on the geology of the vicinity of Portland, Maine, and following him divided the rocks of the region on the basis of lithology into a number of varieties of schists and assigned them to his Huronian and Cambrian, or Paleozoic (?). Furthermore, he recognized these sedimentary rocks of the Portland and Casco Bay region as distinct from those of adjacent areas. The gneisses to the north and west of the Portland rocks he assigned to the "Laurentian or Azoic," but later he correlated part of these gneisses with his Coos group (Paleozoic) of New Hampshire. He further

[1] Hitchcock, C. H., General report upon the geology of Maine: Maine Board Agr. Sixth Ann. Rept., pp. 146–328, 1861; The geology of Portland [Maine]: Am. Assoc. Adv. Sci. Proc., vol. 2, pt. 2, pp. 163–175, 1874; The geology of New Hampshire, pt. 2, Stratigraphical geology, and atlas; Concord, N. H., 1877; Geology of northern New England (Maine, with map), 1885; The geology of New Hampshire: Jour. Geology, vol. 4, pp. 44–52, 1896.

noted in York County, Maine, the continuation of his Merrimack slates ("flinty slates") of New Hampshire, and northwest of these in Maine and New Hampshire, in the vicinity of Rochester and elsewhere, he mapped and described the "Rockingham mica schists" and "Kearsarge group" (andalusite schists), both of which he stated to be more or less equivalent to his Merrimack slates and related to the Huronian as well as the Cambrian but referred doubtfully to the Paleozoic. The relation of Hitchcock's several subdivisions and his petrographic units can not be reconciled with those of the present paper. An attempt is made, however, by means of footnotes in the stratigraphic table to indicate so far as possible the correspondence of his subdivisions.

STRATIGRAPHY.

GENERAL FEATURES.

The region under discussion is a part of the New England coastal lowland, here a belt 10 to 25 miles wide, whose rock surface is abundantly mantled with glacial drift and over broad areas deeply buried under outwash deposits, both terrestrial and marine, of late Pleistocene age.[1] This condition, with the further handicap that the sedimentary rocks so far as known are nonfossiliferous and are metamorphosed to an extent which makes the discovery of fossils improbable, is a considerable hindrance to stratigraphic work. However, over a large part of the region outcrops are found at intervals short enough for positive correlation on the basis of pronounced lithologic characteristics, and furthermore, although the structure is complex in detail, the region shows a dominant and simple major structure—that of elongated folds on approximately parallel northeast axes—which is of assistance in tracing and correlating stratigraphic units. The rocks include (1) an assemblage of more or less severely deformed and metamorphosed sediments, with which are associated some volcanic materials, and (2) a number of types of intrusive rocks, some of which also are metamorphosed. None of the rocks have been sufficiently altered by mashing and recrystallization to lose their original character completely.

The differentiation of the sedimentary formations and their classification and mapping have been based upon recognition of a general and characteristic lithologic facies for each formation, upon careful consideration of their petrographic similarities and differences, upon cautious use of character and degrees of deformation and metamorphism as criteria, and upon areal distribution as interpreted in the light of distinguishable structure. Thus eight cartographic units have been recognized. The igneous rocks are roughly grouped by means of their obvious petrographic features, areal distribution, and relation to the sediments. The resulting classification of the rocks and their stratigraphic relations and equivalences are shown in the accompanying table.

The map (Pl. LXI), on account of its small scale and the lack of precise data in a large part of the area, is very much generalized as to position and minor features of the formation boundaries. Because of lack of outcrops the following parts are wholly arbitrary and inferential: The southwest termination of the Towow formation in Lebanon, Maine; the approximately north-south line which bounds part of the Berwick gneiss and cuts off the Carboniferous rocks in Rollinsford and Somersworth, N. H.; and the line between the Casco Bay group and the Kittery quartzite in Biddeford and Saco, Maine. The igneous rocks are represented as continuous over some areas, and their boundaries are drawn with solid and smooth lines where they have most irregular outlines and partly or wholly include large blocks of sediments. Furthermore, the relations of formations at contacts, whether of intrusion, faulting, conformable succession, or otherwise, are nowhere indicated by the character of the lines on the map. With these exceptions, however, the map is presented with considerable assurance that it conforms generally with the facts.

SEDIMENTARY ROCKS.

PRE-CARBONIFEROUS ROCKS.

BERWICK GNEISS.

The Berwick gneiss, named from the town of Berwick, Maine, occupies a continuous belt in the central and northeastern parts of the region here discussed and extends both northeast and southwest for undetermined distances. The

[1] Katz, F. J., and Keith, Arthur, The Newington moraine, Maine N. H., and Mass.: U. S. Geol. Survey Prof. Paper 108, pp. 11-29, 1917 (Prof. Paper 108-B).

Formations in southwestern Maine and southeastern New Hampshire.

	Sedimentary rocks.				Igneous rocks.
				Triassic.	Gabbro, diabase, and other dikes.
				Post-Carboniferous.	Gneissoid biotite-muscovite granites and pegmatites in Milton, Lebanon, Acton, Sanford, etc. Biotite granites in Lyman, Alfred, Dayton, and Rochester. The assemblage in Mount Agamenticus; biotite granites, gabbros, and other differentiates in Wells, South Berwick, and York. *Biddeford granite:* Medium-grained biotite granite and pegmatite in Biddeford, Kennebunk, etc. *Exeter diorite:* Fine to medium grained light-gray diorite in Rollinsford, Dover, Newmarket, Exeter, etc. Medium to coarse, partly gneissoid diorite in Saco.
Carboniferous (Pennsylvanian(?)).	*Casco Bay group:*[a] *Mackworth slate:* Quartzites and quartz slates, 200 feet (?). *Jewell phyllite:*[b] Siliceous and argillaceous slates and phyllites, 500 feet (?). *Spurwink limestone:* Limestone and phyllites, 200 feet (?). *Scarboro phyllite:* Black and gray argillaceous phyllite, 200–600 feet. *Diamond Island slate:* Black carbonaceous quartz slate, 75–150 feet. *Spring Point greenstone:* Hornblende schists, etc., 0–600 feet. *Cape Elizabeth formation:* Graywacke, siliceous slates, and argillaceous slates and phyllites, 600 feet (?). *Kittery quartzite:*[f] Quartzite, argillite, slate, and schist, 1,500 feet (?).	*Eliot slate:*[c] Gray slates, calcareous argillite (lydite), and black phyllite.	*Towow formation:* Black carbonaceous quartz slate and phyllite, 200–300 feet (?). *Rindgemere formation:*[d] Dark-gray carbonaceous phyllites, slates, graywacke, and quartzite, 1,000 feet (?). *Gonic formation:*[e] Graywacke schists, mica schists, and phyllites, 500 feet (?).	Late Carboniferous (?).	Basic dikes. *Cushing granodiorite:* Fine-grained porphyritic gneissoid granodiorite.
Pre-Carboniferous.	Quartzites with rhyolite flows and tuffs; slates, schists, and hornblende schists; quartzite and graywacke gneisses of Algonkian (?) age.[g]			Unknown (probably pre-Carboniferous).	White (tourmalinic) pegmatites. Fine-grained muscovite granites. Coarse biotite granites, augen gneiss. Fine-grained diorite, etc.
				Unknown (post-Berwick).	*Westbrook granite and Falmouth pegmatite:* Gneissoid biotite granite and white tourmaline-garnet pegmatite.
	Berwick gneiss:[h] Graywacke gneisses and schists and quartzite.				

[a] C. H. Hitchcock's Huronian and Cambrian in the vicinity of Portland, except as indicated in note [b].
[b] Part of this formation in Saco is C. H. Hitchcock's Cambrian slate.
[c] Included in C. H. Hitchcock's Merrimack slates.
[d] Approximately equivalent to C. H. Hitchcock's Kearsarge group in the vicinity of Rochester (a part of his Huronian and Cambrian or Paleozoic?).
[e] Included in C. H. Hitchcock's Rockingham schist (a part of his Huronian and Cambrian or Paleozoic?).
[f] Included in C. H. Hitchcock's Merrimack slates and Rockingham schist (a part of his Huronian and Cambrian or Paleozoic?).
[g] Included in C. H. Hitchcock's Merrimack slates.
[h] That part in New Hampshire and York County, Maine, placed by C. H. Hitchcock in his Merrimack slates and Rockingham schist (a part of his Huronian and Cambrian or Paleozoic?); that in the Portland region partly in his Laurentian or Azoic and partly in his Coos group or Paleozoic.

belt ranges in width from 2½ miles at the southwest, on the west side of the Dover quadrangle, to at least 9 miles at the northeast, where it occupies the northwest corner of the Casco Bay quadrangle, the northwest half of the Portland quadrangle, and the east half of the Buxton quadrangle.

The formation is composed chiefly of graywacke gneiss but contains also clean quartzites, micaceous quartzites, mica schist, and argillite schist and slate. The beds range from about an inch to a few feet in thickness. Almost all the rocks are moderately fine grained and delicately banded. Their colors are medium to dark gray, bluish gray, and brown. In the Portland quadrangle a few layers, 1 to 3 inches thick, of light-blue and white crystalline limestone have been found. The most abundant and characteristic rocks are moderately fine grained banded gray and bluish-gray graywacke or quartz-feldspar-biotite gneiss and micaceous quartzite. The formation is marked by a high degree of crystallinity, by an abundance of metamorphically developed biotite, and in places by actinolite in graywacke and quartzite. Many of the beds are flecked with metacrysts of black biotite. The most distinctively characteristic alteration is a recrystallization of the graywacke into nonfoliate diorite-like aggregates which contain chiefly quartz, feldspar, and hornblende and in some places also garnet and which have the form of seam selvages or bands, lenses, and small spheroidal and irregular patches. On the northwest end of the belt, in parts of the Buxton, Portland, and Casco Bay quadrangles and farther north, where this formation is heavily injected by granite and pegmatite, it is metamorphosed to wholly crystalline quartz-biotite and quartz-feldspar-biotite gneisses of fine to medium grain.

The thickness of the Berwick gneiss is not determinable.

From the prevailing northeast strikes, which range, however, from nearly north to nearly east, with dips generally moderate to steep toward the northwest but in some places steep toward the southeast, and from intricate crumpling and close folding on northeasterly axes discernible only in some exposures of thin-bedded members, the Berwick gneiss is inferred to be closely folded and overturned toward the southeast on approximate parallel northeasterly axes. In very small areas a few wide departures from the prevailing attitude indicate local intricacies in structure.

Along its southeast border the Berwick gneiss within this region is in contact with the Casco Bay group, with the partly equivalent slates in Dover, Madbury, and Lee, and with the Kittery quartzite. Its north and northwest boundaries have not been determined except in the Dover, Berwick, and Kennebunkport quadrangles, where it is adjoined on the northwest by the Gonic formation. Several bodies of massive granitic and dioritic rocks are intrusive in the Berwick and also cut younger formations. In the northwestern part of the region there are bodies of intrusive gneissic granite and pegmatite, which are restricted to the area of the Berwick. Its greater deformation and more complex structure, its notably greater metamorphism, and the presence in it of deformed intrusives not known to invade other formations show that the Berwick gneiss is older than the sedimentary formations which adjoin it. Evidence is lacking to determine whether the juxtapositions are due to unconformity or to faulting. There are also no data on the relative stratigraphic positions of the Berwick gneiss and the other pre-Carboniferous sediments. The age of the Berwick gneiss is unknown.

ALGONKIAN (?) COMPLEX.

In the southeastern part of the region a greatly metamorphosed crystalline complex occupies a belt 1½ to 4½ miles wide trending northeast to east-northeast along the coast in Gerrish Island, Maine, the islands in the mouth of Piscataqua River, New Castle, and Rye, and parts of Portsmouth, North Hampton, and Greenland, N. H. Among the stratiform rocks of this complex there have been recognized fine-grained gray and whitish quartzites associated with rhyolite flows and breccias, seemingly overlying dark-colored banded slate and schist, including abundant hornblendic schist, which in turn appear to overlie medium to coarse grained micaceous quartzite and graywacke. In these rocks the cleavage is almost uniformly vertical or has a very steep dip; it seems to be parallel to the bedding wherever that is discernible, and the strike of both cleavage and bedding swings from northeast on the south end of the belt to nearly east on the north end. All these rocks are intruded by large masses and interleaved with layers of a variety of granitic and some dioritic rocks, which are generally deformed and more or less foliated.

The stratiform rocks of this complex lie in the general trend of the belt of outcrops of presumed pre-Cambrian (Algonkian?) formations, the Westboro quartzite and Marlboro formation of eastern Massachusetts,[1] and are very probably counterparts of those formations. The areal relations and the similarities [2] in lithology and association of the rocks in Rye and Portsmouth, N. H., to those of the Algonkian(?) in eastern Massachusetts afford the basis for tentative assignment of these rocks in Maine and New Hampshire to the Algonkian.

CARBONIFEROUS ROCKS.

KITTERY QUARTZITE.

The Kittery quartzite, named from the town of Kittery, Maine, in which typical exposures abound, occupies a 45-mile belt from Exeter, N. H., to Saco, Maine. This belt is 7 to 13 miles wide and lies along the coast, except for about 11 miles in the southeastern part, in Kittery, Portsmouth, Greenland, Rye, and North Hampton, where pre-Carboniferous rocks intervene, and thence continues inland southwestward beyond the region here considered. Within this belt, especially along the coast, the exposures of the quartzite are practically continuous, being interrupted only by two very large and several small areas of granitic rocks and an area of slate described on pages 169–170. Within the granite areas, particularly along their coastward sides, are many inclusions and large engulfed blocks of Kittery quartzite, which assist in establishing the continuity of the formation.

This formation consists of banded flinty and vitreous quartzites, subordinate amounts of argillitic and micaceous quartzites, some argillite, and very thin beds of micaceous slate and schist. All these rocks are very fine grained. The formation is characteristically thin bedded, few of the beds exceeding 2 feet in thickness, and the thicker beds are generally marked parallel to the bedding by thin layers of different colors. The most striking feature of the formation is a fine interbanding of various tones of dark gray, bluish, chocolate-brown, and black with a little light gray and white. On weathered surfaces there is an equally characteristic and more pronounced interbanding of white, drab, green, blue, and chocolate-brown. The dark-gray and brownish beds in particular are in many places banded, mottled, and intricately patterned in drab shades as the result of leaching and silicification, and argillitic beds are commonly dotted with small variously colored spots. The Kittery quartzite is only slightly metamorphosed; except in relatively few included thin beds of micaceous schist, recrystallization and foliation are weakly developed.

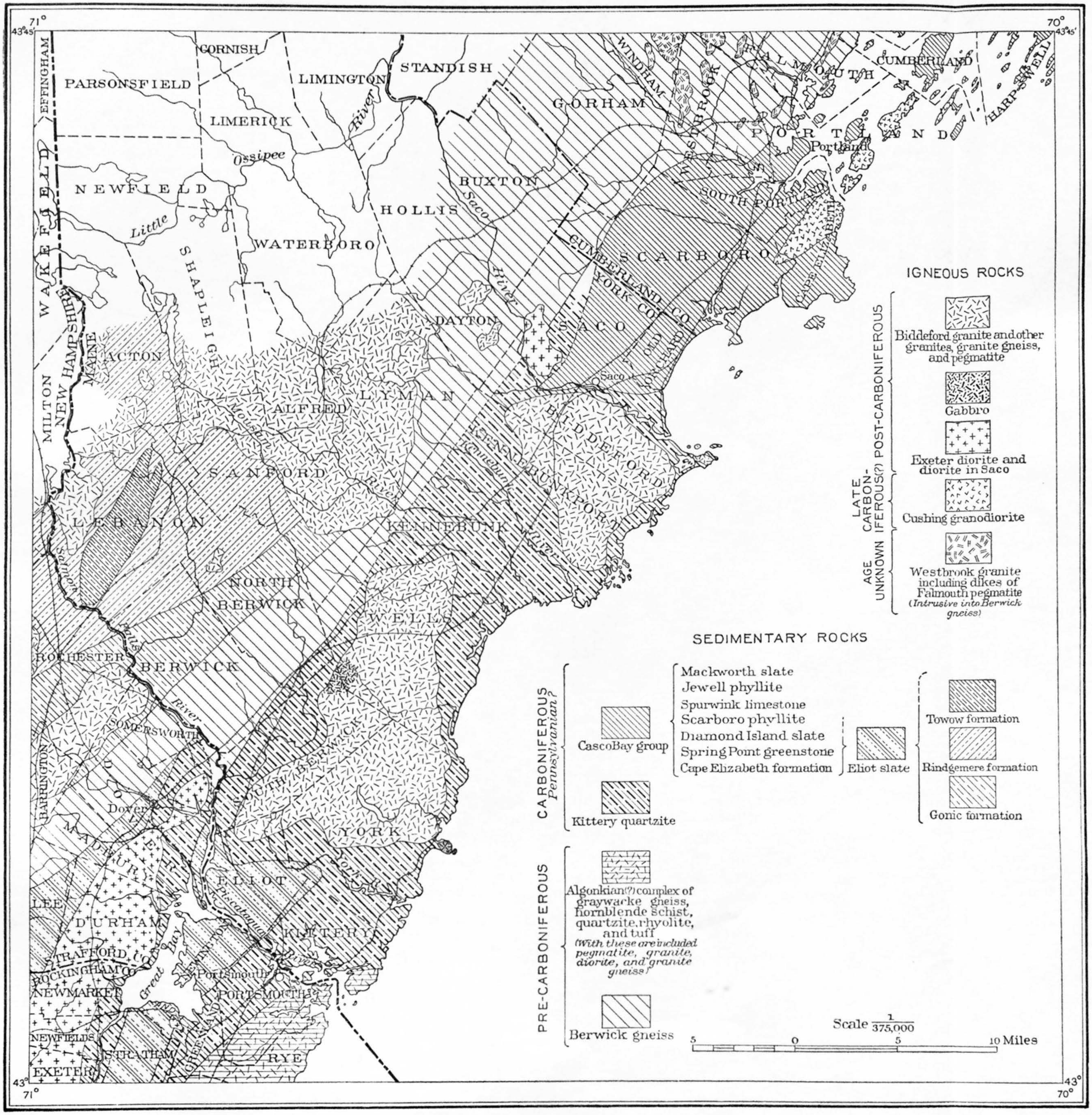
Several exposures of the Kittery quartzite show that it has been folded into a great number of small open to moderately close rolling folds that trend northeast in most places but east-northeast in Kittery and nearly east near Biddeford Pool. Generally, however, the only observable structure is a northeasterly strike and vertical or high dips. Over small areas, notably near Ogunquit, Maine, and thence northward along the coast, and on Fox Point in Newington, N. H., there is considerable irregularity and departure from the normal strike and dips. The few data obtained along the west border of the granite in the Dover quadrangle indicate that the quartzite lies vertically against the granite or dips away from it. A few observations made in Portsmouth and Eliot along the east side of the Eliot slate (see p. 169) indicate that the quartzite dips toward (under) the slate.

No reliable measurement of the thickness of the Kittery quartzite is possible. The best estimate, made at York Harbor, where there is no evidence of repetition of beds, indicates a minimum of 1,500 feet at that place.

The Kittery quartzite is bounded by diorite, granite, and gabbro, which intrude it; by the slate in Eliot, Newington, Dover, Stratham, and Exeter, and the rocks of the Casco Bay group, which conformably overlie it; along most of its northwest boundary by the Berwick gneiss,

[1] Emerson, B. K., Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597 (in press).

[2] Laurence LaForge, who has examined the rocks in both regions, has in personal communications reported these similarities.



GEOLOGIC SKETCH MAP OF SOUTHWESTERN MAINE AND SOUTHEASTERN NEW HAMPSHIRE.

against which it is either faulted or is in unconformable superposition; and by the other pre-Carboniferous sediments, with which its relations are unknown. The intrusive contacts are exhibited and conclusively established in several exposures. The conformable relation of the overlying slate in Eliot and elsewhere is inferred from two facts—(1) the greater abundance of argillite in the Kittery quartzite near the exposures of Eliot slate in Eliot Neck and in the vicinity of York River, which suggests transition of lithologic character from one to the other, and (2) the areal distribution and the apparent attitude of the quartzite with relation to the slate. The quartzite surrounds the slate with approximately parallel strike and seems to dip toward it. The areal distribution of the quartzite and slate with respect to the granitic masses—that of successive surrounding belts—also indicates the same relation. (See map, Pl. LXI.) For similar reasons the rocks of the Casco Bay group are inferred to overlie the Kittery quartzite, probably conformably, because the basal formations of that group are probably equivalent to the Eliot slate. According to Mr. LaForge, outcrops across the Newburyport and Haverhill quadrangles, Mass., indicate that the belt of Kittery quartzite and overlying slate extends southwestward to Merrimack River and is continuous with the Carboniferous Merrimack quartzite.[1] The quartzite facies in the vicinity of Lowell, Mass., and in Kittery, Maine, are lithologically identical, but the Merrimack quartzite as defined and mapped in the work cited includes some slate and phyllite, which are very probably equivalent to those in the Eliot slate. By correlation with the Merrimack quartzite, the Kittery quartzite and overlying slate are assigned to the Carboniferous period.

ELIOT SLATE.

The Eliot slate, named from the town of Eliot, Maine, occupies two parallel belts trending southwest through about 13 miles—one in Eliot and Kittery, Maine, and extending thence through Dover and Newington into Stratham and Exeter, N. H.; the other in Dover, Madbury, Durham, and Lee, N. H. Both extend southwestward for undetermined distances beyond the limits of the region here considered. These belts are 2 to 5 miles and half a mile to 3 miles wide, respectively, and are separated by a 3 to 5 mile belt of Kittery quartzite and intruded diorite.

The rocks of both belts are identical in all respects, comprising an assemblage of gray sericitic and siliceous sericitic slates; beds of light-gray and drab argillo-quartzitic rocks, some of which are also calcareous; thin laminae of light-bluish limestone; and thin layers of black carbonaceous sericite phyllite. Almost the whole formation is uniformly fine grained and thin bedded. In the central part of the eastern belt, and presumably at the highest horizons in the formation, the black sericite phyllite layers are more abundant and thicker than elsewhere.

The thickness of the Eliot slate is not determinable; there are no formations overlying it, and its top may be absent.

The Eliot slate has the appearance of greater deformation and schistosity than the Kittery quartzite, but this appearance is due to the fact that the formation is predominantly thin bedded and argillaceous; deformation has produced about the same degree of metamorphism in the Eliot slate as in the similar thin-bedded argillaceous rocks in the Kittery quartzite. The Eliot slate is somewhat less deformed structurally and less well recrystallized than the Casco Bay group.

Where discernible the strike of the bedding of the Eliot slate is almost uniformly northeast and the dip vertical or very high to the northwest; small folds pitch gently southwest. In a few areas there are easterly strikes indicating local folds. The structure of the eastern belt is inferred to be synclinal, the slate being infolded in the Kittery quartzite, as indicated in the discussion of that formation.

The Eliot slate is in contact with the Berwick gneiss along a straight northeastward-trending boundary of unknown structural significance; with a diorite by which it is intruded in Dover and Exeter, N. H., and intervening towns; and with the Kittery quartzite, which it overlies conformably. It is therefore of Carboniferous age. The Eliot slate is correlated with the lower part of the Casco Bay group, more particularly with the Cape Elizabeth formation, on the basis of very close lithologic similarity, expressed not only in the colors, texture, and composition of the various rocks but also roughly in the proportions of each and the manner of inter-

[1] Emerson, B. K., op. cit.

lamination of the thin layers of black phyllite and calcareous beds. There is, however, a greater abundance of black phyllite in the upper part of the Eliot slate, which gives it an approach in character to the Scarboro portion of the Casco Bay group. Hence the Eliot slate does not appear to be precisely equivalent to the Cape Elizabeth formation but may represent also a part of the Scarboro phyllite. It is therefore given a separate name.

CASCO BAY GROUP.

General features.—The Casco Bay group derives its name from Casco Bay, Maine, in and around which its parts are well developed. The rocks of the group are limited in their distribution to the northeastern part of the region here considered, where they occupy a compact area about 30 miles long and 12 miles wide, including the extreme northeast corner of the Kennebunk quadrangle, the north edge of the Biddeford quadrangle, the southeast half of the Portland quadrangle, and all but the northwest corner of the Casco Bay quadrangle. From the central part of this area is excluded a strip, occupied by intrusive granodiorite, some 16 miles long and as much as 3 miles wide, in Cape Elizabeth and the central islands of Casco Bay.

The Casco Bay group has an aggregate thickness of 1,500 to 2,000 feet and consists of slate, phyllite, and schist, dominantly of argillaceous origin; siliceous slate, graywacke, and quartzite; calcareous beds; and some greenstone and associated schist, probably of volcanic origin. These rocks are divided into seven formations, as described below.

Cape Elizabeth formation.—The Cape Elizabeth formation, the lowest unit in the Casco Bay group, is named from Cape Elizabeth, Maine, where it is best and most completely exposed. The formation crops out in many other places throughout the area occupied by the Casco Bay group. The Cape Elizabeth formation is an assemblage of mostly thin-bedded light-gray siliceous and sericitic slates, heavier beds of graywacke slate, schist, and quartzite, and it contains at short intervals thin layers or laminae of black micaceous phyllite and light-bluish calcareous schist or slate. Near High Head, on Cape Elizabeth, the lowest exposed parts contain about 10 feet of massive drab graywacke or quartzite, succeeded by 12 to 15 feet of gray slate and sericite phyllite, with calcareous laminae, followed by about the same thickness of gray sericite-quartz phyllite containing thin layers of blackish phyllite. Above these are thin layers of fine gray sericite-quartz slate interbedded with coarse-grained graywacke slate in beds 1 to 2 inches thick. These beds are succeeded by a considerable thickness (not measurable) made up chiefly of gray sericite slate and schist, which are finer grained, darker colored, and more micaceous toward the top. In other localities the formation contains beds of gneissic micaceous (biotite) quartzite, 1 to 3 or 4 feet thick; garnetiferous mica schist; and finely intermingled micaceous and siliceous schists. The thickness of the Cape Elizabeth formation is difficult to estimate but seems to be about 600 feet, which is sufficient to account for all exposures, for although they cover large areas the dips are in the aggregate very low.

Spring Point greenstone.—The Spring Point greenstone, which lies above the Cape Elizabeth formation, is named from Spring Point, South Portland, Maine. It is made up of gray to dark-green actinolite schist, in part thoroughly schistose and in part somewhat massive; chloritic schists; and some schistose rocks that still show their original coarsely and irregularly fragmental texture and contain secondary felts of small actinolite needles and small blebs of blue quartz. In composition and texture the more massive phases resemble moderately mafic igneous rocks and the schistose fragmental varieties resemble tuff, agglomerate, or flow breccia. The formation is very probably volcanic material locally but conformably intercalated between the Cape Elizabeth formation and the Diamond Island slate. Its distribution is not so wide as that of the other formations—that is, it is not found in all places where its horizon is exposed but chiefly only in the central part of the Portland region in parts of Portland, South Portland, Cape Elizabeth, and southeastern Scarboro. Its thickness is irregular but attains a maximum of probably 600 feet.

Diamond Island slate.—The Diamond Island slate is named from Great Diamond Island and Little Diamond Island, in Casco Bay, where it is typically exposed. It conformably overlies the Spring Point greenstone but is more extensive than that formation and also overlies directly the Cape Elizabeth formation in the northeastern part of Casco Bay and in the southern part of Cape Elizabeth Township. The Diamond Island slate seems to be continuously developed in a tract $6\frac{1}{2}$ miles wide and 18 miles long within the region examined and to extend for an undetermined distance northeast; but the formation is not known and is seemingly not developed at its horizon in Richmond Island and in the western part of the area occupied by the Casco Bay group. The formation is made up in major part of a black pyritiferous, graphitic, and slightly micaceous quartz slate of very fine grain and in lesser part of a black or bluish-black, somewhat graphitic and also pyritiferous quartz-sericite phyllite. The rock is characteristically black and studded with small masses and crystals of pyrite, which weather out on the surface of exposures and give rise to abundant copperas and rust coatings. Equally characteristic of the Diamond Island slate are intricate crumpling on a small scale and an abundance of small crumpled quartz veins. Estimates based on width of outcrops where the beds are vertical indicate a thickness between 75 and 150 feet.

Scarboro phyllite.—The Scarboro phyllite takes its name from the town of Scarboro, Maine, in which it crops out abundantly, particularly in the vicinity of Scarboro Beach, where the several phases of the phyllite are exposed. The Scarboro phyllite overlies the Diamond Island slate and the Cape Elizabeth formation. It consists of uniformly fine-grained sericite phyllite, for the most part dark bluish gray to black from the presence of biotite and carbonaceous matter, but locally light gray and white in the upper half of the formation. The rocks are typically not siliceous. They are in places somewhat garnetiferous, and the dark-colored parts are in general heavily impregnated with pyrite. The presence of vein quartz in chunky lenticles and irregularly contorted seams is characteristic, as are also knobby and undulatory rather than plane cleavage surfaces. Estimates of thickness based on width of outcrops of vertical beds indicate 200 to 600 feet.

The Scarboro phyllite and Diamond Island slate are connected by rocks of intermediate and transitional lithologic type. In some sections both formations are present, the slate at the bottom; in other sections, in western Scarboro, Old Orchard, and Saco, the slate is absent. The phyllite is thus more widely distributed than the slate and may be regarded as overlapping on the Cape Elizabeth formation because of local failure of deposition of the Diamond Island slate or a change from siliceous (Diamond Island) to argillaceous (Scarboro) sedimentation.

Spurwink limestone.—The Spurwink limestone conformably overlies the Scarboro phyllite. It is named from Spurwink River, in Scarboro and Cape Elizabeth, Maine, where it crops out. The formation is exposed in the eastern and southern parts of the Portland region but is probably also present under a heavy drift cover in the western part. It is composed of thin interlaminated lenses of fine-grained white and light-bluish crystalline limestone, fine-grained dark-gray calcareous mica schist, and fine gray siliceous mica phyllite. The layers of pure limestone which predominate in the lower and middle parts of the formation are from a small fraction of an inch to 2 or 3 inches thick. The gray phyllite bands of similar thickness are more abundant in the higher than in the lower parts and seem to dominate in the upper 50 feet. The formation is pyritiferous, in places richly so. Weathering produces ribbed and rugose surfaces on the ledges and reddish soils. Deformation has developed a characteristic intermingling of the fragments of disrupted limestone beds with the laminae of phyllite and slate. The Spurwink limestone is about 200 feet thick.

Jewell phyllite.—The Jewell phyllite conformably overlies the Spurwink limestone. It is named from Jewell Island, in Casco Bay, and is geographically coextensive with the Casco Bay group as mapped. The formation is an assemblage of alternating gray and bluish to black fine-grained sericite phyllites in thin beds (a few inches to a few feet thick) containing also interbedded gray siliceous slate and very thin layers of quartzite. In some places the formation is dominantly light colored; in others it is dark, resembling the black phase of the Scarboro phyllite. It is also like that formation in that its dark-colored parts are in some places heavily impregnated with small grains and crystals of pyrite. However, the Jewell phyllite is distinguished by the dominance of very fine grained medium-gray phyllite of silky luster and by the abundance in this rock of metacrysts, chiefly of garnet, but including ottrelite, staurolite, magnetite, and other minerals, which commonly range from those of minutely microscopic size to some measuring an eighth of an inch. In some places crystals of ottrelite and andalusite (?) an inch in length are abundant.

No reliable measurement of the thickness of the Jewell phyllite is possible in view of the crumpling and repetition of the beds, but 500 feet seems more than ample to account for all the outcrops, and the actual thickness may be much less than that.

Mackworth slate.—The Mackworth slate, named from Mackworth Island, Casco Bay, probably overlies the Jewell phyllite conformably. It is the uppermost formation of the Casco Bay group and is known only in and around the northern and northeastern parts of of Casco Bay. The formation is composed of quartzite and quartz-chlorite-mica slate in beds ranging from less than an inch to 2 or 3 feet in thickness. The rocks are dominantly siliceous and laminated and are characterized by abrupt alternations in lithologic character from flinty to chloritic slate. In color they range from white through drabs and light grays to dark grays and browns. Probably a thickness of 100 feet is shown by the several exposures in and around Casco Bay. The top and whole thickness of the formation are unknown.

Relations of the Casco Bay group.—The metamorphism of the Casco Bay group is moderate and of the regional or dynamic type. It has resulted from the complex folding and intricate plication of its weaker members. All its parts except the nearly pure quartzitic beds are thoroughly deformed, recrystallized, and foliate.

In structure the Casco Bay group is as a whole synclinal, with a slight northeasterly pitch at the southwest end. In the longitude of Portland at least three secondary anticlines and two synclines are indicated, in which all the formations are involved, and throughout the area there are many series of parallel minor folds that pitch northeast or southwest and involve one or several formations.

The area mapped as occupied by the Casco Bay group is bordered on the south and southwest by an area of Kittery quartzite and on the northwest by the Berwick gneiss. On the south and southwest the Cape Elizabeth formation, the lowest one of the group, approaches but is not in visible contact with the Kittery quartzite and the Berwick gneiss. Farther northeast the Jewell phyllite and Mackworth slate are the areally marginal members of the Casco Bay group and closely approach the Berwick gneiss. The relation to the Berwick gneiss thus indicated is structural or stratigraphic discordance (fault or overlap). By correlation of the Cape Elizabeth formation with the Eliot slate the conformable superposition of the Casco Bay group on the Kittery quartzite is indicated. This inference is supported by the structure in the southwestern part of the area occupied by the Casco Bay group, where the rocks lie in a northeastward-pitching syncline and where the surrounding quartzite strikes east on the south side and northeast on the northwest side of this syncline. The age of the Casco Bay group is therefore Carboniferous.

GONIC FORMATION.

The Gonic formation, named from the village of Gonic, N. H., near which it is exposed, occupies a southwesterly belt 2 to 6 miles wide and 18 miles long from Sanford, Maine, to Barrington, N. H.

This formation is made up of arenaceous (graywacke) and argillaceous materials, metamorphosed to schist and phyllite, which are for the most part rather thin bedded, fine grained, and whitish or light gray to dark gray. The rocks include mica schist and phyllite and interbedded fine to medium grained micaceous graywacke schists in beds as much as 2 feet thick; fine-grained light and dark gray phyllites abundantly studded with dark staurolite crystals, some minute, others an inch or more long, or with red or brown garnets, commonly in dodecahedrons about one-eighth to one-fourth inch in diameter, or with both minerals; and a little coarse muscovite schist composed almost wholly of mica and very thin laminae of quartz. The beds of argillaceous origin that have developed into garnetiferous and staurolitic phyllites and mica schist predominate, but the arenaceous beds (graywacke) are prominent.

The metamorphism of the formation is regional or dynamic and has progressed little further and produced only slightly more general crystallinity than in the Casco Bay group. There is no evidence of significant contact metamorphism, although the granitic intrusive masses in the formation are large. The development of garnet and staurolite has no apparent relation to the granite.

The beds of the Gonic formation are in general minutely crumpled, but folding on a large scale is not discernible. The strike is uniformly about northeast and the dip vertical or steep to the northwest. The thickness of the formation is unknown. About 100 to 150 feet of the coarser-grained phyllite and graywacke schist is shown in the hill northwest of Gonic village, and there may be two or three times as much in the rest of the formation.

The Gonic formation is in contact on the southeast with the Berwick gneiss along a seemingly straight line. The inferred relation, on the assumption of greater age of the Berwick, is either fault contact or unconformable overlap. The northwest boundary of the belt of the Gonic formation, as drawn on the map, is a line between outcrops of rocks of dominantly Gonic type on the one side and of Rindgemere type on the other. The Gonic formation is intruded by biotite granite and pegmatite at both ends of the belt here considered.

Discussion of the stratigraphic relations and age of the Gonic formation follows the description of the Rindgemere and Towow formations.

RINDGEMERE FORMATION.

The Rindgemere formation is named from Rindgemere station (East Rochester), N. H., on the Worcester, Nashua & Portland division of the Boston & Maine Railroad, at Salmon Falls River. The formation is exposed in the central and northern parts of the Berwick quadrangle in an area at least 12 miles wide and 15 miles long. On the northeast it is cut off by granite and gneiss in Sanford and Acton, Maine, and it extends southwest from Rochester, N. H., for an undetermined distance beyond the region examined. Within this area it surrounds a belt 3 miles wide by 10 miles long occupied by the Towow formation, described below.

The rocks of the Rindgemere formation are slate, phyllite, and schist derived from somewhat carbonaceous shale and argillite, with subordinate amounts of interbedded argillaceous quartzite, graywacke, and limestone. They are generally thin bedded—few beds exceed 2 feet in thickness—and fine grained. The colors range from white and light gray or bluish in the quartzite, graywacke, and limestone beds to dark bluish, gray, and black in the argillaceous beds. The rock varieties found in this region are light and dark gray micaceous slates and sericite phyllite associated with very fine grained micaceous graywacke schist, all abundantly speckled with small to minute sporadic phenocryst-like minerals; fine-grained gray sericite slate and phyllite which are pyritiferous and studded with chiastolite; interbanded light and dark gray and black carbonaceous quartz-sericite phyllites speckled with biotite flakes and abundantly filled with large crystals of chiastolite in the dark-gray and black bands; coarse mica schist with chiastolite crystals measuring 6 to 8 inches by one-half to three-fourths of an inch; dark-gray ferruginous chiastolite-bearing phyllite with which are interbedded dense quartzite and graywacke; and (in Acton and Shapleigh, Maine) some thin layers of white to bluish crystalline limestone.

Andalusite and chiastolite in large prismatic forms, in places with well-developed "crosses," are abundant in certain beds, notably in Rochester, 1½ miles north of the center of the city, and in East Rochester, N. H., and on the summit and upper east slope of Bauneg Beg Mountain in North Berwick, Maine.

In the central part of the area occupied by the Rindgemere formation, and therefore, because of the structure, toward its top, the fine-grained carbonaceous and argillitic sediments are the most abundant, although thin beds of quartzite and graywacke are present. At South Lebanon, however, very near exposures of the Towow formation, there is a zone of thin-bedded light-gray slate and quartzite. In the outlying parts of the area, as in the northeast corner of Rochester and the eastern part of Lebanon, and therefore near the base of the Rindgemere formation, quartzitic and graywacke beds are dominant; but as a whole the Rindgemere is made up dominantly of argillaceous and somewhat carbonaceous rocks.

The incomplete sections afforded by isolated outcrops provide no basis for a measurement of thickness. Several hundred feet is indicated for each of the different rock facies in East Lebanon, East Rochester, and North Rochester. The aggregate thickness of the formation is therefore considerable and may be about 1,000 feet.

The data on the structure of the Rindgemere formation in the Berwick quadrangle are meager. The observed strikes are, in general, northeast, with high northwest or vertical dip, except between Rochester and West Lebanon, where there is an easterly strike and a lower dip, thus indicating a large major syncline inclosing the elongate oval area of the Towow formation. Another fold of considerable size is suggested by the west-northwest strike and high northwest dip in East Lebanon, and many subordinate folds are shown by crumpling of the beds. Northwest dips in the hill 5 miles north of Rochester suggest that the major syncline may be overturned to the southeast.

The Rindgemere formation surrounds the Towow formation areally and is in contact with the Gonic formation along an approximately straight northeast line on the southeast. The northern, northeastern, and northwestern limits of the Rindgemere have not been determined, because in those directions numerous masses of granite and pegmatite have disrupted and extremely metamorphosed the sediments, so that their delineation is not yet possible. Besides these intrusives on the border of the mapped area of the Rindgemere formation there are granitic intrusives in North Berwick, Maine, and in Rochester, N. H.

Discussion of the stratigraphic relations and age of the Rindgemere formation follows the description of the Towow formation.

TOWOW FORMATION.

The name of the Towow formation is derived from the original name of the first settlement in the town of Lebanon, Maine. The formation has been found only within that town, where it occupies a northeasterly belt about 10 miles long and 2 to 3 miles wide. It is composed of uniformly very fine grained and thin-bedded dark-gray to black carbonaceous or graphitic siliceous slates and sericitic slate or phyllite. Except for some light-gray siliceous sericitic slate in North Lebanon and South Lebanon and for some interbedded layers of light-gray quartzite a few inches thick in South Lebanon, the formation is richly carbonaceous and in places graphitic and is impregnated with pyrite in small individual crystals and lenticular masses. These rocks are lithologically identical with the Diamond Island slate and the black pyritiferous part of the Scarboro phyllite of the Casco Bay group. The light-gray and quartzitic phases of the Towow formation were seen near its contact with the Rindgemere formation and are therefore at the base of the Towow. The top of the Towow formation is presumably not present, and no overlying formations are known.

There is no means of determining the thickness of the part of the formation present in this region, but it seems to be a few hundred feet.

The beds of the Towow formation are severely crumpled, and the formation as a whole is probably intricately folded. Its relation to the Rindgemere formation indicates that the Towow formation here lies in the trough of a large syncline, whose east end is split by a secondary anticline that pitches southwest.

STRATIGRAPHIC RELATIONS AND AGE OF THE GONIC, RINDGEMERE, AND TOWOW FORMATIONS.

The Towow formation is surrounded by the Rindgemere formation, which occupies the area between the Towow and Gonic formations. Between these three formations there are intermediate or transitional phases, and all three show a general lithologic similarity in being dominantly fine grained and thin bedded and containing an abundance of argillaceous material. They are, furthermore, allied by a content of fine carbonaceous matter, inconspicuous in the Gonic formation but increasing to abundance in the Rindgemere formation and to dominance in the Towow formation. They are structurally conformable and show no differences in degree of metamorphism between beds of similar character. For these reasons and, furthermore, because there are no data to indicate the contrary, they are assumed to form a stratigraphically conformable succession, of which the Gonic, on the basis of the structural data present, is the lowest and the Towow the highest.

These formations are assigned to the Carboniferous period and are approximately equivalent to the lower formations of the Casco Bay group—the Cape Elizabeth, Diamond Island, and Scarboro—and so also to the Eliot slate and to the Carboniferous Worcester phyllite in the Worcester Basin, Massachusetts. This correlation rests on the following considerations: (1) The Towow formation and the Diamond Island slate are of identical character. (2) The three groups correspond closely in lithologic facies—that is, all three contain basal thin interbanded gray arenaceous (graywacke) and argillaceous beds with abundant black carbonaceous laminae, succeeded by increasingly argillaceous beds, which in turn are followed by black carbonaceous and pyritiferous siliceous slates and sericite phyllite. Furthermore, the data on the thickness of the several members and formations, though not sufficient to establish close resemblance, nevertheless indicate comparable thicknesses or at least measurements compatible with the argument for correlation. Thus the maximum aggregate thicknesses of the formations compared are about 1,300 and 1,800 feet, of both of which the far larger parts are in the lower arenaceous and gray argillaceous members and much smaller parts in the black carbonaceous slates. (3) Similarity in structure and in type and degree of metamorphism indicate identical history for both. (4) In lithology, deformation, and metamorphism these formations are similar to a formation of Carboniferous age (Worcester phyllite) in the Worcester Basin, described by Emerson.[1] Mr. Keith and Mr. LaForge[2] report that these formations of the Worcester Basin extend northeastward into New Hampshire within 30 miles of Rochester, in a belt trending approximately toward the area of the equivalent Eliot slate. They are on the northwest side of a belt of graywacke and other gneisses that Mr. LaForge[2] reports to be, in part at least, continuous with and equivalent to the Berwick graywacke gneiss, which is in similar relation to the Gonic formation.

IGNEOUS ROCKS.

The relations of the igneous rocks of this region to the surrounding sediments have been determined so far as opportunity for field observation permitted. Very few of the igneous rocks have yet been studied petrographically. The following statements are made merely to point out the areal distribution of the larger associated groups of igneous rocks and to indicate roughly their stratigraphic relations.

Westbrook granite and Falmouth pegmatite.—In Westbrook, Falmouth, and Portland, Maine, granite and pegmatite intrude the Berwick gneiss and, so far as is known, are restricted to the northeast part of the gneiss belt. These rocks are named the Westbrook granite and Falmouth pegmatite, after the towns in which they are well developed and exposed.

The Westbrook granite protrudes through the Berwick gneiss in a number of bodies elongated in northeasterly and northerly directions and ranging in size from those that are very small to some 5 miles or more long and 2 or 3 miles wide. It is a gneissoid granite of medium-gray color and fine, even texture and contains conspicuous crystals of biotite. Its essential components are microcline or orthoclase, quartz, oligoclase, and biotite, named in the order of abundance. Some very small masses of gneissoid granodiorite and diorite are included with the Westbrook granite.

The Falmouth pegmatite occurs as dikes ranging from about an inch to many hundred feet in thickness and from a few feet to 3 or 4 miles in length. They are generally parallel to the northeasterly trend of the gneiss, although some of the smaller dikes transect or irregularly invade the gneiss they intrude. The Falmouth is a normal medium to very coarse grained pegmatite composed of perthitic microcline, quartz, muscovite, and albite, in places carrying abundant crystals of black tourmaline and red garnet. With it is associated a fine-grained white or light-gray garnetiferous aplite. The pegmatite and aplite in many places have diffuse contacts with each other and with the Westbrook granite, indicating transition or intimate relation between them, although the Westbrook granite is cut by the pegmatite and aplite and is very evidently somewhat older. Some of the larger pegmatite dikes in Falmouth have been slightly crushed.

The age of the Westbrook granite and Falmouth pegmatite is post-Berwick and presumably pre-Carboniferous, because they are not known to intrude the near-by rocks of the Casco Bay group.

Igneous rocks of the Algonkian (?) complex.—An assemblage of igneous rocks restricted in distribution to the area of the Algonkian (?) complex includes chiefly several varieties of fine to medium grained, evenly granular and porphyritic pink or buff-colored muscovite granites which are generally free of or deficient in biotite. They are very commonly gneissoid

[1] Emerson, B. K., Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597 (in press).

[2] Personal communications.

in texture. The series also includes fine-grained dark-gray diorite, a gneissoid coarse porphyritic biotite granite (augen gneiss), and a very coarse white feldspar-quartz-muscovite pegmatite which in places contains black tourmaline and some of which is crushed. The small masses of granitic rocks and the pegmatites very closely parallel the trend of the sedimentary bands and are injected along the cleavage. Larger masses are elongate and have the same or approximately the same trend, as the result of injection along the beds or of infolding with them, or probably both.

Except that they are presumably pre-Carboniferous, because they do not invade the Kittery quartzite, the age of these intrusives has not been determined. However, a small body of white or buff fine-grained muscovite granite and aplite that intrudes the Kittery quartzite at Brave Boat Harbor, though not deformed, is otherwise not unlike some of the fine muscovite granites in Rye and New Castle. This rock at Brave Boat Harbor makes the assignment of the similar rocks in Rye and New Castle doubtful.

Cushing granodiorite.—The Cushing granodiorite, named from Cushing Island, in Casco Bay, occupies a single northeasterly belt extending for 16 miles from Scarboro, Maine, across Casco Bay to the northern limit of the region here discussed. It is narrow at its ends and has a maximum width of about 3½ miles. The granodiorite is thoroughly gneissoid, of light to dark gray color, and for the most part finely and evenly but only slightly porphyritic in texture. Its principal components are albite-oligoclase as phenocrysts and quartz, feldspar, biotite, and hornblende in the groundmass. Muscovite or sericite, probably all of secondary origin, is abundant, but in proportions differing from place to place. Along part of the northwest border there is a white aplite-like facies. In places toward the southwest end of the belt the granodiorite is dark gray, very biotitic, and richer in hornblende than elsewhere. At the northeast end it is very light gray and deficient in biotite.

The Cushing granodiorite is infolded in and deformed with the rocks of the Casco Bay group. It is known to be in contact chiefly with the Cape Elizabeth formation but also with the Jewell phyllite and rocks doubtfully referred to the Mackworth slate. The visible contacts are so badly mashed and recrystallized that the intrusive nature there indicated is not decisively shown. This nature is, however, further indicated by transgression of the bedding of the formations and by the aplite-like border facies. The Cushing granodiorite, though younger than the Carboniferous Casco Bay group, is not improbably late Carboniferous, because it is older than undeformed post-Carboniferous granite, which in turn is older than supposed Triassic dikes. (See below.)

Altered basic dikes.—A considerable number of small black and dark-green dikes of basic rocks (all less than 10 feet wide) are abundant in the rocks of the Casco Bay group and the Cushing granodiorite. They are now severely altered schistose biotite-hornblende and hornblende-garnet rocks. They may be closely related in age to the Cushing granodiorite.

Diorite in Saco.—The diorite in Saco, Maine, is an irregular elliptical body about 3 miles long and 1½ miles wide. The rock is medium to dark gray, moderately coarse grained, and in some places massive, in others gneissoid; it is composed essentially of orthoclase (?), andesine, hornblende, biotite, and subordinate amounts of quartz. This rock invades the Berwick gneiss and the Kittery quartzite and is therefore post-Carboniferous. An argillaceous quartzite in contact with the diorite is slightly altered to a rock somewhat like hornfels.

Exeter diorite.—The Exeter diorite, in Exeter, Newmarket, Durham, Madbury, Dover, and Rollinsford, N. H., occupies an area 15 miles long and from half a mile to 5 miles wide. The small area of diorite in Greenland, N. H., is a similar and probably related rock. The rock is a generally even, medium-grained light to medium gray hornblende-biotite diorite or quartz diorite, which changes in composition considerably but gradually from place to place. In Newmarket, N. H., both aplitic and basic varieties are present. These dioritic rocks are intrusive in the Kittery quartzite and Eliot slate and are therefore post-Carboniferous.

Biddeford granite.—The Biddeford granite, in Biddeford, Kennebunkport, Kennebunk, and Dayton, Maine, is a generally even or slightly porphyritic medium-grained biotite granite of light-gray or pinkish-buff color, composed of white microcline or orthoclase, quartz, oligoclase, biotite, and in some places also a little muscovite. A few very small dikes of pegmatite and aplite are associated with it. The rock is intrusive in the Kittery quartzite and is post-Carboniferous.

Other granites.—The granitic mass in Wells, York, South Berwick, and Eliot, Maine, is an assemblage, including chiefly a granite of the Biddeford type and several more mafic varieties, probably differentiates, among which are the gabbros of Cape Neddick and South Berwick. These rocks are intrusive into the Kittery quartzite and are of post-Carboniferous age.

The granite in Rochester, Dover, and Barrington is generally a fine or medium and even-grained but in places somewhat porphyritic and moderately coarse grained biotite-muscovite granite containing orthoclase and plagioclase and in places garnetiferous. In it are abundant large bodies of coarse pegmatite, consisting of microcline, quartz, muscovite, and albite.

In North Berwick, Maine, there is a small body of very fine grained muscovite-biotite granite surrounded by and probably intrusive into the Rindgemere formation. It is, therefore, probably post-Carboniferous.

The large area of granitic rocks in Lyman, Alfred, Sanford, and Shapleigh, Maine, contains many included patches of gneiss (metamorphosed sediments) and a variety of granites, the most conspicuous of which are large masses of granite of the Biddeford type; some quartz diorite, composed of oligoclase, biotite, quartz, dark hornblende, and magnetite; and somewhat gneissoid coarse-grained biotite-muscovite granite, with which is associated abundant coarse pegmatite. These rocks are intrusive in the Berwick gneiss and the Gonic and Rindgemere formations and are post-Carboniferous. The assemblage may include also some older but as yet unrecognized granitic rocks.

The areas of granitic rocks in Milton, N. H., and Acton and Lebanon, Maine, shown on the map, are occupied chiefly by medium to coarse grained gneissoid muscovite-biotite granites and coarse pegmatite. Included with these are various other granitic rocks and many patches of metamorphosed sediments.

Trap dikes.—Throughout this region there are large numbers of small to moderately large trap dikes, for the most part of fine-textured gabbroic, diabasic, or doleritic habit. A few of the larger dikes are coarse grained, and many are in part glassy. They have been observed in all the other rocks of the region and many are themselves cut by others. Most if not all of them are younger than the post-Carboniferous granitic intrusives and are tentatively correlated with the Triassic eruptions of Nova Scotia and southwestern New England.

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THE FLAXVILLE GRAVEL AND ITS RELATION TO OTHER TERRACE GRAVELS OF THE NORTHERN GREAT PLAINS

BY

ARTHUR J. COLLIER

AND

W. T. THOM, JR.

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THE FLAXVILLE GRAVEL AND ITS RELATION TO OTHER TERRACE GRAVELS OF THE NORTHERN GREAT PLAINS.

By Arthur J. Collier and W. T. Thom, Jr.

INTRODUCTION.[1]

In Nebraska and South Dakota there are widespread deposits of gravel and other material, largely surficial and generally unindurated, known as the White River, Arikaree, Ogalalla, and other formations,[2] which range in age from Oligocene to Pleistocene. West of these deposits, on the flanks of the Rocky Mountains, are several high plateaus covered with gravel, whose age, though not known, is generally regarded as Pleistocene. At some places the position of this gravel indicates its continuity with the Tertiary formations farther east, but their equivalency has not been proved. It is the purpose of this paper to outline the evidence obtained by the writers in 1915 and 1916 regarding the age of the gravel found on two high terraces in the northern part of the Great Plains and to show its relation to a still higher gravel, known to be of White River age, discovered by Canadian geologists some years ago. Messrs. R. F. Baker, E. T. Conant, and H. R. Bennett were enthusiastic coworkers in collecting this evidence, and to them much of the credit is due.

The area described, as shown in Plate LXII, extends along the south side of the international boundary from Redstone, about 30 miles west of the Montana-North Dakota line, westward to the west side of Boundary Plateau,[3] a distance of 175 miles. It continues northwestward from the plateau far enough to take in the whole of the Cypress Hills, where Canadian geologists have discovered deposits of White River (Oligocene) age.

[1] An abstract of this paper has been published by the Washington Academy of Science.

[2] Osborn, H. F., Cenozoic mammal horizons of western North America: U. S. Geol. Survey Bull. 361, p. 65, fig. 10, 1909.

[3] The name Boundary Plateau was used by McConnell to designate the northern extension of what is called Cherry Ridge on the American side. It is retained in this paper for convenience.

FLAXVILLE GRAVEL.

The Flaxville gravel, named from the town of Flaxville, on the Scobey branch of the Great Northern Railway, was deposited in Miocene or early Pliocene time. The history of its discovery is as follows:

During the field seasons of 1915 and 1916, in the course of an investigation of the lignite resources of northeastern Montana, the writers found some extensive plateaus that are so deeply buried beneath a cap of gravel and kindred materials as to make the location of lignite outcrops impossible. This gravel has been described by several writers under the names "glacial overwash," "quartzite gravel," etc. Bauer[4] had recognized the possible significance of this terrane and had provisionally referred it to the Oligocene of the Cypress Hills.[5]

On the third day in the field the senior writer inquired of Atle Taerum, the proprietor of the store at Avondale, whether in digging his well he had seen any signs of lignite. Being answered in the negative, the writer made a personal examination of the well and found on the dump some fragments of bone said to have been found in sand at a depth of 30 or 40 feet. From this beginning as close an inspection as the circumstances would permit was made of wells and other natural and artificial exposures of the gravel by members of the Geological Survey party. In many places fragments of fossil bones had been found but not preserved, as their significance was not appreciated. D. H. Linton, Hagen Hayenga (postmaster at West Fork), L. T. Greenup, Martin Presnell, Warren Redfield,

[4] Bauer, C. M., Lignite in the vicinity of Plentywood and Scobey, Sheridan County, Mont.: U. S. Geol. Survey Bull. 541, p. 301, 1912.

[5] Cope, E. D., Species from the Oligocene or lower Miocene beds of the Cypress Hills: Canada Geol. Survey Contr. Canadian Paleontology, 1891.

J. A. Stewart, Herman Forbregd, and Prof. L. O. Swenson contributed specimens.

As a result of the search, fragments of fossil bones have been collected from 25 widely distributed localities. These fragments were submitted to Dr. J. W. Gidley, of the United States National Museum, who identified them as representing various forms of the three-toed horse (protohippid, *Protohippus*, *Neohipparion*, and *Merychippus*), horned gopher (mylagaulid), rabbit (*Lepus*), rhinoceros (*Teleoceras*), oreodont (*Merycodus*), camel (*Procamelus*, camelid, and *Camelops*), saber-tooth tiger (machaerodont), doglike animal (amphicyonid), and fish. His full report follows:

F. 1. SE. ¼ sec. 26, T. 34 N., R. 42 E., Atle Taerum's well at Avondale:
  Protohippid (astragalus).

F. 2. Near north side of SW. ¼ sec. 27, T. 34 N., R. 42 E., excavation on land of D. H. Linton, Avondale:
  Protohippid (distal end of radius).
  ?Mylagaulid (proximal half of humerus).
  Lagomorph cf. ?*Lepus* (fragment of maxillary and toe bone).

F. 4. 300 feet southwest of northwest corner sec. 5, T. 35 N., R. 45 E.
  Protohippid (astragalus).
  ?*Procamelus* sp. (phalanx).

F. 5. SW. ¼ NW. ¼ sec. 24, T. 34 N., R. 44 E., Hagen Hayenga's well:
  Neohipparion sp. (part of upper cheek tooth).
  Procamelus sp. (distal end of metapodial).

F. 6. Near West Fork post office, T. 34 N., R. 44 E.:
  ?*Neohipparion* sp. (upper cheek tooth of left side).

F. 7. NW. ¼ SW. ¼ sec. 25, T. 34 N., R. 44 E.:
  Protohippid (fragments).

F. 11. NE. ¼ sec. 31, T. 36 N., R. 45 E., "from gravel and sand resting on top of Fort Union bluff."
  Protohippid cf. *Neohipparion* sp. (astragalus, portion of upper molar, and fragments).
  Camelid cf. *Procamelus* sp. (astragalus, piece of toe bone, and fragments).

F. 13. SW. ¼ sec. 13, T. 34 N., R. 45 E., slope of Taylor-Green prospect:
  Camelid cf. *Procamelus* sp. (distal end of phalanx).

F. 14. Near east quarter corner of sec. 6, T. 34 N., R. 47 E., from well at depth of 28 feet:
  ?Camelid (lumbar vertebral centrum).

F. 15. NE. ¼ sec. 33, T. 35 N., R. 47 E.:
  Mylagaulid (lower molar).

F. 19. Sec. 20, T. 36 N., R. 45 E.:
  Protohippid (fragment of upper molar).
  ?*Procamelus* sp. (phalanx and astragalus).

F. 20. Sec. 15, T. 37 N., R. 44 E.:
  Protohippid (genus and species not determined).

F. 21. SW. ¼ sec. 7, T. 36 N., R. 44 E.:
  Merycodus sp. (fragment of a left lower jaw containing four deciduous premolars).

F. 22. Near center of T. 35 N., R. 41 E.:
  Neohipparion sp.

F. 23. Sec. 12, T. 35 N., R. 41 E., J. A. Stewart's well:
  Protohippid.

F. 26. Sec. 32, T. 36 N., R. 49 E.:
  Protohippid (end of metapodial, fragment of lower molar).

F. 27. Cut of Great Northern Railway a mile west of Flaxville station:
  ?*Teleoceras* sp. or ?*Aphelops* (toe bone and fragments).
  ?*Procamelus* sp. (tooth and toe-bone fragments).
  Protohippid, probably *Neohipparion* sp. (fragment of lower jaw containing teeth, three parts of teeth, astragalus, and fragments).

F. 28. Just south of quarter corner between secs. 28 and 29, T. 35 N., R. 50 E.:
  Protohippus sp. (fragments of teeth).
  Carnivore (?amphicyonid) (fragment of left maxillary containing fangs and alveoli).

F. 29. T. 35 N., R. 50 E., first cut of Great Northern Railway west of Flaxville.
  Neohipparion ?*affine* or n. sp. (upper molar and lower molar possibly belonging to same species).
  Neohipparion sp. (lower molar).
  Procamelus sp. (fragmentary foot bones and teeth).
  ?*Camelops* sp. (large tooth, last right lower molar, wrapped in mud ball). Apparently Pleistocene species.
  Machaerodont, genus and species not determined (metapodial).
  Fish, not determined (lower jaw).

F. 31. Sec. 33, T. 36 N., R. 50 E., 2 miles north of Flaxville:
  Camelid cf. *Procamelus* sp. (portion of posterior molar or left lower jaw).

F. 33. In railroad cut a mile west of Flaxville:
  Protohippid (fragments of jaw, toe, and limb bones).
  Artiodactyl, probably *Merycodus* (single phalanx).

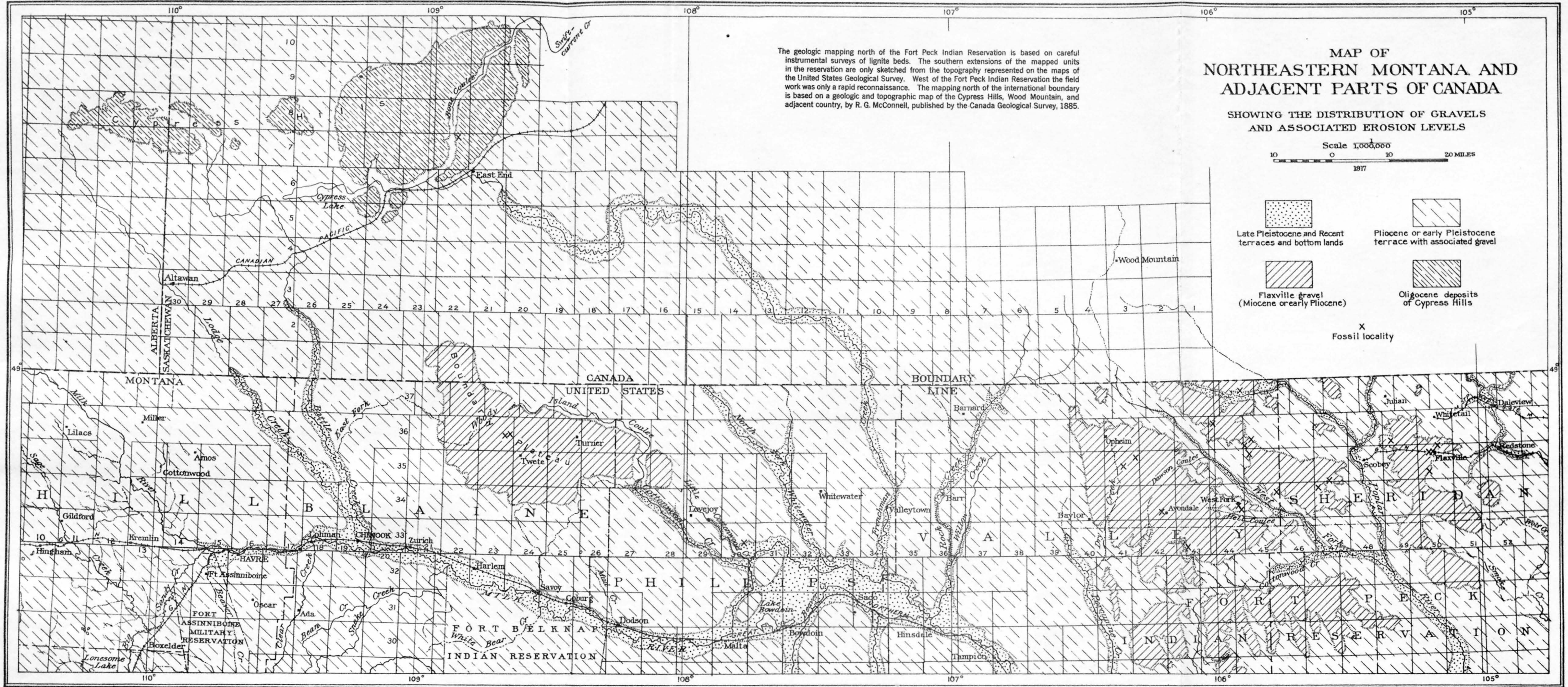
F. 34. Cut of Great Northern Railway a mile west of Flaxville:
  Mylagaulid cf. *Ceratagaulus* sp. (large cheek tooth).
  Protohippid cf. *Neohipparion niobrarensis* (right upper molar).
  Protohippid ?*Neohipparion* sp. (fragments of three upper teeth).

F. 35. Railroad cut a mile west of Flaxville:
  ?*Procamelus* sp. (part of ulna, much broken).

F. 36. Southeastern part of T. 33 N., R. 43 E., collected by W. C. Alden:
  Merychippus sp. (toe bone and fragment of jaw). Certainly one of the Miocene three-toed horses; probably upper Miocene.

F. 37. Sec. 23, T. 36 N., R. 23 E., Prof. Swenson's well:
  ?*Protohippus*, fragments of fossil mammals, one piece recognizable as fragment of upper molar of one of the Miocene horses.

F. 38. Sec. 24, T. 36 N., R. 23 E., Louis Hoff's well:
  ?*Protohippus*, fragments of mammalian remains; among them portion of an upper molar of one of the Miocene horses.



The geologic mapping north of the Fort Peck Indian Reservation is based on careful instrumental surveys of lignite beds. The southern extensions of the mapped units in the reservation are only sketched from the topography represented on the maps of the United States Geological Survey. West of the Fort Peck Indian Reservation the field work was only a rapid reconnaissance. The mapping north of the international boundary is based on a geologic and topographic map of the Cypress Hills, Wood Mountain, and adjacent country, by R. G. McConnell, published by the Canada Geological Survey, 1885.

MAP OF NORTHEASTERN MONTANA AND ADJACENT PARTS OF CANADA

SHOWING THE DISTRIBUTION OF GRAVELS AND ASSOCIATED EROSION LEVELS

Scale $\frac{1}{1,000,000}$

10 0 10 20 MILES

1917

Late Pleistocene and Recent terraces and bottom lands

Pliocene or early Pleistocene terrace with associated gravel

Flaxville gravel (Miocene or early Pliocene)

Oligocene deposits of Cypress Hills

× Fossil locality

Base from U.S. Geological Survey map of Montana and geologic and topographic map of the Cypress Hills, Wood Mountain, and adjacent country by R.G. McConnell, published by the Canada Geological Survey, 1885.

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Mr. Gidley further remarks:

None of the material is sufficiently good or complete to make positive specific determinations, and it is therefore of no value as indicating horizon, except in a broad way. With the exception of the specimen reported as Pleistocene all the material appears to belong to the upper Miocene. It can be stated positively, I think, that with the exception noted, the beds from which these fragments were collected can not be older than Miocene or younger than lower Pliocene.

The formation from which these fossils were collected caps a series of even-topped plateaus ranging in altitude from about 2,600 feet at its east end, a few miles south of Redstone, to 3,200 feet in the west front of the Boundary Plateau in the Cherry Creek quadrangle. It is from a few feet to 100 feet thick and rests upon the eroded surfaces of the Fort Union, Lance, and Bearpaw formations. A characteristic view of the plateau surface is given in Plate LXIII, *A*. In the opinion of the writers this plateau represents an erosional level developed during a period subsequent to the Oligocene as represented in the Cypress Hills, and the fossil-bearing formation must have been deposited in Miocene or early Pliocene time. It seems hardly possible that these fossils could have been eroded and redeposited over so wide an area in the Pleistocene epoch, especially as no source from which they could have come has been recognized. Moreover, there seems to be no intermingling of Pleistocene fossils with the Miocene.

The distribution of the Flaxville gravel is shown on the accompanying map (Pl. LXII). It is generally composed of yellowish to ash-gray gravel, clay, and sand, but in some places it contains beds of white marl and volcanic ash. The gravel consists of well-rounded pebbles from less than an inch to a foot or more in diameter, of quartzite and argillite derived from the Rocky Mountains. Limestone pebbles from the same source may have been dissolved and the lime redeposited as cementing material and beds of marl. The materials composing the Flaxville gravel are mostly noncoherent and are excavated easily by well diggers, though beds of hard sandstone and conglomerate cemented with calcite from 1 foot to several feet thick are encountered in most of the wells. In places the formation is very thoroughly cemented with calcite and forms prominently outcropping ledges of sandstone and conglomerate, as shown in Plate LXIII, *B* and *C*. Many such outcrops present a great deal of cross-bedding and are not continuous over large areas.

In the railway cuts west of Flaxville (see Pl. LXV, *A*), where the best collection of fossils was made, about half the material exposed is gravel and the remainder clay and sand; about 1 foot of marl or concretionary calcite is also present. The bedding is very irregular, as might be expected of deposits on the flood plain of a river. North of Flaxville the road to Whitetail crosses a considerable thickness of gravel. Ten miles southeast of Flaxville, in the escarpment at the edge of a plateau, the formation consists of about 35 feet of cemented sand and gravel overlain by uncemented sand. Northeast of Scobey about 55 feet of more or less cemented sand and gravel is overlain by 25 feet of uncemented gravel and soil. Plate LXIV, *A*, shows a bed of gravel interstratified with sand. The following section of a well southwest of Scobey was given by Martin Presnell, the owner:

Section of a well southwest of Scobey, Mont., in sec. 33, T. 35 N., R. 47 E.

	Ft.	in.
Gravel	6	0
Clay	52	0
Lignite slack		6
Clay	2	0
Lignite slack	1	0
Gravel and bones; water.		
	61	6

In a well 2 miles southwest of the Presnell well 28 feet of coarse gravel, carrying bones, was found. About 20 miles west of Scobey there are several good exposures of the lower 20 feet of the formation, together with the underlying Fort Union. The gravel is uncemented and interstratified with cemented sand, and the surface is strewn with loose gravel containing bone fragments. A very striking exposure of the formation occurs 5 miles west of West Fork post office, south of Hell Coulee, in sec. 30, T. 34 N., R. 44 E., where about 30 feet of hard sandstone showing very marked cross-bedding caps the edge of the plateau. This feature is shown in Plate LXIV, *B*. The sandstone probably rests on gravel, for an exposure of uncemented gravel was found near the bottom of the coulee. In secs. 19, 20, and 29, T. 35 N., R. 43 E., 8 miles northeast of Avondale, south of Dawson Coulee, a slightly different phase is presented, as shown by the following generalized section:

Generalized section of Flaxville gravel in secs. 19, 20, and 29, T. 35 N., R. 43 E.

[Thicknesses approximate.]

	Feet.
Marl, containing a few scattered quartzite pebbles	15
Sandstone cemented with calcite	30
Volcanic ash, white to yellow, very pure but mixed with the underlying gravel at the base	15
Gravel, more or less cemented	20
Fort Union formation.	
	80

The marl (an impure soft white limestone) was either deposited by water flowing over the surface into a shallow pond or gathered from the underlying beds and brought to its present position by percolating waters. Similar occurrences are indicated by fragments of marl in the soil of the townships to the west and north. This is the only locality where pure volcanic ash has been recognized, though similar material mixed with sand has been noted about 12 miles to the northeast. The gravel is very coarse, and well-rounded pebbles at least a foot in diameter, which must have been derived from it, were noted on the surface a short distance away in Dawson Coulee.

On Boundary Plateau in the vicinity of Cherry Ridge 74 feet of sandy gravel overlies 8 feet of cemented sandstone in a well in sec. 10, T. 36 N., R. 23 E., south of which two other wells of somewhat less depth have yielded fragments of fossil bone. The eastern edge of the formation is exposed in Tps. 35 and 36 N., R. 27 E., where it is dissected by Woody Island Coulee; the western edge of the formation along the west escarpment of the Boundary Plateau has been mapped by Stebinger in Tps. 35, 36, and 37 N., R. 21 E., where it consists of cemented sand, gravel, and marl.

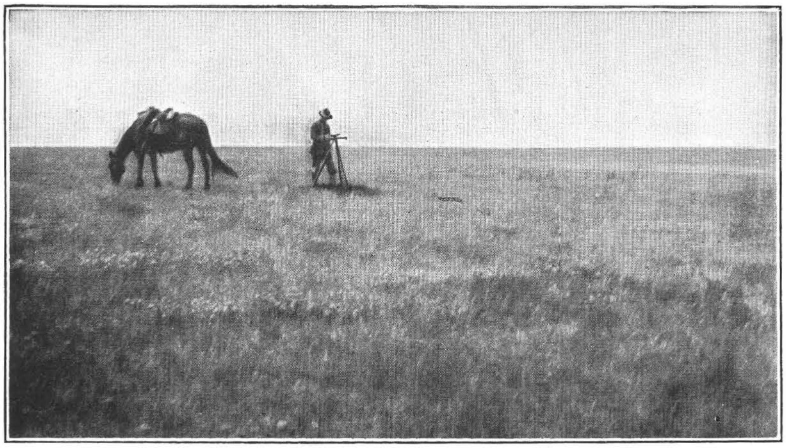
LATE PLIOCENE OR EARLY PLEISTOCENE GRAVEL.

Below the Flaxville level there are extensive areas varying in altitude from 2,500 to 2,800 feet on which the bedrock is exposed or can be found in wells at no very great depth. The relative altitudes of this bedrock surface are indicated on the maps prepared but not yet published by the International Boundary Commission. In the vicinity of Redstone it is a well-marked plateau or bench ranging in altitude from 2,400 to 2,500 feet. This feature extends westward near the international boundary to Scobey (altitude 2,450 feet), at the forks of Poplar River.

Between Opheim and the Boundary Plateau the same period of erosion is represented by a great expanse of highly dissected country including level-topped areas, sloping grass-covered hills, and badlands on which the Bearpaw shale is exposed, ranging in altitude from 2,500 feet near Milk River to 3,000 feet at the international boundary near the crossing of Frenchman Creek. Small bodies of stratified gravel and silt have been noted in sec. 3, T. 36 N., R. 52 E., east of Daleview; in several wells in the neighborhood of Julian; west of Opheim, in sec. 13, T. 37 N., R. 39 E., and west of Baylor, in sec. 25, T. 35 N., R. 38 E. The best exposures seen are in sec. 23, T. 33 N., R. 30 E., north of Malta, a few miles from Milk River, where about 25 feet of interstratified gravel and yellowish silt caps the edge of the bench at an altitude of about 2,500 feet above the sea, or 300 feet above Milk River. The gravel is cemented, presumably with calcite, forming a conglomerate that crops out in the form of a small cliff. Fragments of bone and a single tooth were obtained from the face of the cliff. Dr. Gidley identified the tooth as that of a horse resembling the living species and states that it can not be so old as the Flaxville fauna. The formation here rests upon the Judith River formation, but about 5 miles east of this locality it rests upon the Claggett shale and consists of about 25 feet of yellowish silt containing two beds of gravel, one at its base and another 15 feet higher. The gravel is comparatively fine, the pebbles being less than an inch in diameter. In the light of the evidence now at hand this formation is regarded as of late Pliocene or early Pleistocene age. The erosion of the very extensive areas below the Flaxville level must have been accomplished during middle Pliocene time.

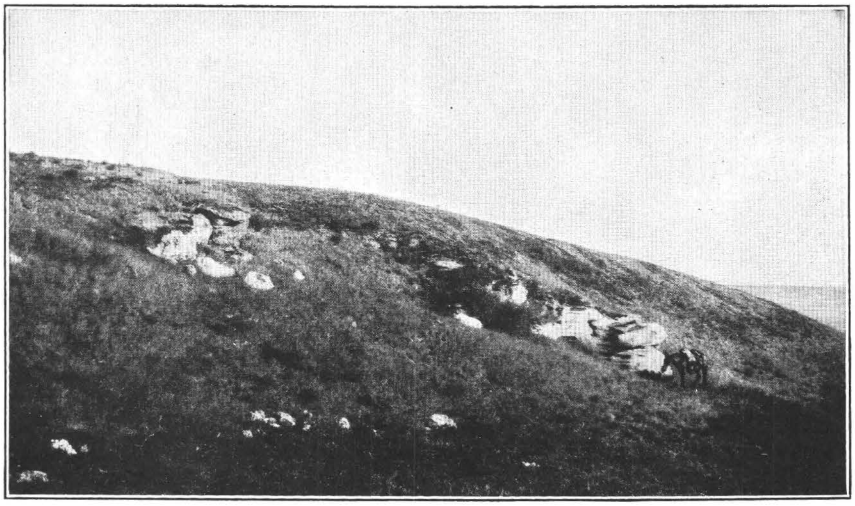
LATE PLEISTOCENE AND RECENT EROSION AND DEPOSITION.

The streams of the region have eroded their valleys from 100 to 500 feet below the level assigned to the late Pliocene or early Pleistocene. Milk River now occupies a valley 1 to 5 miles wide eroded by Missouri River before the last great invasion of ice in the glacial

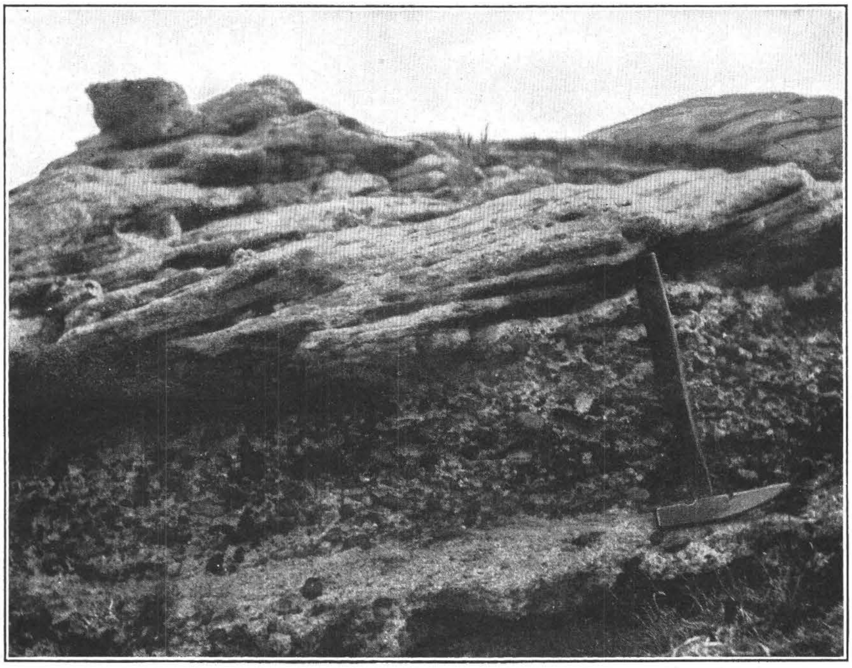


A. SURFACE OF THE FLAXVILLE PLATEAU, NORTHEASTERN MONTANA.

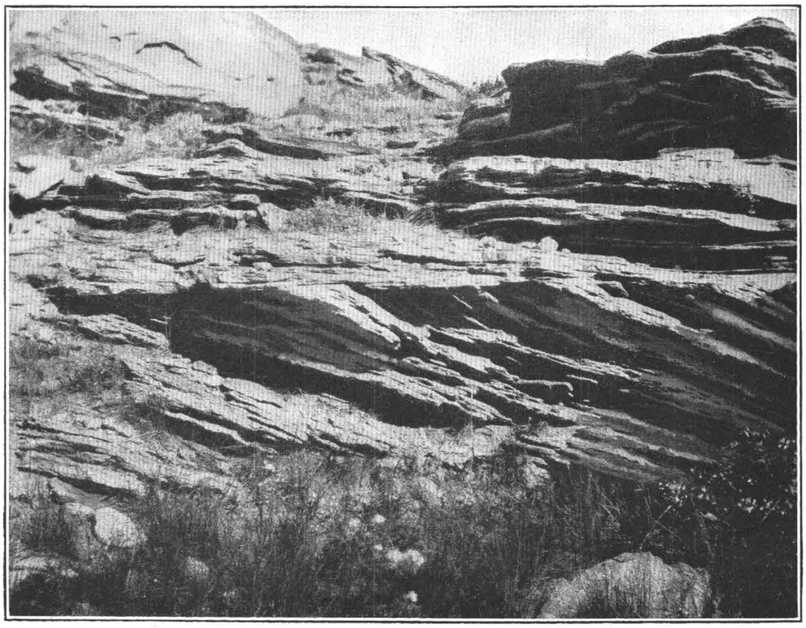
B. OUTCROP OF CEMENTED FLAXVILLE GRAVEL IN ESCARPMENT OF PLATEAU NORTHWEST OF OPHEIM, MONT.



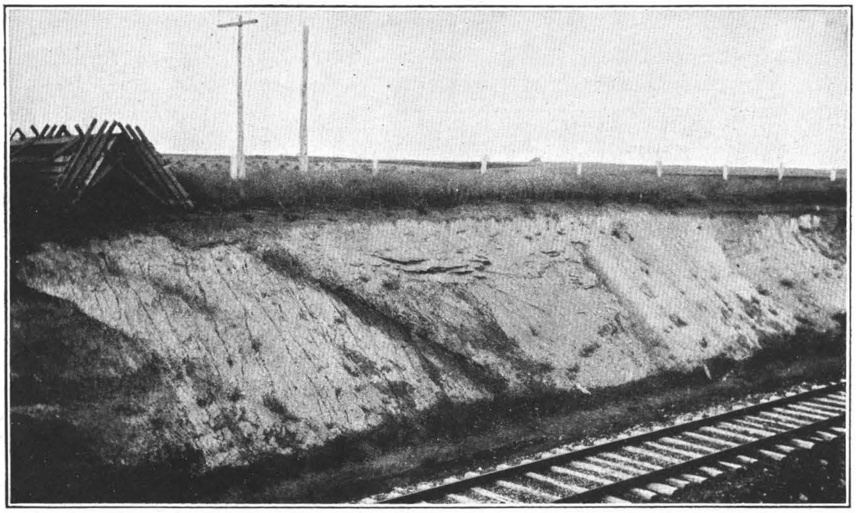
C. ESCARPMENT OF THE FLAXVILLE PLATEAU, NORTHEASTERN MONTANA, SHOWING OUTCROPS OF CEMENTED SAND AND THE THICKNESS OF THE FLAXVILLE GRAVEL.



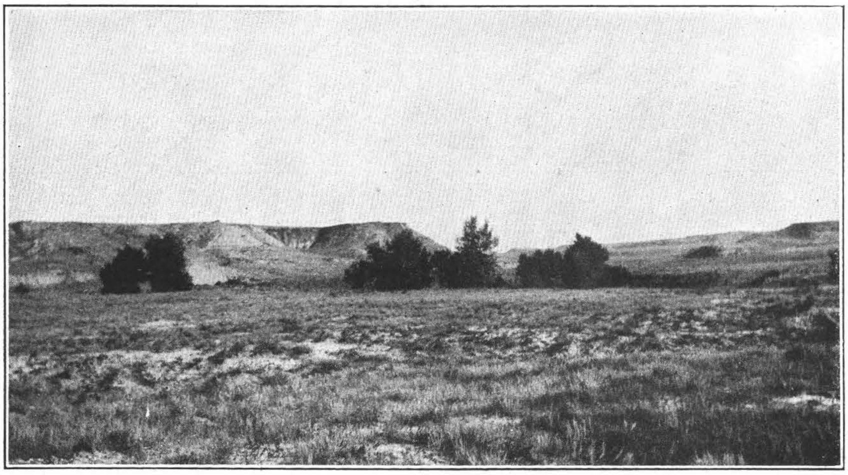
A. CEMENTED GRAVEL INTERSTRATIFIED WITH CEMENTED SAND 9 MILES NORTHEAST OF SCOBEY, MONT.



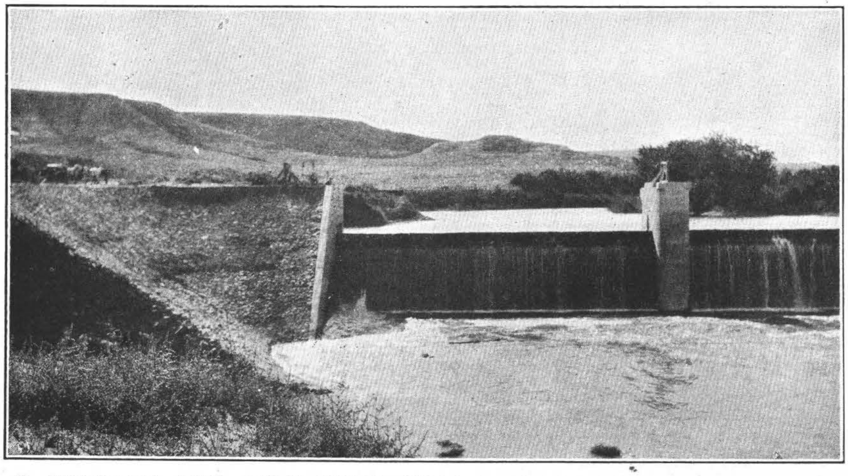
B. CROSS-BEDDING OF FLAXVILLE GRAVEL 5 MILES WEST OF WEST FORK POST OFFICE, MONT.



A. RAILWAY CUT WEST OF FLAXVILLE, MONT



B. ESCARPMENT SURROUNDING THE LATE PLIOCENE OR EARLY PLEISTOCENE BENCH IN MILK RIVER VALLEY, MONT.



C. VANDALIA DAM, MILK RIVER, MONT., SHOWING THE ESCARPMENT SURROUNDING THE LATE PLIOCENE OR EARLY PLEISTOCENE BENCH.

epoch.[1] This valley contains alluvium deposited by Missouri River, glacial drift, and the Recent alluvium of Milk River and is bounded on the north and south by steep escarpments rising 100 to 500 feet to the late Pliocene or early Pleistocene bench. Plate LXV, *B* and *C*, shows views of these escarpments taken from the flood plain of Milk River. Big Muddy Creek flows in a valley cut 200 feet in the same bench. Similar benches are found along Poplar River and its branches. The canyon of Rock Creek where it crosses the bench is so precipitous as to have been considered unsurveyable by the United States Land Office. Frenchman Creek and Woody Island Coulee occupy narrow valleys, and the latter was diverted from its old course westward into Whitewater Creek by the last glacial advance.

OLIGOCENE BEDS IN CYPRESS HILLS.

In 1883 and 1884 McConnell[2] and Weston, of the Canada Geological Survey, examined the Cypress Hills and made a very good collection of fossil vertebrates at Bone Coulee, in the east end of the hills. This collection was submitted to Cope,[3] who identified several species and pronounced them to be of Oligocene age and equivalent to the fauna of the White River formation of Nebraska. The locality was visited in 1904 by Lambe,[4] who made further collections of the fauna and reaffirmed the determination that the beds are of White River age.

The formation exposed in the Cypress Hills is shown on McConnell's map as capping a series of plateaus ranging from 3,700 feet in altitude at the east to 4,800 feet at the west. The gravel on the Swift Current Creek plateau, which lies northeast of the Cypress Hills, is regarded by McConnell[5] as an eastern extension of the Oligocene gravel, though only unidentifiable bone fragments were found in it. As its altitude is about 2,900 feet, or 200 feet below that of the nearest exposure of Flaxville gravel, it is suggested by the writers that a more thorough search might result in the discovery of the Flaxville fauna. The Oligocene beds exposed near Bone Coulee, Cypress Hills, are described by McConnell[6] as follows:

> The Miocene [Oligocene] beds are characterized by the great quantity of waterworn pebbles, derived from the quartzite formations of the Rocky Mountains, which are found in every part of the series. The pebbles are usually cemented together into massive beds of hard conglomerate but also occur distributed irregularly through or arranged in layers and lenticular beds in the sands and sandstones. The more massive conglomerate beds are found toward the western part of the area or around its outskirts. * * * [The beds] are all very irregular and seldom remain constant in composition for any distance along their strike.

SUMMARY.

The gravel that caps the Cypress Hills in Canada is of Oligocene (White River) age. It is made up of materials from the Rocky Mountains, to the west, and rests upon a series of plateaus cut on the Fort Union, Lance, and Bearpaw formations and ranging from 4,800 feet in altitude at its west end to 3,700 feet near its east end.

The Flaxville gravel in Montana is from a few feet to 100 feet thick and is composed of well-rounded quartzite and argillite pebbles from the Rocky Mountains, sand, clay, marl, and volcanic ash. It rests upon a series of plateaus cut on the Fort Union, Lance, and Bearpaw formations, and ranging in altitude from 2,600 feet at the east to 3,200 feet at the west. Fragmentary fossils collected at 25 well-distributed localities were not good enough for specific determination, but it can be stated positively that the formation can not be older than Miocene nor younger than early Pliocene.

Below the Flaxville level there are extensive areas, eroded since its deposition, on which the covering is thin or absent. Stratified gravels and silts have been noted at several localities. A single fossil tooth collected from one of these exposures of gravel was identified as that of a horse resembling the living species. It certainly is not so old as the fauna of the Flaxville gravel. The formation is known to be older than the advance of the Wisconsin glacier.

[1] Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, pp. 32–45, 1906.

[2] McConnell, R. G., On the Cypress Hills, Wood Mountain, and adjacent country: Canada Geol. Survey Ann. Rept., vol. 1, new ser., pp. 1c–78c, 1886.

[3] Cope, E. D., The Vertebrata of the Swift Current Creek region of the Cypress Hills: Idem, pp. 79c–85c; The species from the Oligocene or lower Miocene beds of the Cypress Hills: Canada Geol. Survey Contr. Canadian Paleontology, 1891.

[4] Lambe, L. M., A new species of *Hyracodon* (*H. priscidens*) from the Oligocene of the Cypress Hills, Assiniboia: Canada Roy. Soc. Proc. and Trans., 2d ser., vol. 11, sec. 4, pp. 37–42, 1906; Fossil horses of the Oligocene of the Cypress Hills; Idem, pp. 43–52; Vertebrata of the Oligocene of the Cypress Hills; Saskatchewan: Canada Geol. Survey Contr. Paleontology, vol. 3, pt. 4, 1908.

[5] McConnell, R. G., op. cit., p. 34c.

[6] Idem, p. 69c.

It must therefore be of late Pliocene or early Pleistocene age.

Present drainage has eroded valleys from 100 to 500 feet below the late Pliocene bench. Most of this cutting was accomplished before the advance of the Wisconsin glacier, whose drift deposits lie alike on uplands and bench lands and in the valleys.

The relative altitudes of these four erosion levels and the gravel assigned to them are shown diagrammatically in figure 27. The Oligocene of the Cypress Hills is the highest, the Miocene or early Pliocene Flaxville gravel bench represents a second stage of erosion and deposition, the late Pliocene or early Pleistocene bench a third stage, and the late Pleistocene and Recent level a fourth stage.

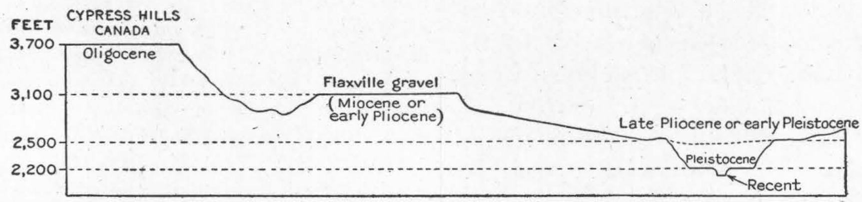


FIGURE 27.—Diagrammatic section showing the relative altitudes of the four erosion levels represented in northeastern Montana and the adjacent part of Canada.

The correlation of these erosion levels with the Blackfoot peneplain and the second and third lower benches in the Glacier National Park region, described by Alden and Stebinger,[1] is suggested but must be regarded as not yet proved. These relations are at present under investigation.

Terrace gravel found by Bowen[2] in the neighborhood of Musselshell River, south of the Missouri, is probably either Oligocene or Miocene; that around the Bearpaw,[3] Little Rocky, Highwood, Judith, Big Snowy, Little Belt, Crazy, and other mountain groups is probably of Tertiary age and represents one or more of the erosion levels described. The relation of these erosion epochs to the physiographic history of the Rocky Mountains, as presented by Atwood[4] and Blackwelder,[5] is very problematic and can not be solved until all the factors are known.

[1] Alden, W. C., and Stebinger, Eugene, Pre-Wisconsin glacial drift in the region of Glacier National Park, Mont.: Geol. Soc. America Bull., vol. 24, p. 569, 1913.

[2] Bowen, C. F., The anticlines of the Musselshell Valley (in preparation).

[3] Bowen, C. F., The Cleveland coal field, Blaine County, Mont.: U. S. Geol. Survey Bull. 541, p. 348, 1912.

[4] Atwood, W. W., The physiographic conditions at Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, pp. 697-749, 1916.

[5] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, Nos. 2, 3, and 4, May-June, 1915.

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UNITED STATES GEOLOGICAL SURVEY
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THE HELDERBERG LIMESTONE OF CENTRAL PENNSYLVANIA

BY

JOHN B. REESIDE, JR.

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THE HELDERBERG LIMESTONE OF CENTRAL PENNSYLVANIA.

By John B. Reeside, Jr.

INTRODUCTION.

This paper presents the results of a study made during 1913, 1914, and 1915, while the writer was a student at Johns Hopkins University. The formations discussed have been studied in Maryland, New Jersey, and New York, and described with more or less detail, but concerning their occurrence in the intervening area in Pennsylvania little exact information has been available. The conflict in opinion as to the proper position and correlation of the Keyser limestone and as to the interpretation of some of the standard New York sections has made further data very desirable, and the present paper is an attempt to meet a part of the deficiency.

The writer wishes to express his indebtedness to the members of the geologic faculty of Johns Hopkins University, especially to Prof. W. B. Clark and Prof. C. K. Swartz, and for many helpful suggestions also to Mr. E. O. Ulrich, Mr. Charles Butts, and Mr. Arthur Keith, of the United States Geological Survey.

HISTORICAL SUMMARY.

The first systematic discussion of the rocks of Pennsylvania is contained in the first annual report of H. D. Rogers, as State geologist, to the Pennsylvania legislature, made in 1836.[1] The present Helderberg limestone and an indeterminate thickness of late Silurian beds seem to be included in his division "No. 6," which is described [2] as "an argillaceous blue limestone" that "contains between its beds thin layers of shale resembling that last described (No. 5), though these grow less as we ascend, while the rock becomes progressively purer and less argillaceous." Rogers states also: "This stratum is terminated by layers of gray chert." In later reports Rogers used the Roman numeral (VI).

In 1843 Mather[3] correlated his *Pentamerus* limestone with Rogers's No. VI, and in the same year James Hall [4] correlated the beds in the interval from the Niagara group to the "Upper *Pentamerus*" limestone inclusive with Rogers's No. VI.

In 1858 Rogers, in the long-delayed final report of the First Pennsylvania Survey, applied the so-called transcendental nomenclature to supplement the numerical designation of the preliminary reports. To No. V, the "Scalent series," he assigned three divisions-the uppermost of which he described [1] as

> a blue flaggy limestone, sometimes containing bands of chert. Certain portions have thin-bedded, wavy stratification * * * This rock contains the *Cytherina alta*, *Tentaculites ornatus*, and a few other distinctive fossils.

No. VI, the "Pre-Meridian series," he described[1] as

> a diversified calcareous formation, usually of some shade of grayish blue. It is argillaceous and flaggy in its lower beds and shaly toward the middle. It frequently contains layers and nodules of chert, especially near its upper limits. It has many characteristic fossils, the *Pentamerus galeatus* and other shells, with corals.

Overlying these is the "Meridian slate," which apparently includes the shales at the top of the New Scotland and at the base of the Oriskany. Rogers correlated the limestone of his No. V with the "Waterlime" of New York, and his No. VI with the "Lower Helderberg" of New York. In discussing the rocks of the United States as a whole Rogers seems to transfer the "Meridian slate" and the "Scalent" limestone to the "Pre-Meridian

[1] Rogers, H. D., Pennsylvania State Geologist First Ann. Rept., Harrisburg, 1836.

[2] Idem, p. 14.

[3] Mather, W. W., Geology of New York, pt. 1 [First district], p. 325, 1843.

[4] Hall, James, Geology of New York, pt. 4 [Fourth district], pp. 80, 144, 145, 519, 1843.

[5] Rogers, H. D., Geology of Pennsylvania, vol. 1, p. 107, 1858.

series." Hence in its larger aspect No. VI included the limestones of the late Silurian, the Helderberg, and the shales of the Oriskany.

In 1874 was established the Second Geological Survey of Pennsylvania, under J. P. Lesley. During the following 20 years this organization issued many county and special reports, in which the utmost freedom was allowed to the several geologists in the usage of stratigraphic names. The volumes therefore disagree among themselves. Very little detailed stratigraphic discussion is given in these reports. The following table shows the usage of the several geologists in describing the sections discussed in another part of this paper:

Usage of the Second Pennsylvania Geological Survey, correlated with stratigraphic divisions of the present paper.

<table>
<tr><th colspan="2">This report.</th><th>White, Grovania.[a]</th><th>White, Selinsgrove.[b]</th><th>White, Dalmatia.[b]</th><th>Claypole, Perry County, Clark's Mill.[c]</th><th colspan="2">D'Invilliers, Mifflin County, Lewistown.[d]</th><th colspan="2">White, Huntington County, Mapleton.[e]</th><th>Platt, Blair County, Tyrone.[f]</th></tr>
<tr><td colspan="2" rowspan="2">Oriskany.</td><td>Oriskany.</td><td>Oriskany.</td><td>Oriskany.</td><td>Oriskany.</td><td colspan="2">Oriskany.</td><td colspan="2">Oriskany.</td><td>Oriskany.</td></tr>
<tr><td rowspan="2">Stormville shales.</td><td rowspan="2">Stormville shales.</td><td rowspan="2">Stormville shales.</td><td rowspan="3">Flint shales.</td><td rowspan="5">Lewistown limestone.</td><td rowspan="2">Lime shale.</td><td colspan="2">Stormville shale.</td><td rowspan="5">Lewistown limestone.</td></tr>
<tr><td rowspan="3">Helderberg.</td><td>New Scotland.</td><td rowspan="4">Lewistown limestone.</td><td>Lime shale.</td></tr>
<tr><td>Coeymans.</td><td>Stormville conglomerate.</td><td rowspan="2">Stormville and Bastard limestones.</td><td rowspan="2">Stormville and Bastard limestones.</td><td rowspan="3">Lower massive limestone.</td><td rowspan="2">Massive limestone.</td></tr>
<tr><td>Keyser.</td><td>Stormville and Bastard limestones.</td><td>Clarks Mill shales.</td></tr>
<tr><td colspan="2">Tonoloway.</td><td>Bossardville.</td><td>Bossardville.</td><td>Bossardville.</td><td>Lewistown.</td><td>Shaly limestone.</td></tr>
</table>

[a] Pennsylvania Second Geol. Survey Rept. G7, p. 88, 1883.
[b] Idem, p. 93.
[c] Idem, Rept. F2, p. 182, 1885.
[d] Idem, Rept. F3, p. 256, 1891.
[e] Idem, Rept. T3, 1885.
[f] Idem, Rept. T, 1881.

In 1892 Lesley[1] correlated No. VI in a general way with the "Lower Helderberg" (Helderberg) of New York, which he regarded as Silurian. His comment on this subject is characteristic:

> Considering the great variety of thickness, quality, order of subdivision, and fossil distribution exhibited by the formation as a whole along its northern outcrop through New York and its far more extensive and numerous lines of outcrop through Pennsylvania, it would be simply misleading to describe it as composed of any fixed number of beds, or groups of beds, arranged in a definite series, each group characterized by one or more species of organic form. All that can be said of it with truth is this: (1), that it is mainly a limestone formation, underlying the whitish sandstone formation No. VII and overlying the reddish shale formation No. V; (2), that many of its beds are crowded with *Pentamerus*, *Delthyris*, *Tentaculites*, encrinal stems, and masses of coral; (3), that one or more of its beds are nearly solid layers of the sponge coral *Stromatopora;* (4), that at its bottom, whether included in it or not, are hydraulic limestone beds, containing the remains of lobsterlike creatures, *Eurypterus* and *Polygnotus;* and (5), that it might perhaps be made by a downward extension to include the whole Salina shale and Niagara limestone formations of western New York and Canada, were it not for the extraordinary thickness of the Salina red shales, especially in Pennsylvania, by which the Niagara is very far separated from the limestones of No. VI above.

In 1903 Schuchert[2] stated that he had traced the Cobleskill and Manlius faunas through New Jersey, Pennsylvania, Maryland, and West Virginia, and that in central Pennsylvania these are still distinct, but that they become more confused in Maryland.

[1] Lesley, J. P., Pennsylvania Second Geol. Survey Summary Final Rept., vol. 2, p. 904, 1892.

[2] Schuchert, Charles, On the Manlius formation of New York: Am. Geologist, vol. 31, p. 176, 1903.

In 1906 Grabau [1] considered White's Stormville limestone of Pennsylvania to represent the Manlius and in part the Coeymans. The top of this limestone he believed to represent generally a marked break, indicated by conglomerate beds, composed at many places almost entirely of quartz. The section at Grovania, Pa., he cited as an example of overlap, the sandstone present being considered New Scotland and the underlying limestone Manlius and Decker.

In 1909 Grabau [2] expressed the view that the Lewistown represented only the upper part of his Monroan series—that is, the Rosendale-Manlius interval of New York.

In 1911 Ulrich [3] announced the presence of an unconformity of considerable time significance in certain beds of the Appalachian region previously referred to the upper Cayugan. The rocks between this horizon and another well up in the Coeymans of Schuchert and other authors he referred to as the Keyser limestone . For the Silurian beds beneath the Keyser limestone he used the name Tonoloway limestone. Ulrich did not discuss either unit in detail.

In 1912 Stose [4] gave an adequate description of the Tonoloway limestone and presented a statement (furnished by Ulrich) of the fauna and of its correlation. In this statement the beds just above the Tonoloway limestone were differentiated, as "the lowest faunal zone of the Helderberg," from the beds containing the Coeymans, New Scotland, and Becraft faunas.

In 1913 Grabau [5] suggested the occurrence of the Bertie limestone at Selinsgrove Junction, Pa., and again referred the entire Lewistown to his upper Monroan, disputing the reference of the Keyser and equivalent beds to the Devonian.

In 1913 also Brown,[6] on paleontologic evidence, considered the Decker and Rondout present in Milesburg Gap, near Bellefonte, Pa.

[1] Grabau, A. W., Guide to the geology and paleontology of the Schoharie Valley in eastern New York: New York State Mus. Bull. 92, p. 173, 1906.

[2] Grabau, A. W., Physical and faunal evolution of North America during Ordovicic, Siluric, and early Devonic time: Jour. Geology, vol. 17, p. 247, 1909.

[3] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 590, 1911.

[4] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Pawpaw-Hancock folio (No. 179), p. 7, 1912.

[5] Grabau, A. W., Early Paleozoic delta deposits of North America: Geol. Soc. America Bull., vol. 24, p. 510, 1913.

[6] Brown, T. C., Notes on the Silurian limestone of Milesburg Gap, near Bellefonte, Pa.: Am. Jour. Sci., 4th ser., vol. 35, p. 83, 1913.

In the same year the Maryland Geological Survey,[7] in its volume on the Lower Devonian of Maryland, divided the Helderberg into the Keyser, Coeymans, New Scotland, and Becraft members, named in ascending order. The last three were correlated with the divisions of the same names in Pennsylvania and other States, and the Keyser with beds in sections at Clark's mill, Selinsgrove Junction, and Grovania, Pa., which are discussed in some detail. Regarding the State as a whole, the suggestion was made that the top of the Keyser is a plane of unconformity.

Schuchert [8] in 1916 gave a brief discussion of the section in the Tyrone region. He attributed all the beds referable to the Helderbergian to the Keyser limestone, and expressed the opinion that there is a marked stratigraphic break at the top of the Keyser and possibly another at the base.

As this brief summary indicates, the amount of detailed information available concerning the Lower Devonian and late Silurian horizons of Pennsylvania leaves much to be desired. The present study of seven selected localities, it is hoped, will contribute toward the solution of some of the problems involved, though the writer recognizes fully the difficulties and limitations imposed upon correlations which are made without field work throughout the areas between the exposures discussed and which are based entirely upon the fossils collected.

GENERAL FEATURES OF THE TONOLOWAY AND HELDERBERG LIMESTONES.

TONOLOWAY LIMESTONE.

The type exposures of the Tonoloway limestone are in the lower slopes of Tonoloway Ridge, and the type locality is just west of Rock Ford, W. Va., where Great Cacapon River cuts through the ridge. The name was given by Ulrich, as stated above, but the formation was first adequately described by Stose.[4] Typically it is composed of finely laminated light-gray limestone and calcareous shale and is generally more shaly toward the top.

[7] Maryland Geol. Survey, Lower Devonian, 1913.

[8] Schuchert, Charles, Silurian formations of southeastern New York, New Jersey, and Pennsylvania: Geol. Soc. America Bull., vol. 27, p. 552, 1916.

The Tonoloway formation in central Pennsylvania has, at all the exposures studied except Tyrone, the same characteristic lithology, consisting of platy, in places laminated fine-grained gray limestones and calcareous shales. The uppermost beds in the Susquehanna region are heavy, pure, and very dark. At Tyrone the strata referred to the Tonoloway are relatively light cream-colored to buff limestones, in places platy and in places containing shale. These beds probably represent a special facies very much like the Wills Creek shale of Maryland. Indeed, if there were sufficient evidence of an unconformity and hiatus at the top, the lithology of these beds would suggest their correlation with the Wills Creek. The Tonoloway at Tyrone also contains a bed of material that seems to be siliceous oolite.

The Tonoloway is not fully exposed at any of the localities studied. The maximum thickness observed is 325 feet.

The fauna of the Tonoloway in Pennsylvania as displayed in the sections studied comprises *Camarotoechia? lamellata*, *Camarotoechia litchfieldensis*, *Spirifer keyserensis*, *Rhynchospira globosa* var., *Favosites* sp. and other corals, *Ectomaria minuta*, *Orthoceras* sp., *Leperditia* sp., and other Ostracoda, Pelecypoda. *Spirifer keyserensis* occurs in the thick upper beds at Lewistown and near Dalmatia. It also occurs at about the same horizon in the Maryland Tonoloway. Associated with it are the two species of *Camarotoechia*. At Mapleton there is a bed about 40 feet below the top of the Tonoloway which is very fossiliferous. This bed carries *Camarotoechia litchfieldensis*, *Spirorbis laxus?*, *Proetus* sp.?, corals, Bryozoa, Pelecypoda, and abundant *Leperditia*. Below this is a bed with many poorly preserved brachiopods, almost all a species of *Rhynchospira*. Usually, however, the Tonoloway contains nothing but ostracodes, and in some places, as at Tyrone, even these are very rare. All the forms mentioned above occur also in the Maryland Tonoloway.

The Tonoloway and Keyser succession has been considered by most observers as uninterrupted, but Ulrich believes the two limestones to be separated by a marked break. The change from the platy fissile gray limestone of the Tonoloway to the much thicker-bedded nodular bluish limestone of the Keyser, in some places very dark in color, is usually sharp. Even where the uppermost Tonoloway is massive, the nodular structure of the Keyser permits a separation.

HELDERBERG LIMESTONE.

GENERAL CHARACTER.

The Helderberg formation is a series of calcareous deposits of varied character. It includes some shale but is chiefly limestone. In lithology individual beds may represent any stage in the gradation between a coarse agglomeration of fossil fragments and a dense, very fine grained subcrystalline rock, or between a somewhat calcareous shale and a laminated impure limestone. Some parts of the formation have in all exposures much bedded chert, and locally chert is present as nodules in other parts of the formation. In very minor quantity arenaceous limestone and even calcareous sandstone are present.

Figure 28 shows the surface distribution of the Helderberg limestone in Maryland and Pennsylvania.

Four members are recognized in the Helderberg limestone—the Keyser limestone at the base, and above it, in order, the Coeymans limestone, the New Scotland limestone, and the Becraft limestone.

KEYSER LIMESTONE MEMBER.

SALIENT FEATURES.

The name Keyser limestone was first used by Ulrich,[1] who cited Keyser, W. Va., as the source. He made several brief references as to its age and structural relation to the inclosing beds, but gave no adequate discussion. The first detailed account of the Keyser is to be found in the Lower Devonian volume of the Maryland Geological Survey cited above. This discussion is considered under the heading "Correlation of the Helderberg limestone" (pp. 194–199.)

The Keyser limestone forms the larger part of the Helderberg of central Pennsylvania. It is divisible into two major lithologic units—a lower limestone series with many nodular layers and an upper series of relatively shaly limestone, which contains very few nodular beds. At Tyrone no nodular limestone whatever was recognized, but everywhere else it is a prominent feature. At Mapleton and near

[1] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pl. 28, 1911.

Lewistown a thick bed of very pure massive crinoidal limestone lies near the base of the member. Here and there the Keyser contains chert and in many places *Stromatopora*-bearing beds.

The thickness is variable in the area studied, ranging from 88 feet in one of the Tyrone sections to 202 feet at Selinsgrove Junction.

Dalmatia a distinct transitional unit lies between them, and at Selinsgrove Junction and Clark's Mill the faunas mingle somewhat near the limits of the two zones.

The *Chonetes jerseyensis* zone and the *Favosites helderbergiae* var. *praecedens* zone may be divided into the following subzones, each with its diagnostic faunule:

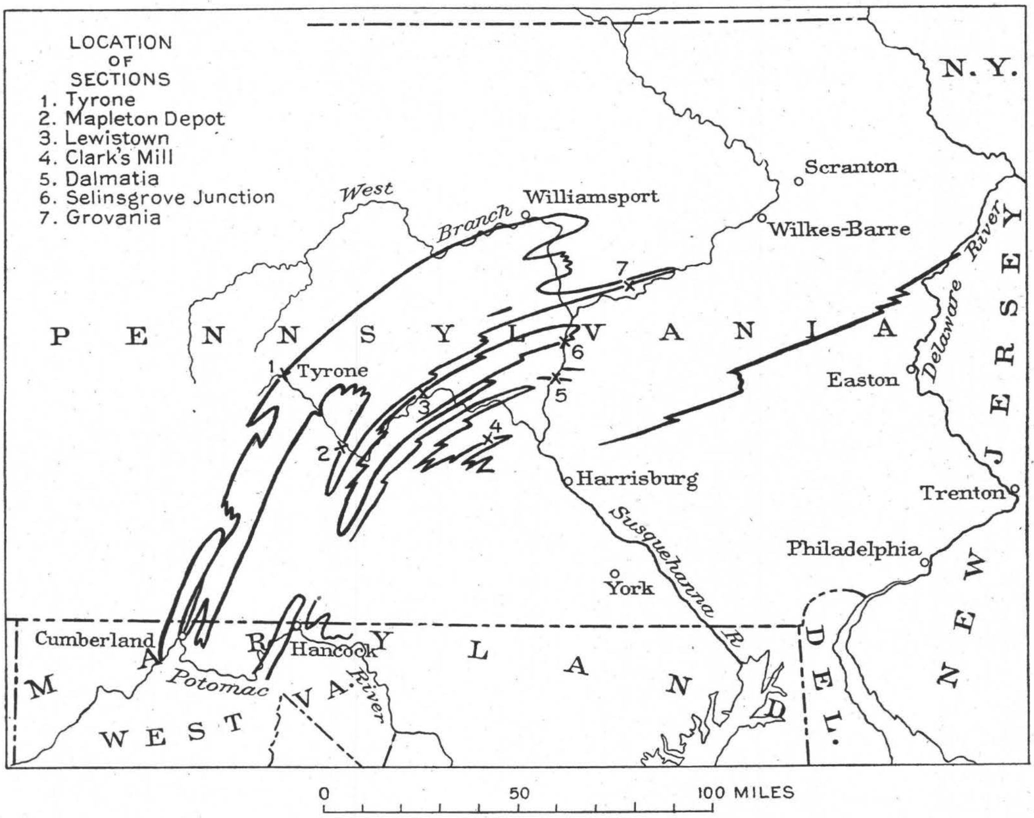

FIGURE 28.—Map showing outcrops of Helderberg limestone in Pennsylvania and Maryland.

Two major faunal units were recognized in the Keyser of Maryland, and were designated the *Chonetes jerseyensis* zone and the *Favosites helderbergiae* var. *praecedens* zone.[1] As corresponding faunal units are present in the Keyser of Pennsylvania and agree in every essential with those found in Maryland, the same names will be used. The favositoid corals have not been studied in detail, but *Favosites helderbergiae* var. *praecedens* is known to occur in the *Favosites* zone in Pennsylvania. The faunal zones do not coincide with the two lithologic units described above. These faunal zones are sharply separated in some of the sections, but at Lewistown and south of

[1] Swartz, C. K., Maryland Geol. Survey, Lower Devonian, p. 99, 1913.

Favosites helderbergiae var. *praecedens* zone:

17. Upper *Leperditia* subzone.
16. *Tentaculites* subzone.
15. *Stromatopora* subzone B.
14. *Rensselaeria mutabilis* subzone.
13. *Pholidops ovata* subzone.
12. Lower *Leperditia* subzone.
11. Coral subzone B.
10. *Spirifer vanuxemi* var. *prognosticus* subzone.

Chonetes jerseyensis zone:

9. *Calymene camerata* subzone.
8. Bryozoan subzone.
7. *Gypidula* subzone.
6. *Dalmanella clarki* subzone.
5. *Spirifer modestus* subzone.
4. *Stromatopora* subzone A.
3. Coral subzone A.
2. *Rhynchospira* subzone
1. *Camarotoechia? lamellata* subzone.

Figure 29 shows the relations of the faunal zones and subzones in the several sections and brings out the similarity of the faunal sequence at most of the localities studied. The sections at Grovania and Tyrone resemble one another and differ from those farther south and east, respectively. This fact suggests that some fundamental factor governing the deposition of the Keyser had its effect in a line nearly parallel to the present strike; possibly the amount of muddy sediment derived from the land mass to the east permitted greater coralline growth away from its shore.

fer modestus, *Stenoschisma formosa*, *Schuchertella deckerensis*, and locally *Orthostrophia strophomenoides*, *Dalmanella clarki*, *Sphaerocystites multifasciatus*, *Tentaculites gyracanthus*, *Calymene camerata*, *Proetus protuberans*, and *Proetus pachydermatus*.

Córal subzone A.—At Tyrone the *Rhynchospira* subzone is overlain by beds containing a profusion of *Cladopora rectilineata* and *Halysites catenulatus*. Associated with them are *Strophonella leavenworthana* var., *Spirifer octocostatus*, *Atrypa reticularis*, and *Rhynchospira globosa* var.

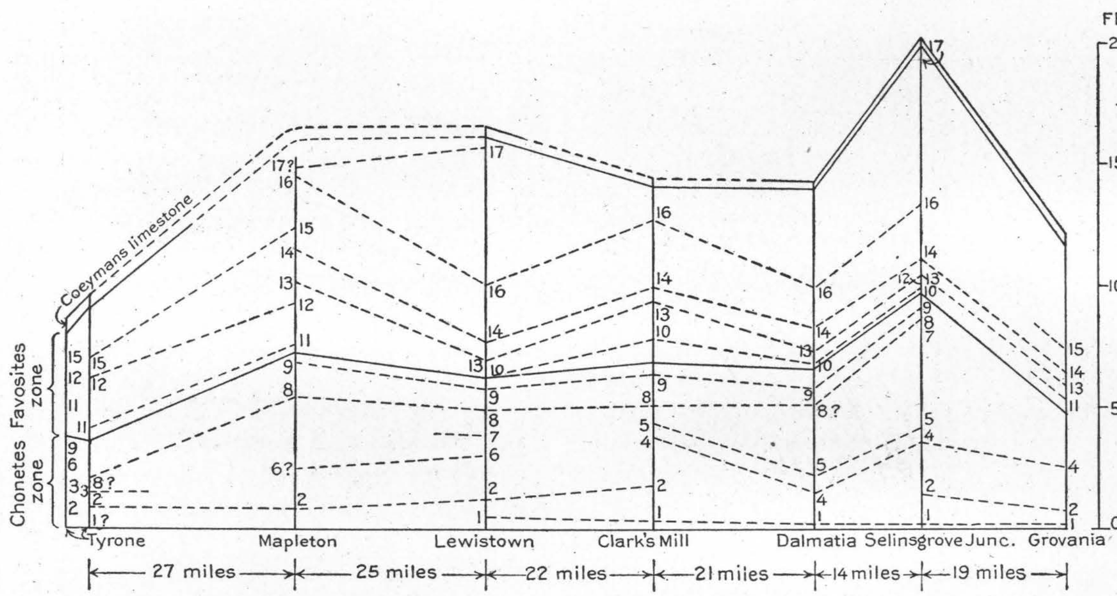

FIGURE 29.—Diagram showing relations of the zones and subzones of the Keyser limestone member of the Helderberg limestone in Pennsylvania.

CHONETES JERSEYENSIS ZONE.

Camarotoechia? lamellata subzone.—*Camarotoechia? lamellata* characterizes a subzone at the base of nearly all the sections. It is especially well shown at Dalmatia and Selinsgrove. *Leperditia* sp., *Spirifer vanuxemi*, and *Rhynchospira globosa* var. commonly occur in the subzone; *Tentaculites gyracanthus*, *Pholidops ovata*, *Spirifer modestus*, *Orthostrophia strophomenoides*, and *Stenoschisma formosa* are less abundant.

Rhynchospira globosa var. subzone.—Above the *Camarotoechia? lamellata* subzone a variety of *Rhynchospira globosa* is abundant. Associated with it are *Atrypa reticularis*, *Chonetes jerseyensis*, *Camarotoechia litchfieldensis*, *Leptaena rhomboidalis*, *Spirifer octocostatus*, *Spiri-*

Stromatopora subzone A.—At Selinsgrove Junction a 6-foot bed of stromatoporoids lies about 20 feet above the *Rhynchospira* subzone. This bed is represented at Grovania by scattered heads of stromatoporoids, at Dalmatia by a 6-inch layer of stromatoporoids, and at Clark's Mill by a unit that bears loose on the surface numerous stromatoporoid fragments. The stratigraphic position of these occurrences is so nearly alike as to warrant the assumption that they are at the same horizon.

Spirifer modestus subzone.—Above the *Stromatopora* subzone A at Selinsgrove, Dalmatia, and Clark's Mill a definite horizon is marked by an abundance of *Spirifer modestus*, associated with which are *Camarotoechia litchfieldensis*, *Chonetes jerseyensis*, *Rhynchospira for-*

mosa, *Schuchertella deckerensis*, *Stenoschisma formosa*, *Stenoschisma deckerensis*, *Calymene camerata*, and undetermined corals and ostracodes.

Dalmanella clarki subzone.—At Tyrone, Mapleton, and Lewistown *Dalmanella clarki* occurs between the *Rhynchospira* subzone and the *Gypidula* subzone and seems to characterize a definite horizon. The associated forms are very numerous and include most of the characteristic species of the *Chonetes jerseyensis* zone.

Gypidula coeymanensis var. prognostica subzone.—At Lewistown and Selinsgrove Junction *Gypidula coeymanesis* var. *prognostica* is abundant in a very massive nodular limestone. The form was not observed at any other horizon nor at any other locality. The associated species are *Atrypa reticularis*, *Chonetes jerseyensis*, *Dalmanella concinna*, *Merista typa*, *Leptaena rhomboidalis*, *Orthostrophia strophomenoides*, *Schuchertella deckerensis*, *Spirifer octocostatus*, *Stenoschisma deckerensis*, *Stenoschisma formosa*, *Proetus protuberans*.

Bryozoan subzone.—Above the *Gypidula* subzone at Lewistown and at a corresponding horizon at Mapleton, Dalmatia, and Clark's Mill there is a profusion of unstudied Bryozoa. At Tyrone and Selinsgrove a similar Bryozoan zone seems to be present, though not conspicuous. The forms associated with the Bryozoa include many of the characteristic species of the *Chonetes jerseyensis* zone.

Calymene camerata subzone.—*Calymene camerata* occurs above the Bryozoan subzone in nearly all the sections. In several sections this is the only occurrence, and in those in which the fossil occurs at several horizons it is the highest one. The associated forms are commonly *Atrypa reticularis*, *Stropheodonta bipartita*, *Merista typa*, *Dalmanella concinna*, *Leptaena rhomboidalis*, and less abundantly *Schuchertella deckerensis*, *Camarotoechia litchfieldensis*, *Rensselaeria mutabilis*, *Spirifer vanuxemi* var. *prognosticus*, and *Uncinulus keyserensis*.

TRANSITION ZONE.

At Lewistown and Dalmatia and to a less marked degree at Selinsgrove Junction and Clark's Mill *Rensselaeria mutabilis*, *Beachia proavita*, and *Uncinulus keyserensis*—forms which are usually confined to the *Favosites* zone—and *Spirifer vanuxemi prognosticus* and *Pholidops ovata*—forms which are abundant only in the *Favosites* zone—are associated with or beneath species which are confined at most localities to the *Chonetes jerseyensis* zone—that is, *Dalmanella concinna*, *Leptaena rhomboidalis*, *Stropheodonta bipartita*, *Strophonella geniculata*, *Camarotoechia litchfieldensis*, *Atrypa reticularis*, *Merista typa*, and *Calymene camerata*.

This transition zone varies in vertical thickness and in the number of subzones included in it in the four sections mentioned.

FAVOSITES HELDERBERGIAE VAR. PRAECEDENS ZONE.

The beds above the *Calymene camerata* subzone carry a fauna that is rather sharply separated from that of the *Chonetes* zone. The few forms which are common to both zones differ much in relative abundance. Such forms as *Pholidops ovata*, *Spirifer vanuxemi* var. *prognosticus*, and *Tentaculites gyracanthus* are unimportant members of the lower fauna, but they are abundant in the upper fauna. The complete absence of *Atrypa reticularis* and *Leptaena rhomboidalis* from the upper zone and their abundance in the underlying zone and the overlying Coeymans member is noteworthy.

The presence of a transitional zone between the *Favosites* and *Chonetes* zones in some of the sections modifies the sharpness of the separation of the two faunas, but in general the statements made above hold good.

There are eight subzones in the *Favosites* zone.

Spirifer vanuxemi var. prognosticus subzone.—Just above the *Calymene camerata* subzone in several of the sections an abundance of *Spirifer vanuxemi* var. *prognosticus* marks apparently the same horizon.

Coral subzone B.—In the Grovania and Tyrone sections a thick bed of massive limestone is composed of a profusion of *Cladopora rectilineata*, *Halysites catenulatus*, *Favosites* sp., and other corals. Associated with these are scattered heads of *Stromatopora*, Bryozoa, and very rarely brachiopods of the genera *Rhynchospira* and *Camarotoechia*. At the top of this subzone is a bed of *Stromatopora* which might well be separated as a distinct subzone. At Mapleton this coral horizon is represented by a sparse occurrence of *Cladopora rectilineata*, *Favosites*, and other corals.

Lower Leperditia subzone.—Above the coral subzone B at Tyrone and Mapleton there is an abundance of large Leperditias. These are associated at Mapleton with *Uncinulus nucleolatus* and *Spirifer vanuxemi prognosticus.* At Selinsgrove Junction a zone with *Leperditia* was observed which seems to be identical with that occurring farther west.

Pholidops ovata subzone.—*Pholidops ovata* occurs above the lower *Leperditia* subzone at Mapleton and Selinsgrove Junction and at a corresponding horizon in all the sections except at Tyrone. The associated forms are numerous and include species usually diagnostic of both *Favosites* and *Chonetes* zones.

Rensselaeria mutabilis subzone.—One of the most persistent subzones of the Pennsylvania sections is that marked by *Rensselaeria mutabilis.* In some of the sections this subzone contains the only specimens of this form, in others it is the horizon of greatest abundance. The associated species are the characteristic forms of the *Favosites* zone—*Spirifer vanuxemi prognosticus, Uncinulus nucleolatus, Meristella praenuntia,* and others.

Mapleton Stromatopora subzone.—At Mapleton the beds carrying the greatest abundance of *Stromatopora* are well up in the section and correspond to the upper *Stromatopora* beds at Grovania and Tyrone.

Tentaculites gyracanthus subzone.—A well-marked and persistent subzone carries *Tentaculites gyracanthus,* though in some of the sections where *Tentaculites* occurs at numerous horizons this subzone can be identified only by the characteristic association with *Schuchertella prolifica.*

Upper Leperditia subzone.—At Lewistown and Selinsgrove Junction *Leperditia* occurs at the very summit of the Keyser. This subzone may also be represented by the *Leperditia* at the top of the Mapleton section, though this is doubtful.

COEYMANS LIMESTONE MEMBER.

The Coeymans member is variable in its lithology. In the west it is locally arenaceous at the base and consists of coarse crinoidal limestone in the upper part. Farther east this sandy character extends through the whole of the member and becomes so pronounced at Grovania that the Coeymans is a sandstone. Usually chert is present.

The thickness of the Coeymans in the sections studied varies from 3 to 10 feet, though it is possible that the minimum thickness should be increased by including some of the overlying limestone.

The fauna is diagnostic, containing the characteristic species *Gypidula coeymanensis,* together with *Atrypa reticularis, Camarotoechia* sp., *Dalmanella perelegans, Leptaena rhomboidalis, Lingula* sp., *Meristella* sp., *Pholidops ovata, Rhipidomella oblata?, Schuchertella woolworthana, Stropheodonta arata, Strophonella leavenworthana, Spirifer cyclopterus, Uncinulus* sp., *Dalmanites* sp., and *Phacops logani.*

The Coeymans-Keyser boundary is everywhere strikingly clean cut. The uppermost beds of the Keyser are platy, banded impure limestones. The base of the Coeymans is coarse, commonly arenaceous limestone or sandstone. The faunal change is likewise sharp.

NEW SCOTLAND LIMESTONE MEMBER.

The New Scotland member usually has a thin bed of limestone at its base, above which lie shales, interbedded in many places with impure limestone and with white chert.

In the vicinity of Dalmatia the basal limestone is very thin or lacking. It was likewise not observed in Perry County. At Tyrone it is 12 feet thick; at Lewistown, 6 feet; at Selinsgrove Junction, 12 feet; at Grovania it seems to be about 13 feet thick and contains much shale. The limestone is arenaceous at Selinsgrove Junction, but in most other places it is simply a coarse-grained bluish-gray fossiliferous rock.

The fauna of the limestone contains the characteristic form *Spirifer macropleurus* and *Atrypa reticularis?, Anoplotheca concava, Camarotoechia* sp., *Chonostrophia helderbergiae, Dalmanella perelegans, Eatonia medialis, Meristella* sp., *Orbiculoidea* sp., *Rhipidomella oblata, Schuchertella woolworthana, Stropheodonta planulata?, Stropheodonta becki?, Strophonella punctulifera, Spirifer cyclopterus, Spirifer perlamellosus, Uncinulus nucleolatus, Dalmanites pleuroptyx, Dalmanites micrurus,* and *Phacops logani.*

The shale is ashy gray, fissile or splintery, and fine grained and contains more or less impure limestone in thin layers. It weathers yellow and is not usually very fossiliferous. The only measurement of the thickness, made at Selinsgrove Junction, gives a total of 44 feet. Some uncertainty as to the position of the upper boundary renders the accuracy of this figure only approximate.

The shale is relatively barren of fossils at most places, but at Dalmatia the following species were observed: *Anoplotheca concava*, *Chonetes* cf. *C. hemisphericus*, *Dalmanella perelegans*, *Meristella* sp., *Pholidops ovata*, *Stropheodonta becki*, *Strophonella punctulifera*, *Spirifer cyclopterus*, *Spirifer perlamellosus*, and *Phacops logani?*. At the Emerick & Lebo quarry, 4 miles northeast of Dalmatia, *Spirifer macropleurus* was found in the shale.

The New Scotland-Coeymans boundary is not well defined lithologically. The division has been made arbitrarily between the highest beds with *Gypidula coeymanensis* and the lowest with *Spirifer macropleurus*.

BECRAFT LIMESTONE MEMBER.

No lithologic or faunal evidence of the presence of the Becraft member of the Helderberg was obtained at any locality studied.

CORRELATION OF TONOLOWAY LIMESTONE.

The Tonoloway limestone of central Pennsylvania includes the beds at Grovania, Selinsgrove Junction, and Dalmatia, referred by I. C. White to the Bossardville limestone. It includes also the beds at Clark's Mill, referred by Claypole to the Lewistown limestone, the term being used by him in a restricted sense. At the other localities treated in this paper it forms a part of "Formation No. VI," or the Lewistown limestone, these terms having been used so loosely as to prevent an exact statement of equivalency.

The Tonoloway in Pennsylvania agrees in all its lithologic details with the formation of the same name in Maryland. Both are mainly platy, laminated limestones. Both have, locally, heavy beds at the top.

As shown on page 188, the small fauna identified from Pennsylvania is duplicated in Maryland. Considering, then, the stratigraphic position, lithologic similarity, and faunal likeness, the identity of the Maryland and Pennsylvania Tonoloway seems assured.

The relations with the formations toward the east and north are more difficult to decipher. Lithologically and stratigraphically the Tonoloway resembles the Bossardville limestone of New Jersey, but the lack of paleontologic evidence from the Bossardville renders correlation with it uncertain. *Camarotoechia? lamellata* and *Camarotoechia litchfieldensis* occur in the Decker limestone of New Jersey and in the Cobleskill and Rondout of eastern New York. The former species occurs in the Cobleskill and Rondout and *Ectomaria minuta* in the Manlius of central New York. Inasmuch as these three forms occur also in the Keyser, it seems inadvisable to say more at present than that the Tonoloway is equivalent to some part of the late Silurian of the standard New York section.

CORRELATION OF HELDERBERG LIMESTONE.

KEYSER LIMESTONE MEMBER.

CORRELATION WITH BEDS IN MARYLAND.

The Keyser member of the Helderberg in Pennsylvania duplicates in a striking way the lithologic succession in Maryland. The lower beds in both are nodular and the upper relatively shaly. Banded, laminated impure limestones of varying thickness occur at the top of both. Both have *Stromatopora* reefs, and both have locally, as at Lewistown and Mapleton, a heavy crinoidal bed near the base.

The faunal likeness of the Pennsylvania sections (except those at Tyrone and Grovania) to sections in Maryland is as striking as the similarity in lithology. The same species occur with much the same stratigraphic ranges in both States. The same two major faunal zones are recognized in both, and these are divided into subzones which correspond in a remarkable fashion in the two areas. (See figs. 29, p. 190, and 30, p. 194.)

The following table affords a comparison:

Central Pennsylvania.	Maryland.[1]
Favosites zone:	
17. Upper *Leperditia* subzone.	14. *Leperditia* subzone.
	13. Corriganville *Stromatopora* subzone.
16. *Tentaculites* subzone....	12. *Tentaculites* subzone.
15. *Stromatopora* subzone B.	11. Corriganville lower *Stromatopora* subzone.
14. *Rensselaeria mutabilis* subzone.	10. *Rensselaeria* subzone.
13. *Pholidops ovata* subzone.	(Present, not named?)

[1] Swartz, C. K., Maryland Geol. Survey, Lower Devonian, p. 99, 1913.

Central Pennsylvania.	Maryland.
Favosites zone—Continued.	
12. Lower *Leperditia* subzone.	(Present, not named?)
11. Coral subzone B........	9. Keyser coral reef.
10. *Spirifer vanuxemi prognosticus* subzone.	(Present, not named?)
Chonetes zone:	
9. *Calymene camerata* subzone.	(Present, not named?)
8. Bryozoan subzone......	8. Bryozoan subzone.
7. *Gypidula* subzone......	7. *Gypidula* subzone.
6. *Dalmanella clarki* subzone.	(Present, not named?)
5. *Spirifer modestus* subzone.	6. Cystid-*Spirifer* subzone.
4. *Stromatopora* subzone A.	5. Rawlings *Stromatopora* reef.
3. Coral subzone A.........	4. *Cladopora rectilineata* subzone.
2. *Rhynchospira* subzone...	2, 3. *Rhynchospira* subzone.
1. *Camarotoechia? lamellata* subzone.	(Present, not named?)

At Market Street Bridge, Cumberland, Md., there is an abundance of *Camarotoechia lamellata* near the base of the Keyser, which probably represents subzone 1 of central Pennsylvania. The occurrence of *Dalmanella clarki* at Cash Valley, about 3½ miles southwest of Cumberland, Md., harmonizes very well with subzone 6 of Pennsylvania. *Spirifer vanuxemi* var. *prognosticus* occurs at Millers Spring, near Ridgely, Md., at about the horizon of subzone 10 of Pennsylvania. *Leperditia gigantea* occurs at Devils Backbone, near Cumberland, Md., above the "Corriganville lower *Stromatopora* reef" and may represent subzone 12 of Pennsylvania. The *Pholidops ovata* subzone and *Calymene camerata* subzone probably have parallel occurrences in Maryland. In short, the subzones of the more central sections in Pennsylvania are practically duplicated in Maryland.

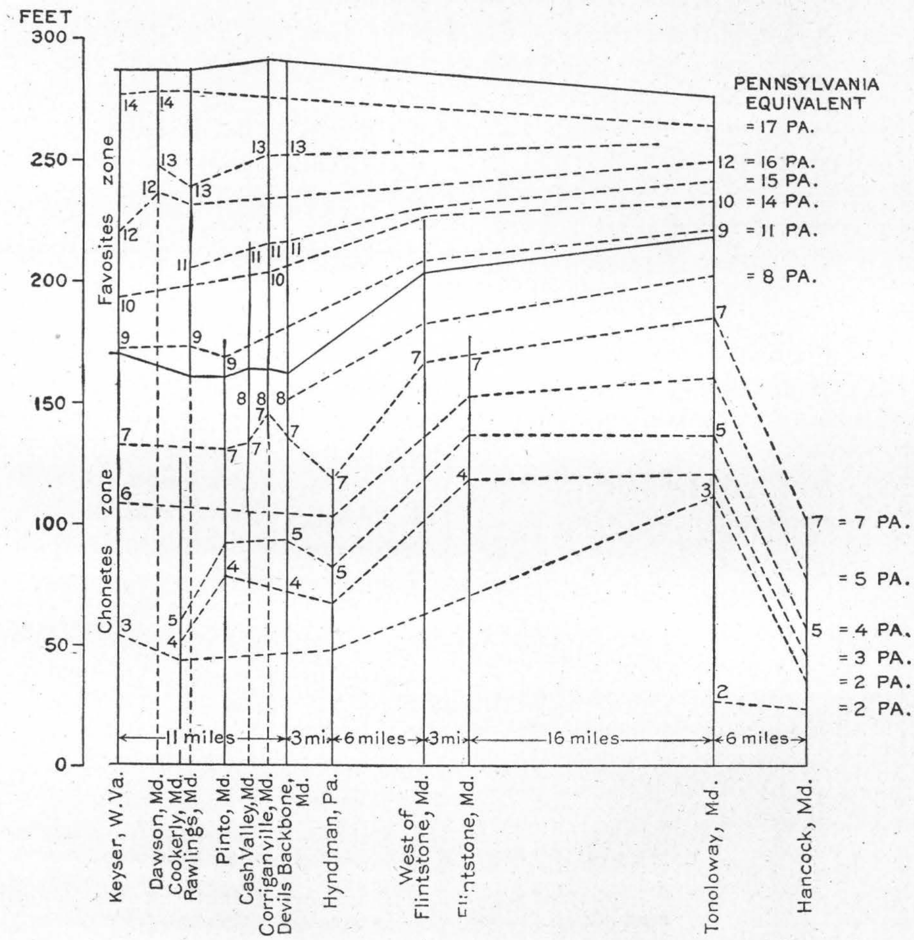

FIGURE 30.—Diagram showing relations of the zones and subzones of the Keyser limestone member of the Helderberg limestone in Maryland.

The sections at Tyrone and Grovania, however, offer some difficulty. In both the fauna of the *Chonetes jerseyensis* zone is well developed, though some of the subzones that are well marked in the other sections are not discernible in these two. The *Favosites* zone is characterized by the great abundance of corals and stromatoporoids. On the other hand, the remaining members of the upper fauna are conspicuously absent at Tyrone and almost lacking at Grovania. There are no sections in the Maryland area which present these peculiarities nor that of the small thickness shown in these two Pennsylvania sections. Possibly the facies exposed at Tyrone and Grovania is buried beneath the later rocks of western Maryland, for the sections of the westernmost Maryland exposures most closely resemble those at Mapleton, Lewistown, and Selinsgrove. The chief difference lies in the lesser thickness in Pennsylvania.

These facts lead to the conclusion that the Keyser member of the Helderberg in Maryland and the Keyser member in central Pennsylvania are essentially identical.

CORRELATION WITH BEDS IN NEW JERSEY.

Weller[1] divided the Lower Devonian and late Silurian limestones of New Jersey as follows:

Helderberg:
- Becraft.
- New Scotland.
- Coeymans.

Silurian:
- Manlius.
- Rondout.
- Decker Ferry.
- Bossardville.

The probable equivalence of the Bossardville and the Tonoloway has been mentioned (p. 193).

The Decker (or "Decker Ferry" limestone) was divided by Weller[2] into the *Chonetes jerseyensis* zone, the *Ptilodictya frondosa* zone, and the *Rhynchonella lamellata* zone. The *Chonetes jerseyensis* zone contains a fauna which has many forms common in the lower zone of the Pennsylvania Keyser. The *Ptilodictya frondosa* zone, which is very thin in New Jersey, has not been recognized in Pennsylvania. The *Rhynchonella lemellata* zone of Weller contains many corals, including *Cladopora rectilineata* and *Halysites catenulatus*. The coral subzone A seems to correspond best with this zone, though it might possibly be equivalent to the coral subzone B.

The fauna of the *Chonetes jerseyensis* zone of Pennsylvania as a whole shows a marked relation to that of the Decker limestone of New Jersey. Of 41 species identified in the *Chonetes jerseyensis* zone of Pennsylvania 18, or 44 per cent, occur in the Decker and include its most diagnostic forms. It is probable that further study of the corals, pelecypods, ostracodes, and Bryozoa will show that the percentage of species common to the two units is still greater.

A very marked difference between the Decker limestone and the *Chonetes jerseyensis* zone of the Keyser limestone is the notable percentage of Devonian (typical Coeymans, New Scotland, and Becraft) forms in the Keyser. Three such species are present in New Jersey, but in Pennsylvania there are nine. In Maryland there are still more.

The lithology of the Decker is also like that of the *Chonetes jerseyensis* zone. The lithologic, faunal, and stratigraphic similarity therefore shows that the two units are essentially the same. If the coral subzone B is the equivalent of the coralline zone of the Decker, the upper beds of the Decker are younger than the upper beds of the *Chonetes jerseyensis* zone of the Keyser. The faunal succession given on page 194 makes it very likely that the coral reef of the Keyser of Maryland is equivalent to the coral subzone B. As the coral reef of the Keyser contains a number of species which are limited to the *Favosites* zone, the coral subzone B is probably not the equivalent of the coralline zone of the Decker. If, as seems more probable, then, the coral subzone A is the equivalent of the coralline zone of the Decker, the upper beds of the *Chonetes jerseyensis* zone are younger than the upper beds of the Decker.

The Rondout of New Jersey has no well-defined equivalent in Pennsylvania. The presence of *Leperditia* in the *Favosites* zone suggests similarity of conditions, but there is no real evidence of equivalency.

The Manlius of New Jersey is characterized by the presence of *Stromatopora*-bearing beds and an abundance of *Spirifer vanuxemi*, *Stropheodonta varistriata*, and *Leperditia alta*. *Tentaculites gyracanthus* occurs but is rare. The

[1] Weller, Stuart, Paleontology of New Jersey, vol. 3, p. 9, 1903.
[2] Idem, p. 67.

Favosites zone of the Keyser of Pennsylvania contains stromatoporoids at three localities. *Tentaculites gyracanthus* occurs abundantly in it at four localities, rarely at Mapleton, and not at all at Grovania and Tyrone. *Spirifer vanuxemi* is represented by the variety *prognosticus*, a very abundant form in the *Favosites* zone of most of the sections, except again Tyrone and Grovania. This variety occurs also in the lower zone of Pennsylvania, but nowhere abundantly. *Stropheodonta varistriata* has not been observed in the central Pennsylvania sections, nor was it recognized farther south in Maryland. Leperditias related to if not identical with the New Jersey species are likewise known in the *Favosites* zone of Pennsylvania.

The most marked difference between the fauna of the New Jersey Manlius and that of the *Favosites* zone of Pennsylvania is the presence in the latter of five Devonian (Coeymans, New Scotland, and Becraft) species, in comparison with the single form of Devonian affinity in the New Jersey beds. A still larger number occur at the equivalent horizons in Maryland.

It is shown on page 199 that the Coeymans of central Pennsylvania is the same as the Coeymans in New Jersey and New York. The equivalency of the basal beds of the Keyser and the Decker having been established, it follows that the Keyser is included between the same limits as the Decker, Rondout, and Manlius of New Jersey. Considering this fact and the faunal and lithologic evidence, the equivalency of the formations appears to be as follows:

Coeymans	=	Coeymans.
Keyser	=	Manlius. Rondout. Decker.
Tonoloway	=	Bossardville.

Possibly the top of the Keyser is somewhat younger than the top of the Manlius of New Jersey. It has been shown already that there is probably an unconformity between the Keyser and the Coeymans. Horizons present in Pennsylvania may be missing in New Jersey.

CORRELATION WITH BEDS IN NEW YORK.

FORMATIONS EAST OF THE HELDERBERG MOUNTAINS.

The formations in New York east of the Helderberg Mountains are continuous with those of New Jersey, the chief change being the development of cement beds and the consequent differentiation of new formations. Clarke and Hartnagel [1] recognize the following succession in eastern New York:

Devonian:
- Coeymans.

Silurian:
- Manlius.
- Rondout.
- Cobleskill.
- Rosendale.
- Wilbur.
- Binnewater.
- High Falls.
- Shawangunk.

Unconformity.
Ordovician.

The Coeymans, Manlius, and Rondout are identical with the corresponding formations in New Jersey. There is a difference of opinion as to the equivalency of the Decker. Weller [2] correlated it with the Cobleskill. Hartnagel,[3] however, proposed to restrict the term to the *Chonetes jerseyensis* and *Ptilodictya* zones of Weller, and considered them equivalent to the Wilbur and Rosendale. Hartnagel divided Weller's *Rhynchonella lamellata* zone into two parts, considering only the upper to be of Cobleskill age. If Hartnagel is correct the Keyser is equivalent to the Wilbur-Manlius interval of eastern New York.

FORMATIONS WEST OF THE HELDERBERG MOUNTAINS.

Hartnagel and other authors consider the Cobleskill, Rondout, and Manlius of central New York equivalent to the formations of the same names in the eastern part of the State. If this is true the Keyser is equivalent to formations which have been accepted as Silurian. The Tonoloway horizons would then be considered as entirely lacking in central New York.

Ulrich [4] proposes a view quite different from this generally accepted one—namely, that the Cobleskill-Rondout-Manlius interval of eastern New York is not the same as that of central New York, but that the latter is for the most part older. Ulrich believes that the Manlius

[1] Hartnagel, C. A., Classification of the geologic formations of the State of New York: New York State Mus. Handbook 19, Table 2, 1912.
[2] Weller, Stuart, Paleontology of New Jersey, vol. 3, pp. 74–75, 1903.
[3] Hartnagel, C. A., Notes on the Siluric or Ontaric section of eastern New York: New York State Mus. Fifty-seventh Ann. Rept., vol. 1, pt. 1, p. 348, 1905.
[4] U. S. Geol. Survey Geol. Atlas, Pawpaw-Hancock folio (No. 179), 1912; Maryland Geol. Survey, Lower Devonian, pp. 115–117, 1913.

of the central area contains four divisions, which may be named and correlated as follows:

Manlius of different authors (central area):	
Upper beds	=Manlius of eastern New York.
Cement beds	=Rondout of eastern New York (typical).
Fossiliferous beds	=Cobleskill of eastern New York (typical). Same as Decker.
Typical Manlius of central New York.	=Tonoloway of Pennsylvania and Maryland.
Rondout of central New York.	
Cobleskill of central New York.	

In other words, the typical Manlius of Ulrich, the Rondout, and the Cobleskill of the central area are, in Ulrich's opinion, the equivalent of the Tonoloway of the south and are Silurian, while most of the Manlius of different authors of the central area is equivalent to the typical Cobleskill (same as the Decker, in Ulrich's opinion), the typical Rondout, and the so-called Manlius of eastern New York and is Devonian. There is much to substantiate this view in the relations of the Tonoloway fauna as shown in Pennsylvania and as more fully represented in Maryland. The close relationship of the central New York Cobleskill and the Decker is explained by Ulrich as a recurrence of the fauna of the former in the latter formation. However, the presence of diagnostic Decker forms in the "fossiliferous beds" of the central New York Manlius has not been demonstrated, and Ulrich's solution of the problem can not be finally accepted until this evidence is brought forward, though it does offer a very logical way out of the difficulty.

COEYMANS, NEW SCOTLAND, AND BECRAFT ELEMENTS IN THE KEYSER FAUNA.

The Pennsylvania Keyser as a whole contains 13 species (28 per cent of the species that occur elsewhere) which are found in the Coeymans, New Scotland, and Becraft of New York. Eleven of these (30 per cent of the species of the *Chonetes jerseyensis* fauna that occur elsewhere) are found in the *Chonetes jerseyensis* zone, and six (38 per cent of the species of the *Favosites* fauna that occur elsewhere) are found in the *Favosites helderbergiae* var. *praecedens* zone. If only the number of forms common to the Keyser and the New York and New Jersey Helderberg formations is used as a basis, the percentages of Devonian forms rise to 43 per cent for the whole Keyser, 34 per cent for the *Chonetes jerseyensis* zone, and 45 per cent for the *Favosites* zone.

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In the Maryland Keyser there are 31 species (or 43 per cent of the forms that occur elsewhere) which also occur in the Coeymans, New Scotland, and Becraft of New York. Of these, 19 species (30 per cent of the *Chonetes jerseyensis* fauna) occur in the *Chonetes jerseyensis* zone and 12 species (60 per cent of the forms that occur elsewhere) in the *Favosites* zone.

In the Decker of New Jersey the Devonian (Coeymans, New Scotland, and Becraft) element is very small. Only two such species are cited,[1] with one that is related to a Devonian form—*Pholidops ovata, Rhynchospira formosa, Stenoschisma deckerensis.* The New Jersey Rondout, judged by the published lists, has no Devonian elements, and the Manlius has a single form with Devonian affinities—*Stropheodonta varistriata.*

There seems to be thus a progressive decrease northward in the Devonian aspect of the Keyser and its equivalents. Possibly the Devonian fauna invaded the Maryland area first, attained a lesser development in Pennsylvania, and did not reach New Jersey and New York in large numbers until Coeymans time.

The species of the *Chonetes* zone that occur in the Coeymans, New Scotland, and Becraft of New York or have very close relatives there are *Pholidops ovata, Orthostrophia strophomenoides, Strophonella leavenworthana* var., *Stenoschisma formosa, Rhynchospira globosa* var., *Rhynchospira formosa, Nucleospira ventricosa, Nucleospira elegans,* and *Proetus protuberans.* The species in the *Favosites* zone are *Orbiculoidea discus, Pholidops ovata, Uncinulus nucleolatus, Rensselaeria mutabilis, Nucleospira elegans,* and *Favosites helderbergiae* var. *praecedens.*

ANALYSIS OF THE FAUNA.

The following table summarizes the relations of the species of the Keyser member in Pennsylvania to those of other horizons and other areas. The figures given here are based on the table of distribution on pages 200–203. The occurrences cited for Maryland, New Jersey, and New York are taken from publications of the Maryland Geological Survey, New Jersey Geological Survey, and New York State Museum.

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[1] Weller, Stuart, Paleontology of New Jersey, vol. 3, p. 74, 1903.

Summary of fauna of Keyser limestone member.

	Keyser member.		*Chonetes* zone.		*Favosites* zone.		Transition zone.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Restricted to Pennsylvania	6	11	4	9	2	11	0	0
Species occurring elsewhere	49	89	41	91	16	89	12	100
	54	100	45	100	18	100	12	100
Occurring in the Tonoloway of Pennsylvania	4	8	4	9	0	0	......	......
Occurring in both zones of Keyser	8	15	8	18	8	44	......	......
Occurring in Coeymans, etc., of Pennsylvania	2	4	2	4	0	0	......	......
Ranges of species occurring elsewhere (exclusive of *Atrypa reticularis* and *Leptaena rhomboidalis*)	47	......	39	......	16	......	......	......
Keyser of Maryland	38	81	......	......	......	......	......	......
Chonetes zone	32	68	31	80	6	38	......	......
Favosites zone	11	23	4	10	11	75	......	......
Decker of New Jersey	16	34	16	41	5	31	......	......
Rondout of New Jersey	0	0	0	0	0	0	......	......
Manlius of New Jersey	3	6	3	8	1	6	......	......
Wilbur of eastern New York	5	11	5	13	1	6	......	......
Cobleskill of eastern New York	7	15	7	18	2	13	......	......
Rondout of eastern New York	4	9	4	10	0	0	......	......
Manlius of eastern New York	2	4	2	6	2	13	......	......
Cobleskill of central New York	5	11	5	13	1	6	......	......
Rondout of central New York	3	6	3	8	1	6	......	......
Manlius of central New York	4	9	4	10	1	6	......	......
Coeymans and New Scotland	13	28	11	30	5	31	......	......
Ranges of species occurring in Maryland (exclusive of *Atrypa recticularis* and *Leptaena rhomboidalis*)	38	......	34	......	12	......	......	......
Chonetes zone of the Keyser member	32	84	31	91	6	50	......	......
Favosites zone of Keyser member	11	29	4	12	11	92	......	......
Ranges of species occurring in New Jersey and New York	30	......	28	......	11	......	......	......
Decker of New Jersey	16	53	16	57	5	45	......	......
Rondout of New Jersey	0	0	0	0	0	0	......	......
Manlius of New Jersey	3	10	3	11	1	9	......	......
Wilbur of eastern New York	5	17	5	18	1	9	......	......
Cobleskill of eastern New York	7	23	7	25	2	18	......	......
Rondout of eastern New York	4	13	4	14	0	0	......	......
Manlius of eastern New York	2	7	2	7	2	18	......	......
Cobleskill of central New York	5	17	5	18	1	9	......	......
Rondout of central New York	3	10	3	11	1	9	......	......
Manlius of central New York	4	13	4	14	1	9	......	......
Wilbur to Manlius of eastern New York and New Jersey	20	66	20	71	7	64	......	......
Cobleskill to Manlius of central New York	9	30	9	32	3	27	......	......
Wilbur to Manlius of New York and New Jersey	21	70	20	71	9	82	......	......
Coeymans to Becraft of New York	13	43	10	34	5	45	......	......

AGE OF THE KEYSER LIMESTONE MEMBER.

The Keyser limestone member, as shown above, lies between the Coeymans and beds of unquestioned Silurian age. It is furthermore clearly equivalent to the Keyser of Maryland, which contains a large number of Coeymans, New Scotland, and Becraft forms, and to the Decker, Rondout, and Manlius of New Jersey and eastern New York, which contain very few Coeymans, New Scotland, and Becraft species. If the age of a formation is determined by the youngest element in the fauna, the Keyser is Devonian. If the percentage of an older fauna surviving is taken as the significant factor, the Keyser is likewise Devonian, for it has but few forms in common with the pre-Keyser beds. If, also, considering the small number of species common to the Keyser and the Cayuga group of central New York, Ulrich is correct in the view that these species in the Keyser are really a recurrence, and that the Cayuga of central New York is mainly older than the supposed equivalent in eastern New York, we have a rational explanation for the differences between the deposits of eastern and central New York commonly grouped as Cayuga and for the more definitely Silurian aspect of the Cayuga of the central area. However, the presence of characteristic Decker forms in the "fossiliferous zone" of the Manlius of central

New York (see p. 197) has not yet been demonstrated, and a definite decision must await further investigation. For the present, it seems to the writer that the weight of the evidence favors the reference of the Keyser to the Devonian.

No physical evidence of unconformity was observed at the base of the Keyser in any of the sections studied, but the sharp faunal change and the ordinarily sharp lithologic change at that horizon are very suggestive of a break in the succession and to that extent favor the argument for the Devonian age of the Keyser beds.

COEYMANS LIMESTONE MEMBER.

The Coeymans member of the Helderberg of central Pennsylvania is clearly to be correlated with the beds at the corresponding horizons in Maryland, in New Jersey, and in New York. There is a suggestion of an unconformable contact at the base of the member in Maryland, and still stronger evidence for it in Pennsylvania, New Jersey, and New York. The fauna is marked in all the areas by the presence of the guide fossil *Gypidula coeymanensis*.

Of the ten species identified from the Coeymans of Pennsylvania nine occur in the Coeymans of Maryland and eight in the Coeymans of New Jersey and New York.

NEW SCOTLAND LIMESTONE MEMBER.

The New Scotland member is closely related to the beds at the same horizon in Maryland and in New Jersey and New York. The presence of *Spirifer macropleurus* and other diagnostic forms makes the connection intimate. The species identified from the New Scotland of Pennsylvania number fifteen, of which thirteen (87 per cent) occur in the New Scotland of Maryland and fourteen (93 per cent) in the New Scotland of New Jersey and New York.

DISTRIBUTION OF THE FAUNA.

The following table gives a detailed statement of the occurrence of the fossils found in the Tonoloway and Helderberg limestones:

Distribution of Tonoloway and Helderberg fossils.

[R indicates a related form.]

	Pennsylvania.						Maryland.					New Jersey.					New York.										
		Helderberg.						Helderberg.							Helderberg.		Eastern.				Central.			Helderberg.			
		Keyser.						Keyser.																			
	Tonoloway.	*Chonetes* zone.	Transition zone.	*Favosites* zone.	Coeymans.	New Scotland.	Tonoloway.	*Chonetes* zone.	*Favosites* zone.	Coeymans.	New Scotland.	Decker.	Rondout.	Manlius.	Coeymans.	New Scotland.	Wilbur.	Cobleskill.	Rondout.	Manlius.	Cobleskill.	Rondout.	Manlius.	Coeymans.	New Scotland.	Below Cayuga group.	Above Helderberg.
Coelenterata.																											
1. Favosites sp	×	×		×																							
2. Cladopora rectilineata Simpson		×		×				×				×						×									
3. Aulopora sp		×		×																							
4. Halysites catenulatus Linné		×		×					×			×					×	×			×	×				×	
5. Stromatoporoidea, undetermined	×	×		×																							
Echinodermata.																											
6. Sphaerocystites multifasciata Hall		×						×																			
7. Crinoidea, undetermined		×																									
Vermes.																											
8. Spirorbis laxus Hall	?	×		×																×							
9. Spirorbis sp																											
Molluscoidea.																											
10. Bryozoa, undetermined	×	×	×	×																							
11. Lingula sp				×																							
12. Orbiculoidea disca (Hall)				×																					×		
13. Orbiculoidea cf. O. numula Hall and Clarke				×																×							
14. Orbiculoidea sp																											
15. Pholidops ovata Hall		×	×	×				×	×			×				×									×		
16. Orthostrophia strophomenoides (Hall)		×						×			×					×									×		
17. Dalmanella concinna (Hall)		×	×					×	?																		
18. Dalmanella clarki Maynard		×						×																			

19. Dalmanella cf. D. perelegans (Hall)		×																									
20. Dalmanella perelegans (Hall)					×	×				×	×					×								×	×		
21. Dalmanella sp.																											
22. Rhipidomella emarginata (Hall)		×							×																		
23. Rhipidomella oblata (Hall)						×				×	×				×	×								×	×		
24. Leptaena rhomboidalis (Wilckens)		×	×		×	×		×		×	×	×			×	×	×	×			×			×	×	×	×
25. Stropheodonta arata (Hall)					×					×	×													×	×		
26. Stropheodonta beckii (Hall)					?						×					×									×		
27. Stropheodonta planulata (Hall)					×					×	×				×									×			
28. Stropheodonta bipartita (Hall)		×	×				×	×				×					R	R	R		R						
29. Stropheodonta sp.																											
30. Strophonella geniculata (Hall)		×	×					×																			
31. Strophonella leavenworthana (Hall)					×					×	×					×									×		
32. Strophonella leavenworthana (Hall) var.		×			R					R	R					R									R		
33. Strophonella punctulifera (Conrad)						×				×	×				×	×								×	×		
34. Schuchertella prolifica Schuchert				×					×																		
35. Schuchertella woolworthana (Hall)					×	×				×	×				×	×								×	×		
36. Schuchertella deckerensis (Weller)		×						×				×															
37. Schuchertella interstriata (Hall)?		?										×						×			×						
38. Schuchertella swartzi Reeside				×																							
39. Schuchertella sp.																											
40. Chonetes jerseyensis Weller		×						×				×						×			×						
41. Chonetes cf. C. hemisphericus Hall						×																					×
42. Chonostrophia helderbergiae Hall and Clarke						×					×													×			
43. Gypidula coeymanensis Schuchert					×					×					×									×	×		
44. Gypidula coeymanensis prognostica Maynard		×						×																R			
45. Stenoschisma formosa (Hall)		×						×							×	×									×		
46. Stenoschisma deckerensis (Weller)		×						×				×															
47. Camarotoechia lamellata Hall	×	×					×	×				×					×	×	×		×	×					
48. Camarotoechia litchfieldensis Schuchert	×	×	×				×	×				×					×	×	×								
49. Camarotoechia sp.																											
50. Uncinulus nucleolatus (Hall)				×				×	×	×	×				×										×		
51. Uncinulus keyserensis Schuchert			?	×					×																		
52. Uncinulus convexorus Maynard?		×						×																			
53. Uncinulus mutabilis Hall var.				×																							
54. Uncinulus gordoni Maynard?				×				×																			
55. Uncinulus burnhamensis Reeside		×																									
56. Uncinulus sp.																											
57. Wilsonia globosa Weller		×						×				×															
58. Eatonia medialis (Vanuxem)						×				×	×					×									×		
59. Rensselaeria mutabilis (Hall)			×	×					×		×														×		
60. Rensselaeria keyserensis Swartz				×					×																		
61. Rensselaeria obtusa Reeside				×																							
62. Rensselaeria (Beachia) proavita Schuchert			×	×					×																		
63. Rensselaeria sp.																											
64. Atrypa reticularis (Linné)		×	×		×	×		×		×	×	×			×		×	×			×			×	×		
65. Atrypa rugosa Hall				?																						×	
66. Spirifer macropleurus (Conrad)						×					×				×	×									×		
67. Spirifer perlamellosus Hall					?	×					×					×								×	×		
68. Spirifer modestus Hall		×						×																			
69. Spirifer modestus plicatus Maynard		×						×																			

Distribution of Tonoloway and Helderberg fossils—Continued.

[R indicates a related form.]

	Pennsylvania.						Maryland.					New Jersey.					New York.										
		Helderberg.						Helderberg.							Helder-berg.		Eastern.				Central.			Helder-berg.			
		Keyser.						Keyser.																			
	Tonoloway.	*Chonetes* zone.	Transition zone.	*Favosites* zone.	Coeymans.	New Scotland.	Tonoloway.	*Chonetes* zone.	*Favosites* zone.	Coeymans.	New Scotland.	Decker.	Rondout.	Manlius.	Coeymans.	New Scotland.	Wilbur.	Cobleskill.	Rondout.	Manlius.	Cobleskill.	Rondout.	Manlius.	Coeymans.	New Scotland.	Below Cayuga group.	Above Helderberg.
Molluscoidea—Continued.																											
70. Spirifer octocostatus Hall		×						×							×												
71. Spirifer vanuxemi Hall		×					R	×				R		×					×			×	×				
72. Spirifer vanuxemi prognosticus Swartz		×	×	×				×	×			R															
73. Spirifer keyserensis Swartz	×						×																				
74. Spirifer eriensis Grabau		?					×	×										×	×	×	×						
75. Spirifer cyclopterus Hall					×	×				×	×				×	×									×		
76. Spirifer sp																											
77. Rhynchospira globosa (Hall) var	×	×					R	×			R	×												R	R		
78. Rhynchospira formosa Hall		×						×				×			R										×		
79. Rhynchospira lata Reeside		×																									
80. Rhynchospira sp																											
81. Nucleospira ventricosa (Hall)		×		?				×		×	×				×	×									×		
82. Nucleospira elegans Hall		×		×				×			×														×		
83. Nucleospira swartzi Maynard		×						×																	×		
84. Nucleospira sp																											
85. Anoplotheca concava (Hall)						×		R			×					×								×	×		
86. Anoplotheca flabellites (Conrad)											×																×
87. Whitfieldella? prosseri Grabau				×																						×	
88. Whitfieldella cf. W. nucleolata Hall		×		×			×	×				×						×	×		×	×					
89. Meristella praenuntia Schuchert				×					×																		
90. Meristella sp																											
91. Merista typa (Hall)		×	×					×																			
Mollusca.																											
92. Pelecypoda, undetermined	×	×		×	×	×																					
93. Tremanotus profundus Hall?		×																									×
94. Bellerophon auriculatus? Hall		×						R													×						

95. Ectomaria sp		×																									
96. Coelidium pennsylvanicum Reeside		×																									
97. Coelidium dalmatiae Reeside		×																									
98. Ectomaria minuta (Hall)	×	×					×																×				
99. Hormotoma sp		×		×																							
100. Euomphalus sp		×																									
101. Holopea antiqua (Vanuxem)		×												×									×				
102. Holopea sp																											
103. Cyclonema sp		×																									
104. Loxonema fitchi Hall?		?																	×	×		×				×	
105. Loxonema sp		×																									
106. Platystoma niagarensis Hall?		×						×																		×	
107. Tentaculites gyracanthus (Eaton)		×		×			×	×	×					×						×			×				
108. Orthoceras cf. O. perstriatum Hall		×																							×		
109. Orthoceras cf. O. pauciseptum Hall				×																					×		
110. Orthoceras sp	×	×		×																							
111. Phragmoceras sp		×																									
Arthropoda.																											
112. Goldius barrandi (Hall)		×																							×		
113. Proetus pachydermatus Barrett		×						×				×															
114. Proetus protuberans Hall		×									×				×										×		
115. Proetus sp																											
116. Cyphaspis cf. C. minusculus (Hall)		×																									×
117. Calymene camerata Conrad		×	×				×	×				×					×	×			×						
118. Phacops logani Hall					×	×					×					×											×
119. Dalmanites micrurus (Green)		?				×		R			?														×		×
120. Dalmanites pleuroptyx (Green)						×				×	×				×	×									×		×
121. Dalmanites sp																											
122. Leperditia sp	×	×		×			×	×	×			×	×	×													
123. Ostracoda, undetermined	×	×	×	×	×	×																					

SUMMARY.

The facts presented in the foregoing pages lead to the following conclusions:

1. The Tonoloway limestone and the Keyser, Coeymans, and New Scotland members of the Helderberg limestone may be traced from Maryland through central Pennsylvania with their respective characteristic lithology and faunas, and the essential equivalents of all are to be found in New Jersey and eastern New York.
2. The equivalents of the Tonoloway and Keyser in central New York are in doubt, though Ulrich's view (p. 197) is very suggestive and may prove to be correct.
3. The beds referred to the Tonoloway at Tyrone, Pa., differ from those found in that formation elsewhere, and the sharpness of the supposed Keyser-Tonoloway contact suggests an unconformity. Further work may show that the beds immediately in contact with the Keyser at this point are of Wills Creek age.
4. The Keyser member decreases in thickness northward from Maryland.
5. The Devonian elements in the fauna apparently decrease from Maryland to New Jersey and New York.
6. The Tyrone and Grovania sections of the Keyser limestone resemble each other and differ very materially from the remaining sections in Pennsylvania and from the Maryland sections.
7. The Tonoloway limestone and the Keyser member of the Helderberg limestone in Maryland and Pennsylvania and their probable equivalents in New Jersey were possibly laid down in a basin which was connected with the open sea in the Maryland region and was progressively restricted northward and eastward to New Jersey. There may have been also a second basin which included the Tyrone and Grovania regions. Conditions in this second basin were different and favored the growth of corals and stromatoporoids, owing to a greater distance from the source of sediments or to the presence of some sort of barrier on the east.
8. The suggestion of an unconformity at the top of the Keyser in Maryland is borne out in Pennsylvania by the variations in thickness of the member and the presence of arenaceous material at the base of the Coeymans.

LOCAL SECTIONS OF THE TONOLOWAY AND HELDERBERG LIMESTONES.

In the following discussion the figures following the name of a fossil indicate the stratigraphic distance in feet at which the form occurs above the base of the member containing it. The distances in the Tonoloway formation are given by negative figures which indicate the stratigraphic distance in feet below the base of the Keyser at which the form occurs. The letters a and c mean abundant and common, respectively.

LINCOLN AND FIFTEENTH STREETS, TYRONE.

The exposure represented by the subjoined section begins just behind the house on the southwest corner of Lincoln and Fifteenth streets, Tyrone. It extends along a small creek known locally as Sink Creek and, as the dip is high, comprises within a short horizontal distance an excellent section of part of the Tonoloway formation and the Keyser, Coeymans, and New Scotland limestones.

The Tonoloway-Keyser contact is marked by the abrupt appearance of the *Chonetes jerseyensis* fauna and by the change in lithology from the light-colored limestones of the Tonoloway formation to the darker beds of the Keyser, though parts of the Keyser are unusually light colored and resemble the Tonoloway. The Keyser-Coeymans contact is shown by the abrupt change from the impure platy fine-grained limestone of the uppermost Keyser to the coarsely crystalline limestone of the Coeymans and by the presence of the characteristic Coeymans fauna. The Coeymans-New Scotland contact is not very sharply defined lithologically. In the section it is placed arbitrarily beneath the lowest beds containing *Spirifer macropleurus*. It is probable that at least part of the concealed unit at the top of the section is of New Scotland age.

Schuchert,[1] in discussing the Lower Devonian of this locality, refers 115 feet of the section to the Keyser limestone, stating that the "cystid member" is present at the base and several *Stromatopora*-bearing beds toward the top. The beds beneath the Keyser he referred to the Cayuga; the beds overlying the Keyser he con-

[1] Schuchert, Charles, Silurian formations in southeastern New York, New Jersey, and Pennsylvania: Geol. Soc. America Bull., vol. 27, p. 552, 1916.

siders Oriskany and believes therefore that the Coeymans, New Scotland, and Becraft are absent. However, as the following description shows, both the Coeymans and New Scotland are represented.

Section at Lincoln and Fifteenth streets, Tyrone.

	Thickness.	Total thickness.
Concealed; scattered outcrops of dark-gray and brown fissile shale; a few bands of impure limestone.		
Helderberg limestone:		
New Scotland limestone member:		
Limestone, medium bedded (1 foot), fine grained, light gray; contains chert lentils and shale laminæ. *Leptaena rhomboidalis*, *Stropheodonta becki*, *Strophonella punctulifera*, *Schuchertella woolworthana*, *Eatonia medialis*, *Spirifer perlamellosus*, *Dalmanella* sp., *Camarotoechia* sp., 9.9	*Feet.* 4.4	*Feet.* 14.0
Shale; weathers brown	1.4	9.6
Limestone, impure, fine grained, thin bedded, light gray, in courses 8 inches thick, with shale partings	2.6	8.2
Limestone, shaly, weathered	.8	5.6
Limestone, massive, heavy bedded, coarse grained, crystalline, gray; much interbedded chert. *Lingula* sp., *Orbiculoidea* sp., *Dalmanella perelegans*, *Rhipidomella oblata*, *Leptaena rhomboidalis*, *Stropheodonta planulata?*, *Schuchertella woolworthana* (a), *Uncinulus nucleolatus*, *Eatonia medialis*, *Spirifer cyclopterus*, *Anoplotheca concava*, *Meristella* sp., *Camarotoechia* sp., *Orthoceras* sp., *Phacops logani*, *Dalmanites micrurus*, Pelecypoda, Bryozoa, 3.2; *Spirifer macropleurus* loose on surface	4.8	4.8
	14.0	
Coeymans limestone member:		
Limestone, very impure, shaly, yellowish. *Atrypa reticularis*, *Spirifer* sp., *Dalmanites* sp., Bryozoa, 5.5	3.8	8.3
Limestone, somewhat weathered, light gray, coarsely crystalline; line of chert nodules (2 by 10 inches) near the top. *Dalmanella perelegans*, *Stropheodonta arata*, *Gypidula coeymanensis*, *Atrypa reticularis*, *Spirifer* cf. *S. perlamellosus*, *Dalmanites* sp	2.0	4.5
Limestone, massive, coarsely crystalline, dark	2.5	2.5
	8.3	

Section at Lincoln and Fifteenth streets, Tyrone—Contd.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member:		
Limestone, single bed, light gray, fine grained, impure	*Feet.* 1.1	*Feet.* 88.3
Limestone, very shaly, light gray	1.8	87.2
Limestone, light gray, fine grained, platy	.8	85.4
Shale, brown, weathered	2.9	84.6
Limestone, light gray, fine grained, platy	1.1	81.7
Shale, brown, weathered	2.0	80.6
Limestone, impure, brownish gray, very platy; breaks into sheets half an inch thick. Pelecypoda	4.6	78.6
Limestone, pure, fine grained, brownish gray; in two beds separated by brown shale; has conchoidal fracture	2.7	74.0
Limestone, shaly, banded, dark gray; contains carbonaceous films. *Leperditia* sp., 69.8	1.5	71.3
Limestone, composed entirely of stromatoporoids; *Leperditia* sp., 66.8	2.3	69.8
Limestone, shaly, yellowish gray. Scattered heads of stromatoporoids at 67.0	2.0	67.5
Limestone, composed entirely of stromatoporoids; under surface very irregular	3.2	65.5
Shale, brown, weathered	.4	62.3
Limestone, composed entirely of stromatoporoids and corals; under surface irregular	5.9	61.9
Limestone, buff, fine grained, shaly	1.5	56.0
Limestone, extremely massive, composed entirely of corals, Bryozoa, and stromatoporoids	9.4	54.5
Limestone, with profusion of corals and stromatoporoids	6.0	45.1
Shale	.6	39.1
Limestone, coarsely crystalline, gray	1.0	38.5
Limestone, coarsely crystalline, gray. Scattered stromatoporoids, *Favosites* sp., *Aulopora* sp., *Calymene camerata*, 36.8	3.0	37.5
Limestone, coarsely crystalline, gray. *Dalmanella concinna*, *Calymene camerata*, 34.5; *Dalmanella clarki*, *Rhipidomella emarginata?*, 33.5	3.5	34.5
Limestone, massive, coarsely crystalline. *Cladopora rectilineata*, *Halysites catenulatus* (a), *Aulopora* sp., *Favosites* sp., stromatoporoids	7.7	31.0
Limestone, thin bedded (1 to 6 6 inches), crystalline, light gray	3.5	23.3
Limestone, massive, coarse grained, light gray	5.0	19.8

Section at Lincoln and Fifteenth streets, Tyrone—Contd.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, thin bedded, gray, and shale. *Cladopora rectilineata, Orthostrophia strophomenoides, Leptaena rhomboidalis, Stenoschisma formosa, Atrypa recticularis, Spirifer octocostatus, Nucleospira elegans?, Rhynchospira* sp., *Orthoceras* sp.	*Feet.* 1. 5	*Feet* 14. 8
Limestone, brownish gray to buff, in single bed standing out as a ridge; coarse, crinoidal. Bryozoa, 9.5	3. 9	13. 3
Limestone, thin bedded, coarse, gray	. 6	9. 4
Shale	. 4	8. 8
Limestone, buff, massive, coarse grained, crystalline	3. 6	8. 4
Limestone, brownish gray, single bed. Fragments of fossils on surface	2. 5	5. 8
Limestone, thin bedded, buff; drab on fresh fracture. *Dalmanella concinna, Stropheodonta bipartita, Schuchertella deckerensis, Camarotoechia litchfieldensis, Atrypa reticularis, Spirifer eriensis?, Meristella* sp., Bryozoa, 0. 8	2. 3	2. 3
	88. 3	
Tonoloway limestone:		
Limestone, massive, buff	2. 0	−2. 0
Limestone, massive, fine grained, buff, cherty	1. 4	−3. 4
Limestone, massive, fine grained, buff, banded	6. 4	−9. 8
Limestone, fissile, banded, buff; drab on fresh fracture	11. 7	−21. 5
Shale, buff, calcareous, contorted and in places apparently brecciated	7. 8	−29. 3
Shale, weathered, brown, earthy	1. 0	−30. 3
Limestone, massive, fine grained; weathered surface light gray, fresh fracture drab; banded; contains some thin chert lentils	6. 7	−37. 0
Limestone, platy, banded, fine grained, light gray	2. 3	39. 3
Limestone, platy, laminated, fine grained, buff. *Leperditia* sp., −41.0	. 9	−40. 2
Limestone, buff to light brown, platy; much geodal calcite in small crystals	1. 3	−41. 5
Limestone, fissile, light gray	2. 3	−43. 8
Concealed; probably platy limestone.	4. 0	−47. 8
Limestone, light gray, platy, impure.	1. 0	−48. 8
Limestone, light gray in solid bed; platy fracture	3. 3	−52. 1
Limestone, platy, fine grained, buff	4. 0	−56. 1
Concealed; brown shale in part	15. 0	−71. 1
Limestone, platy, buff	2. 5	−73. 6
Shale, calcareous, and fine siliceous oolite(?); weathered surface ferruginous, brown; bedding irregular	2. 4	−76. 0
Limestone, blocky, fine grained, buff.	1. 3	−77. 3
Shale, weathered brown	2. 5	−79. 8

Section at Lincoln and Fifteenth streets, Tyrone—Contd.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.	*Feet.*	*Feet.*
Limestone, platy, fine grained, buff	2. 3	−82. 1
Shale, calcareous, much weathered; some fine-grained sandy (?) layers (siliceous oolite?) stand out	10. 3	−92. 4
Shale, calcareous, buff to light gray	1. 5	−93. 9
Limestone, fairly pure, fine grained, buff, blocky fracture	4. 0	−97. 9
Limestone, buff, platy, laminated in part	6. 3	−104. 2
Limestone, shaly, platy, yellowish; many geodal calcite masses with large fine crystals	5. 0	−109. 2
	109. 2	

This section is noteworthy in several respects. The lithology of the Tonoloway portion is unlike that of any other save the adjacent Pennsylvania Avenue section. It resembles, in the light color and fine texture, parts of the Wills Creek of Maryland rather than the Tonoloway. There is not sufficient ground for referring the beds to the Wills Creek, however, for they are almost barren of fossils (even *Leperditia* is very scarce), and it would be necessary to assume a hiatus, for which there is little evidence. The *Chonetes jerseyensis* zone of the Keyser is well defined faunally, but the nodular character so prominent elsewhere is lacking here. The presence of an abundance of corals and stromatoporoids, notably *Cladopora rectilineata* and *Halysites catenulatus*, and the absence of the characteristic brachiopods of the *Favosites* zone—*Rensselaeria, Meristella, Uncinulus*, etc.—as well as of *Tentaculites gyracanthus*, are also remarkable features of this section.

PENNSYLVANIA AVENUE, TYRONE.

The section given below was measured at the north end of Pennsylvania Avenue, Tyrone, just north of the West Virginia Pulp & Paper Co.'s plant. Its base is in a small quarry 200 feet northeast of the concrete bridge over Bald Eagle Creek, parallel to which the exposure extends westward to the road cut through it.

The rocks exposed comprise 325 feet of the Tonoloway, the entire Keyser, and the base of the Coeymans. The lower part of the Tonoloway exposure is much crumpled, and the thicknesses given are therefore only approximate. The upper part of the Tonoloway and the overlying beds are overturned about 21°. There are no signs of faulting in the exposure itself, but the Keyser is repeated about 100 yards to the west by a concealed fault.

The Tonoloway-Keyser contact is exceedingly sharp. The light-colored barren beds referred to the Tonoloway are succeeded without any transition by a thin shale carrying Keyser fossils, and this in turn is succeeded by an impure gray "bastard" limestone containing many characteristic species. The lithology of the Tonoloway here, as in the adjacent section at Lincoln and Fifteenth streets, is unlike that in any of the other exposures studied by the writer. It resembles that of the Wills Creek of Maryland, but as assignment of the formation to the Wills Creek would necessitate the assumption of a large hiatus at the top, for which there is insufficient evidence, it is better to refer the beds to the Tonoloway in spite of their lithologic difference from the Tonoloway elsewhere.

The Keyser-Coeymans contact is likewise very sharp. The platy barren beds at the top of the Keyser are overlain immediately by the coarse siliceous fossiliferous limestone of the Coeymans.

Section at north end of Pennsylvania Avenue, Tyrone.

	Thickness.	Total thickness.
Helderberg limestone:		
Coeymans limestone member:		
Limestone, coarse, gray, crystalline, crinoidal; fossil fragments show on surface. Basal 1 foot siliceous	*Feet.* 4.0	*Feet.* 4.0
	4.0	....
Keyser limestone member:		
Limestone, fissile, laminated, fine grained, yellow	1.8	95.5
Concealed; probably shaly limestone	2.9	93.7
Limestone, platy and impure; buff on weathered surface, drab on fresh fracture	7.2	90.8
Limestone, massive, fine grained, yellow; irregular fracture	1.7	83.6
Limestone, fissile, shaly	1.0	81.9
Limestone, massive, fine grained, yellow; irregular fracture. Color probably due to weathering, though the rock is firm	5.1	80.9

Section at north end of Pennsylvania Avenue, Tyrone—Con.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Cont'd.		
Limestone, laminated, fissile; light gray on weathered surface, drab on fresh fracture	*Feet.* 3.4	*Feet.* 75.8
Limestone, relatively impure, platy; light gray to buff	7.0	72.4
Limestone made up mainly of partly silicified stromatoporoids	1.7	65.4
Limestone, shaly, yellow	.2	63.7
Limestone, compact, light gray; conchoidal fracture. Scattered stromatoporoids; *Leperditia* sp., 63.4	.8	63.5
Limestone, impure, platy, buff	.5	62.7
Limestone, compact, fine grained, very light colored. *Leperditia* sp., 61.4	1.0	62.2
Limestone, made up entirely of stromatoporoids and corals, mainly the former	2.0	61.2
Limestone, impure, shaly, fine grained, light gray. Corals and stromatoporoids near base	2.0	59.2
Limestone, fine grained, light gray to buff; conchoidal fracture. Unit partly concealed. Scattered corals and stromatoporoids; *Favosites* sp., *Leperditia* sp., 56.4; *Leperditia* sp., 54.0	6.2	57.2
Limestone, light gray to buff, fine grained, massive. Cross sections of *Leperditia* on weathered surface	3.6	51.0
Concealed; probably shale	1.0	47.4
Limestone made up of stromatoporoids and corals. *Cladopora rectilineata*, 44.4	7.2	46.4
Limestone, light gray; almost entirely coral. Cyathophylloid corals, *Favosites* sp., *Cladopora rectilineata*, and stromatoporoids are very abundant; *Rhynchospira* sp., 30.9	12.3	39.2
Limestone in single bed, light gray, fine grained; conchoidal fracture. *Pholidops ovata*, *Stropheodonta bipartita*, *Whitfieldella* cf. *W. nucleolata*, *Meristella* sp.?, 26.4	1.2	26.9
Limestone, thin bedded (1 to 2 inches), fine grained, impure, weathered, light gray. *Whitfieldella* cf. *W. nucleolata*, 24.9	2.3	25.7
Limestone in two beds, coarse, crystalline, medium gray. *Favosites* sp., *Stropheodonta bipartita*, 22.4	1.3	23.4
Limestone, impure, shaly, indistinctly nodular. *Strophonella geniculata?*, *Schuchertella* sp., *Camarotoechia* sp.?, *Cladopora rectilineata*, Stromatoporoidea, Bryozoa, 21.1; *Whitfieldella* cf. *W. nucleolata*, 18.9	3.7	22.1

Section at north end of Pennsylvania Avenue, Tyrone—Con.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, solid, coarsely crystalline, buffish gray	*Feet.* 1.7	*Feet.* 18.4
Limestone, thin bedded (1 inch), gray, coarsely crystalline. *Strophonella leavenworthana* var., *Atrypa reticularis*, *Spirifer octocostatus*, *Rhynchospira globosa* var., *Cladopora rectilineata*, *Eotomaria* sp., Bryozoa, 15.4	2.4	16.7
Limestone, massive, coarse, crinoidal, buffish gray. *Schuchertella deckerensis*, 10.0, 10.9; *Atrypa reticularis*, *Spirifer octocostatus*, *Camarotoechia* sp., *Favosites* sp., Stromatoporoidea, Bryozoa, 10.0	4.4	14.3
Limestone, "bastard," gray, weathered, shaly. *Cladopora rectilineata*, *Schuchertella deckerensis*, Bryozoa occur throughout; *Atrypa reticularis*, *Rhynchospira globosa* var., *Rhynchospira lata?*, *Chonetes jerseyensis*, 9.4; *Spirifer octocostatus*, 7.4, 9.4; *Stenoschisma formosa*, *Meristella* sp.?, 6.4, 7.4; *Leptaena rhomboidalis*, *Strophonella leavenworthana* var., *Camarotoechia* sp.?, 6.4	4.5	9.9
Limestone, buffish gray, coarsely crystalline; weathers to a distinctly darker gray than the Tonoloway beds. *Stropheodonta bipartita*, *Schuchertella deckerensis*, *Uncinulus* sp., *Atrypa reticularis*, 3.9	1.7	5.4
Limestone, impure, gray; a "bastard" bed. *Dalmanella concinna*, *Stropheodonta bipartita*, *Strophonella leavenworthana* var., *Chonetes jerseyensis*, *Stenoschisma formosa*, *Atrypa reticularis* (a), *Nucleospira elegans*, *Schuchertella* sp., *Camarotoechia* sp.?, Bryozoa, Pelecypoda, Ostracoda, 2.4	1.7	3.7
Shale, weathered, yellow, irregular. *Orthostrophia strophomenoides*, *Atrypa reticularis*, Bryozoa, 0.4	2.0	2.0
	95.5	
Tonoloway limestone:		
Limestone, buff, coarse looking; in single layer	.6	−0.6
Limestone, banded, platy, dark drab on fresh surface, light gray on weathered surface	.8	−1.4
Limestone, solid bed, buff, fine grained; has a diagonal cross fracture	1.8	−3.2
Limestone, solid bed, dark drab; layer of chert at top. Looks as if it had been crushed and recemented. *Leperditia* sp., −3.3	1.7	−4.9
Clay seam	.1	−5.0

Section at north end of Pennsylvania Avenue, Tyrone—Con.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, brown, weathered, impure	*Feet.* 1.5	*Feet.* −6.5
Limestone, buff, banded, thin bedded; fresh fracture brown; some layers rather red	16.3	−22.8
Limestone, vesicular, leached; fresh fracture whitish, with ferruginous spots	4.8	−27.6
Limestone, buff to light drab, laminated; part fissile, in part fairly solid	17.5	−45.1
Limestone, vesicular, leached	1.0	−46.1
Limestone, light drab, laminated, platy, fine grained; dark drab on freash surface	13.5	−59.6
Concealed	6.5	−66.1
Limestone, vesicular, leached	5.0	−71.1
Shale, weathered, and poorly exposed	3.3	−74.4
Limestone, composed mainly of geodal calcite; resists weather and projects above the surface	.4	−74.8
Limestone, buff, shaly, platy, weathered, and poorly exposed	19.7	−94.5
Limestone, very light gray, has an earthy fracture and looks as if it had been leached; much calcite in druses; a little chert	.8	−95.3
Limestone, impure, platy, light drab; many cavities lined with calcite druses	9.0	−104.3
Limestone, buff, fine grained, medium bedded (6 inches), blocky fracture	3.3	−107.6
Limestone, shaly, platy, buff	8.3	−115.9
Limestone, fine grained, drab on fresh fracture	.8	−116.7
Limestone and shale, very platy, fissile, buff	11.0	−127.7
Limestone, massive, fine grained, weathered surface almost white, fresh fracture drab	4.0	−131.7
Shale and shaly limestone, stained yellow	2.8	−134.5
Shale and shaly limestone, buff and light drab	6.2	−140.7
Limestone, buff, fine grained, impure; blocky fracture	1.0	−141.7
Shale, yellow, calcareous; breaks into irregular fragments	1.5	−143.2
Oolite (?), very fine, siliceous, chocolate-brown	11.0	−154.2
Shale, buff, more or less oolitic (?) and siliceous	6.0	−160.2
Oolite (?), very fine, siliceous, chocolate-brown, weathered somewhat; resembles a friable sandstone	20.0	−180.2
Shale, fissile, calcareous, weathered surface very light colored	12.0	−192.2
Concealed; apparently shale. (Thickness of this and underlying units only approximate)	30.0	−222.2
Shale, fissile, calcareous, light colored	28.0	−250.2
Limestone, massive, impure, buff; much calcite in druses in irregular cavities	6.0	−256.2
Concealed; some shale exposed	15.0	−271.2

Section at north end of Pennsylvania Avenue, Tyrone—Con.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, thin bedded (1 to 2 inches), banded, fine grained, buff; geodal calcite	*Feet.* 6.0	*Feet.* −277.2
Clay seam	.5	−277.7
Shale, fissile, calcareous, light colored	10.0	−287.7
Limestone, massive, impure, buff; looks as if it had been crushed and recemented	8.0	−295.7
Clay seam, weathered	1.0	−296.7
Shale, fissile, light drab	5.0	−301.7
Limestone in 6-inch courses, impure, buff	2.0	−303.7
Shale, fissile, calcareous, light drab on fresh surface, almost white on weathered surface	4.0	−307.7
Limestone, in 6-inch courses, impure, buff	4.4	−312.1
Limestone, massive, buff, impure; contains cavities with calcite druses; looks as if it had been crushed and recemented	5.5	−317.6
Limestone, thin bedded (1 to 2 inches), banded, fine grained, buff	8.0	−325.6
	325.6	

This section is remarkable for the barrenness and peculiar lithology of the Tonoloway and for the sharpness of the Tonoloway-Keyser contact. In the Keyser itself the fauna of the *Chonetes jerseyensis* zone is well developed, but the characteristic nodular beds are lacking. The presence of *Cladopora rectilineata* in considerable abundance in this lower zone is noteworthy. The characteristic brachiopods of the *Favosites* zone and *Tentaculites gyracanthus* are not represented by even a single specimen. This zone, on the other hand, carries a profufusion of corals and stromatoporoids, and in this respect the section resembles no other section studied except that at Grovania.

MAPLETON.

A very good exposure of part of the Tonoloway and nearly all of the Keyser member of the Helderberg is to be seen in the quarry of I. N. Swope on the north bank of Juniata River directly opposite Mapleton (or Mapleton Depot). The Tonoloway at this place is characteristically developed and, in addition, contains several beds with fossils that suggest more normally marine conditions than those under which the rather barren facies occurring in most of the other sections studied were laid down. The Keyser has near its base a thick bed of pure crinoidal limestone, which is comparable to that exposed near Burnham, north of Lewistown. The contact of the Keyser and Coeymans was not seen at this locality.

The section was measured from the exposures directly north of the end of the bridge over the Juniata:

Section in Swope quarry, near Mapleton.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member):		
Concealed by talus, quarry waste, etc. Much of the talus of the upper part is ash-colored shale.		
Limestone, light-gray; banded on weathered surfaces; fresh surface dark gray, fine grained, not banded; conchoidal fracture; 3-inch courses separated by shale. *Leperditia* sp., 150, 149.1; Bryozoa, 148.1, 145.7; *Tentaculites gyracanthus*, Ostracoda (a), 148.1; *Spirorbis laxus* (a), 147.2; *Whitfieldella* cf. *W. nucleolata*, 145.7?, 144.7	*Feet.* 9.0	*Feet.* 153.1
Limestone, like unit above but not in courses separated by shale; fairly massive. Pelecypoda, 142.7	4.8	144.1
Shale, calcareous, weathered, yellow	.9	139.3
Limestone, very light gray, compact, fine grained; dark on fresh surface; faintly banded	2.8	138.4
Limestone, composed entirely of stromatoporoids	.9	135.6
Shale, weathered yellow	.8	134.7
Limestone, massive, light gray; composed of stromatoporoids	3.0	133.9
Limestone nodules, large, in shale matrix	.8	130.9
Limestone, rather platy, shaly, dark gray. Stromatoporoids, 129.7; *Leperditia* sp., 128.7	4.3	130.1
Limestone, dark gray, conchoidal, impure, fine grained; in 2 to 12 inch courses, separated generally by thin shale laminae. *Pholidops ovata*, 121.7, 109.7; *Rensselaeria mutabilis*, *Rensselaeria keyserensis*, 121.7; *Spirifer vanuxemi* var. *prognosticus*, 121.7–108.7; *Uncinulus nucleolatus* (a), 119.7–108.7; *Leperditia* sp., 118.7, 108.7; Pelecypoda, 117.2 (a), 109.7 (c); Ostracoda, 113.7, 108.7; *Gypidula coeymanensis prognostica*, 109.7	19.1	125.8
Shale, calcareous, containing large nodules (diameter 5–6 inches) of limestone and one or two beds of fine-grained conchoidal blue limestone. *Uncinulus nucleolatus* throughout; *Aulopora* sp., 106.7, 104.7 (c); Stromatoporoidea, Bryozoa, 106.7 (a), 102.7; *Pholidops ovata*, 106.7; *Favosites* sp., 104.7 (c), 102.7; *Schuchertella interstriata?*, Pelecypoda, Ostracoda, 104.7 (a); *Spirorbis laxus*, *Meristella praenuntia*, 102.7	4.3	106.7

Section in Swope quarry, near Mapleton—Continued.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member)—Continued.		
Limestone, rather shaly, dark gray; single bed. *Favosites* sp., Stromatoporoidea, *Dalmanella concinna*, *Schuchertella prolifica*, *Uncinulus nucleolatus* (a), *Rensselaeria keyserensis*, Ostracoda, 101.7	*Feet.* 1.6	*Feet.* 102.4
Limestone, massive, impure, gray; nodular character indistinct; weathers thin bedded at top of quarry. *Favosites* sp., Bryozoa, *Atrypa reticularis* (c), 99.7	3.1	100.8
Limestone, massive, impure, nodular. *Pholidops ovata*, *Uncinulus keyserensis* (a), 96.7	1.3	97.7
Shale, weathered, yellow	.5	96.4
Limestone, impure, nodular, dark gray, somewhat crystalline. *Favosites* sp., *Aulopora* sp., *Uncinulus keyserensis*, *Orthoceras* sp., *Calymene camerata?*, 95.7; Bryozoa, Ostracoda, 93.2	3.4	95.9
Limestone, impure, dark gray; many cleavage faces of calcite show, giving it a coarse grain; very massive unit; shows indistinct nodular structure. *Favosites* sp., 91.7	5.6	92.5
Limestone, much like unit above but does not show the nodular structure. Stromatoporoidea, 80.0	8.8	86.9
Limestone, dark, much weathered in places, massive. *Favosites* sp., Bryozoa (c), *Rhynchospira globosa* var., 75.7	3.9	78.1
Limestone, pure bluish crystalline layers alternating with shaly dark-gray impure layers; the whole makes a massive unit. Bryozoa throughout; *Cladopora rectilineata*, 74.2, 70.7; *Aulopora* sp., 74.2; *Favosites* sp., 72.7; *Stropheodonta bipartita*, *Schuchertella deckerensis*, *Atrypa reticularis*, *Calymene camerata*, 70.7	5.0	74.2
Limestone, light gray, fine grained, conchoidal fracture	2.0	69.2
Limestone, massive, coarsely crystalline, bluish; many small chert nodules. *Favosites* sp., Bryozoa, *Leptaena rhomboidalis*, *Stropheodonta bipartita* (c), *Camarotoechia* sp.?, 65.2	2.4	67.2
Limestone, blue gray, coarse, crystalline, pure, thin bedded (2 to 6 inches). Bryozoa (a), *Leptaena rhomboidalis*, *Stropheodonta bipartita*, *Strophonella geniculata*, *Schuchertella interstriata?*, *Camarotoechia litchfieldensis*, *Atrypa reticularis*, 63.7	1.1	64.8
Limestone, shaly, impure, "bastard"; weathers light gray and yellow; finely nodular. Bryozoa, *Strophonella geniculata*, *Atrypa reticularis* throughout; *Stenoschisma deckerensis*, 58.7, 55.7; *Spirifer octocostatus*, *Favosites* sp., *Eotomaria* sp., 58.7; *Stenoschisma formosa*, *Spirifer modestus?*, *Spirifer vanuxemi*, *Rhynchospira formosa*, *Dalmanites micrurus?*, 56.7	9.6	63.7

Section in Swope quarry, near Mapleton—Continued.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member—Continued.		
Limestone, bluish gray, crystalline, single bed, fairly pure	*Feet.* 2.8	*Feet.* 54.1
Limestone, very impure, earthy, dark gray; shaly fracture. *Dalmanella concinna*, *Atrypa reticularis*, 50.7	1.5	51.3
Shale, fissile, calcareous; weathers a ferruginous brown; has some nodules near top. Bryozoa, *Pholidops ovata*, *Dalmanella concinna*, *Dalmanella clarki*, *Leptaena rhomboidalis*, *Stropheodonta bipartita?*, *Chonetes jerseyensis*, *Atrypa reticularis*, *Spirifer modestus plicatus*, 49.2	1.0	49.8
Limestone, impure, nodular, dark, single bed. *Orthostrophia strophomenoides?*, *Dalmanella concinna*, *Stenoschisma formosa*, *Atrypa reticularis* (a), 48.7	2.0	48.8
Limestone, fairly pure, blue, crystalline; nodular character lacking on fresh surfaces and very indistinct on weathered surfaces; thin bedded (2 to 4 inches); a few 2-inch chert nodules scattered near top. *Atrypa reticularis*, 41.2–46.7; *Spirifer octocostatus*, 46.7, 45.7; *Orthostrophia strophomenoides*, *Dalmanella concinna*, *Stropheodonta bipartita*, *Schuchertella deckerensis*, 43.7; *Camarotoechia litchfieldensis*, 43.7; Crinoidea, Bryozoa, *Pholidops ovata*, *Stenoschisma deckerensis*, 41.2	5.6	46.8
Limestone, nodular, relatively impure, rather coarse grained and with considerable interlaminated shale; would be classed as a "bastard" limestone, but it is purer than the unit beneath. *Dalmanella concinna*, *Dalmanella clarki*, *Stropheodonta bipartita*, *Chonetes jerseyensis*, *Atrypa reticularis*, *Platystoma niagarensis?*, 39.7	2.4	41.2
Limestone, shaly, very nodular, "bastard," light gray and brown on weathered surfaces. Crinoidea, *Stropheodonta bipartita*, *Chonetes jerseyensis*, *Atrypa reticularis*, *Spirifer octocostatus*, Pelecypoda, throughout; *Orthostrophia strophomenoides*, 38.7; *Dalmanella concinna*, *Nucleospira elegans*, 38.7, 35.5; *Rhipidomella emarginata?*, 37.7; *Leptaena rhomboidalis*, *Strophonella geniculata* (c), *Schuchertella deckerensis*, *Platystoma niagarensis?*, 37.7, 35.5; *Aulopora* sp., *Spirorbis* sp., Bryozoa (a), *Dalmanella clarki*, *Dalmanella* cf. *D. perelegans*, *Schuchertella interstriata?*, *Stenoschisma formosa* (c), *Stenoschisma deckerensis*, *Camarotoechia litchfieldensis*, *Rhynchospira globosa*, *Nucleospira ventricosa*, *Orthoceras* sp., *Calymene camerata*, 35.5	3.5	38.8

Section in Swope quarry, near Mapleton—Continued.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member)—Continued.		
Limestone, coarsely crystalline, light gray, very pure (98 per cent $CaCO_3$), extremely massive and crinoidal. Bryozoa, 32.3, 9.4 (a); *Pholidops ovata, Leptaena rhomboidalis, Camarotoechia* sp., *Proetus pachydermatus*, 32.3; *Stropheodonta bipartita*, 24.7; *Schuchertella* sp., *Meristella* sp., 19.4; *Sphaerocystites multifasciatus, Dalmanella clarki, Stenoschisma formosa* (c), *Camarotoechia litchfieldensis* (a), *Atrypa reticularis* (c), *Rhynchospira globosa* var. (a), *Rhynchospira formosa*, 9.4	*Feet.* 29.8	*Feet.* 35.3
Limestone, thin bedded (2 to 3 inches), dark gray, fine grained, distinctly nodular	1.7	5.5
Limestone, somewhat nodular but yet massive, dark gray, fine grained. *Leperditia* sp., 2.7	3.8	3.8
	153.1	
Tonoloway limestone:		
Limestone, medium bedded (4 to 12 inches), pure, dark gray, not banded; shale between the courses. *Leperditia* sp. throughout; *Favosites* sp., — 30	6.8	— 6.8
Limestone, thin bedded (3 to 6 inches), pure, dark gray, fine grained; banded and light gray on weathered surface	2.8	— 9.6
Shale, calcareous	.2	— 9.8
Limestone, massive, dark gray, fine grained, pure; conchoidal fracture; in places shows a 1-inch bedding. *Leperditia* sp. throughout	3.8	— 13.6
Limestone, light gray, in 3-inch courses with shale between	1.8	— 15.4
Limestone, massive bed, very light gray, fine grained; conchoidal fracture. In this unit there has been dissolved out a good-sized cave reaching down to an unknown depth. The limestone seems very pure and has small scattered masses of crystalline calcite. *Leperditia* sp., —15.4, —16.4	4.0	— 19.4
Limestone, banded, thin bedded (2 inches) but not fissile, light gray, pure. *Leperditia* sp., —20.8	5.5	— 24.9
Travertine	.5	— 25.4
Limestone, banded, thin bedded, light gray. *Leperditia* sp., —26.3	3.6	— 29.0
Limestone, very platy, fissile; weathered surfaces have a faint greenish tinge	2.6	— 31.6
Limestone, rather irregular, heavy bed, fine grained, light gray, pure	1.2	— 32.8
Limestone, very platy, fissile, light gray, fine grained; seems fairly pure. *Leperditia* sp. (a), —33.2	3.4	— 36.2
Limestone, dark gray, with a 4-inch layer of chert at center	1.3	— 37.5

Section in Swope quarry, near Mapleton—Continued.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, massive, finely (1 inch) but distinctly nodular, dark gray, impure. Corals, Stromatoporoidea, *Spirorbis laxus* (c), Bryozoa, *Camarotoechia litchfieldensis, Leperditia* sp. (a)	*Feet.* 3.0	*Feet.* — 40.5
Limestone, massive, fairly pure, blue-gray	3.6	— 44.1
Limestone, fissile, platy, dark gray; layer of chert at —45.2. *Leperditia* sp. (c) throughout	5.2	— 49.3
Limestone, fairly solid, banded, dark gray, fine grained	8.9	— 58.2
Limestone, fissile, shaly, impure; drab on fresh surface. *Leperditia* sp., —62.2	5.6	— 63.8
Limestone, fairly pure, knotty, light gray, fine grained	1.5	— 65.3
Limestone, fissile, weathered, brown and gray, fine grained, impure. *Favosites* sp., *Rhynchospira globosa, Ectomaria minuta* (c), *Leperditia* sp. (a), —66.2	12.4	— 77.7
Concealed	5.9	— 83.6
Shale, weathered, calcareous, gray to brown. *Leperditia* sp., —89.2	7.4	— 91.0
Shale, poorly exposed, weathered	4.0	— 95.0
Limestone, fissile, impure, gray. *Leperditia* sp., —96.5 to —97.5	5.5	—100.5
Limestone, platy, gray; looks much purer than unit above or below	1.0	—101.5
Limestone, fissile, impure, weathered brown	1.0	—102.5
Concealed	3.8	—106.3
Limestone, thin bedded (4 to 6 inches), impure, light gray	5.0	—111.3
Shale, calcareous, gray, and limestone, gray to brown, weathered, fine grained; alternating layers of each about 3 inches thick	9.4	—120.7
Shale, fissile, ash-colored, calcareous	5.5	—126.2
	126.2	

The Mapleton section is noteworthy because it contains several zones of the Tonoloway of a more normally marine facies than was observed in any other section studied. In this feature it resembles parts of the Maryland Tonoloway that carry a relatively large marine fauna. The thick crinoidal unit near the base of the *Chonetes jerseyensis* zone of the Keyser is also notable. The *Favosites* zone of the Keyser contains a subzone with *Cladopora rectilineata* and other corals at about the horizon of the profuse coralline development at Tyrone and Grovania. As in those sections also, it has a *Stromatopora* reef well up in the Keyser and shows a rarity of such forms as *Rensselaeria mutabilis, Meristella praenuntia,* and *Tentacu-*

lites gyracanthus. The abundance of *Uncinulus nucleolatus* in the *Favosites* zone is not paralleled in any other section studied.

MOUNT ROCK, LEWISTOWN.

The section given below begins just across the Kishacoquillas Pike from the Spanogle & Yeager Co.'s flour mill at Mount Rock and extends southward along the pike past the west end of the bridge over Kishacoquillas Creek. It lies about 100 yards south of the Lewistown & Readsville Railway Co.'s power house and car barn.

E. V. d'Invilliers,[1] describing the geology of Derry Township, Mifflin County, refers to this section very briefly. He gives the thickness of the limestone and lime shales of the Lewistown exposed here as 350 feet and mentions several massive beds.

The lowest exposures reveal the top of the Tonoloway. Above these a large part of the Keyser member of the Helderberg is to be seen, though the uppermost part of the Keyser is concealed. The Coeymans, New Scotland, and Oriskany are well developed. The section given below extends from the lowest exposure up into the new Scotland. It is probable that part of the beds overlying those definitely known to be New Scotland are also of that age, but the data at hand are insufficient to determine the position of the New Scotland-Oriskany contact.

Section on Kishacoquillas Pike at Mount Rock, Lewistown.

	Thickness.	Total thickness.
Concealed.		
Helderberg limestone:		
New Scotland limestone member:		
Limestone, very dark, impure, fissile	*Feet.* 3.0	*Feet.* 18.5
Shale, weathered brown, very fissile; contains some bands of very dark impure limestone	10.4	15.5
Limestone in two beds (12 and 9 inches) separated by shale (9 inches), fine grained, blue-gray, crystalline. *Meristella* sp. throughout; *Dalmanella perelegans*, *Stropheodonta beckii?*, *Eatonia medialis*, *Atrypa reticularis?*, *Spirifer macropleurus* (a), *Spirifer perlamellosus*, Ostracoda, 156.7; *Rhipidomella oblata?*, *Schuchertella woolworthana* (a), *Chonostrophia helderbergiae?*, 3.2	2.5	5.1

[1] Pennsylvania Second Geol. Survey Rept. F3, p. 256, 1891.

Section on Kishacoquillas Pike at Mount Rock, Lewistown—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
New Scotland limestone member—Continued.		
Limestone, single bed, light gray, cherty, fine grained; some calcalcite cleavage faces show; does not scratch hammer. Bryozoa, *Dalmanella perelegans*, *Stropheodonta planulata*, *Camarotoechia* sp., *Eatonia medialis*, 2.5	*Feet.* 2.6	*Feet.* 2.6
	18.5	
Coeymans limestone member:		
Shale, weathered, brown	.6	10.6
Limestone, single bed, light gray, cherty. *Stropheodonta arata*, *Schuchertella* sp., *Gypidula coeymanensis*, *Atrypa reticularis*, *Meristella* sp., 8.2	2.3	10.0
Shale, weathered, dark gray, calcareous; limestone bands and large nodules. *Lingula* sp., *Leptaena rhomboidalis*, *Stropheodonta planulata?*, *Schuchertella woolworthana*, *Chonetes* cf. *C. hemisphericus*, Pelecypoda, *Orthoceras* sp., Ostracoda (a), 7.3	1.5	7.7
Limestone, massive, sandy, crystalline, blue; some black chert nodules; very tough, hard rock. *Dalmanella perelegans?*, *Leptaena rhomboidalis*, *Gypidula coeymanensis*, *Atrypa reticularis*, Pelecypoda, 5.3; *Camarotoechia* sp.?, *Spirifer cyclopteris*, 5.3, 2.0; *Stropheodonta arata*, 2.8; Bryozoa, *Pholidops ovata*, *Rhipidomella oblata?*, *Strophonella leavenworthana* (c), *Phacops logani*, *Dalmanites* sp., 2.0	6.2	6.2
	10.6	
Keyser limestone member:		
Limestone, dark gray, fine grained, thin bedded. *Leperditia* sp	1.0	157.9
Limestone, massive, dark gray, fine grained; conchoidal fracture	2.0	156.9
Limestone, shaly, yellow, weathered	1.0	154.9
Limestone, massive, dark gray, impure, fine grained; conchoidal fracture	2.5	153.9
Shale, weathered	2.0	151.4
Limestone, light gray, solid, fine grained; conchoidal fracture	1.0	149.4
Limestone, platy, dark gray, impure	3.0	148.4
Concealed	5.1	145.4
Limestone, platy, light gray, impure, fine grained; conchoidal fracture	2.0	140.3
Concealed	6.2	138.3

Section on Kishacoquillas Pike at Mount Rock, Lewistown—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, impure, platy, yellow; weathered much and poorly exposed	*Feet.* 3.8	*Feet.* 132.1
Limestone, platy, impure, weathered, yellowish, *Meristella* sp.	4.0	128.3
Limestone, massive, light gray; conchoidal fracture	1.5	124.3
Limestone, thin bedded (2 inches), dark gray; conchoidal fracture	1.0	122.8
Concealed. *Dalmanella* sp., *Schuchertella prolifica*, *Rensselaeria keyserensis*, *Meristella praenuntia?*, *Hormotoma* sp., Bryozoa loose on surface	16.6	121.8
Limestone, banded; conchoidal fracture. *Meristella* sp.?, *Tentaculites gyracanthus*, 105.2	.5	105.2
Concealed	1.0	104.7
Limestone, very impure. *Tentaculites gyracanthus*, *Rensselaeria mutabilis*, Bryozoa, Pelecypoda, 103.2	2.0	103.7
Limestone, thin bedded, fine grained, dark gray, impure, poorly exposed. *Pholidops ovata*, *Rensselaeria obtusa*, Pelecypoda, throughout; Bryozoa, *Schuchertella interstriata?*, *Rensselaeria mutabilis*, *Tentaculites gyracanthus*, *Orthoceras* cf. *O. pauciseptum*, Ostracoda, 101.2; *Camarotoechia* sp.?, *Meristella* sp.?, 99.2	4.0	101.7
Limestone, impure, dark gray, thin bedded, fine grained. Bryozoa, Pelecypoda, throughout; *Rensselaeria keyserensis* (a), 97.7; *Tentaculites gyracanthus*, 96.2, 97.7; *Dalmanella* sp., *Schuchertella prolifica*, *Uncinulus keyserensis* (c), 96.2; *Rensselaeria* (*Beachia*) *proavita*, 95.2, 96.2; *Meristella* sp.?, 96.2	4.3	97.7
Concealed. Bryozoa (c), *Pholidops ovata*, *Rensselaeria obtusa?*, *Meristella* sp.?, Pelecypoda, loose on surface	5.9	93.4
Limestone, very shaly, with purer fine grained light-gray bands. *Spirifer vanuxemi prognosticus*, Pelecypodia, throughout; *Uncinulus keyserensis*, *Dalmanella concinna*, *Meristella* sp.?, 87.2; *Pholidops ovata*, *Stenoschisma formosa?*, *Rensselaeria* (*Beachia*) *proavita*, Ostracoda, 86.2	2.8	87.5
Limestone, very coarsely nodular (4 to 6 inches), light blue-gray; conchoidal fracture. Shale between nodules. *Spirifer vanuxemi prognosticus* throughout; *Camarotoechia litchfieldensis*, *Rensselaeria mutabilis*, Pelecypoda, 84.2; *Uncinulus keyserensis*, 82.2; 83.2; *Rensselaeria keyserensis*, 82.2	3.2	84.7

Section on Kishacoquillas Pike at Mount Rock, Lewistown—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, thin bedded, blue-gray, crystalline. *Spirifer vanuxemi prognosticus*, 80.2, 81.2; *Pholidops ovata*, 80.2; *Camarotechia litchfieldensis*, *Rensselaeria mutabilis*, Pelecypoda, 79.2	*Feet.* 2.9	*Feet.* 81.5
Limestone, massive; in part light blue-gray, fine grained; in part subcrystalline. Bryozoa, *Dalmanella* sp., Pelecypoda, 78.2	2.4	78.6
Limestone, thin bedded (2 to 6 inches), fine grained, light bluish gray; conchoidal fracture. *Atrypa reticularis*, *Camarotoechia*, sp., throughout; *Pholidops ovata* (a), *Dalmanella concinna*, *Merista typa*, Ostracoda, 75.2	7.1	76.2
Limestone, impure, shaly, alternating with harder layers, each in about 6-inch courses. *Pholidops ovata*, *Rensselaeria mutabilis* (a), 68.2	3.4	69.1
Concealed	4.2	65.7
Limestone, shaly, impure, with hard layers of more resistant rock. *Dalmanella concinna*, *Leptæna rhomboidalis*, *Stropheodonta bipartita*, *Camarotoechia litchfieldensis*, *Atrypa reticularis*, *Spirifer vanuxemi prognosticus*, 60.7	1.7	61.5
Limestone, dark gray, crystalline. Bryozoa, *Stropheodonta bipartita*, *Rensselaeria mutabilis*, *Merista typa*, *Calymene camerata*, 56.2	5.1	59.8
Limestone, thin bedded (1 to 6 inches), light blue-gray, fine grained, impure; has shale laminæ between the layers and several small lenses of brown weathered chert. Bryozoa, *Leptaena rhomboidalis*, *Calymene camerata*, 52.2, 54.7; *Stropheodonta bipartita*, 50.2, 53.2; *Spirifer vanuxemi*, 53.2; *Merista typa*, 52.2; *Schuchertella deckerensis*,, 50.2	5.8	54.7
Limestone, massive, nodular, impure, dark gray. Bryozoa, 42.2–47.2; *Leptaena rhomboidalis*, *Stropheodonta bipartita*, *Schuchertella interstriata?*, *Atrypa reticularis*, 47.2; *Dalmanella concinna*, *Stenoschisma formosa*, *Spirifer vanuxemi*, *Orthoceras* sp., 45.2; *Gypidula coeymanensis prognostica*, 42.2; *Merista typa*, 41.2	8.3	48.9
Limestone, massive, dark gray, impure, not very nodular. *Orthostrophia strophomenoides*, *Stenoschisma formosa* (c), *Spirifer octocostatus*, *Merista typa*, 40.2; *Gypidula coeymanensis* var. *prognosticus* (a), *Atrypa reticularis*, 38.2, 40.2; Bryozoa, 37.2	4.1	40.6

Section on Kishacoquillas Pike at Mount Rock, Lewistown—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.	*Feet.*	*Feet.*
Shale, weathered, yellow	0.5	36.5
Limestone, very nodular, impure, shaly, gray; many of its fossils are silicified. *Atrypa reticularis* throughout; Pelecypoda, 35.2; Bryozoa, *Dalmanella concinna, Strophonella leavenworthana* var., 34.2	2.4	36.0
Limestone, massive, somewhat nodular, dark gray, subcrystalline, impure. *Gypidula prognostica* (a) throughout. *Schuchertella swartzi?, Atrypa reticularis*, 33.2; *Dalmanella clarki?, Rhipidomella emarginata?, Leptaena rhomboidalis, Strophonella geniculata, Chonetes jerseyensis* (c), *Stenoschisma deckerensis* (a), *Rensselaeria mutabilis?, Nucleospira ventricosa, Goldius barrandi, Cyphaspis* cf. *C. minuscula, Calymene camerata*, Ostracoda, Pelecypoda, 31.2	2.8	33.6
Limestone, very nodular, impure, dark gray, weathered	1.8	30.8
Limestone, massive, not nodular, dark gray, coarsely crystalline	1.6	29.0
Limestone, nodular, impure, weathered; bastard limestone with occasional thin lenses of black chert. Ostracoda, 26.2	2.6	27.4
Limestone, crystalline, dark blue, thin bedded, with shaly laminae. Pelecypoda, 23.8	2.0	24.8
Limestone, crystalline, dark blue, pure, massive, not nodular. *Schuchertella deckerensis* (c), *Chonetes jerseyensis, Uncinulus* sp., *Atrypa reticularis*, 21.9	1.9	22.8
Limestone, weathered, very nodular. *Chonetes jerseyensis, Stenoschisma formosa*, throughout; *Dalmanella concinna, Stropheodonta bipartita, Meristella* sp.?, 17.2	4.4	20.9
Limestone, massive, blue-gray, coarse, crystalline, crinoidal; weathers thin bedded in upper part. *Camarotoechia* sp., *Rhynchospira* sp., throughout	9.4	16.5
Limestone, single massive bed, pure, dark gray, coarsely crystalline and crinoidal in part; fine grained and curly in other parts, which suggest slightly weathered *Stromatopora*. *Spirifer vanuxemi*, 1.9	6.2	7.1
Limestone, nodular, impure, weathered; crystalline on fresh fracture and blue-gray. *Spirifer* abundant on basal face	.9	.9
	157.9	

Section on Kishacoquillas Pike at Mount Rock, Lewistown—Continued.

	Thickness.	Total thickness.
Tonoloway limestone:		
Limestone, rather massive, fine grained, pure, dark gray, almost a blue-black; conchoidal fracture. *Leperditia* sp., *Camarotoechia? lamellata*, −0.2, −2.3; *Camarotoechia litchfieldensis*, −0.2; Ostracoda (c), −17.3; *Spirifer keyserensis*, −2.3	*Feet.* 6.4	*Feet.* −6.4
Limestone, thin bedded (1 inch); much like unit above, but less massive and resistant; looks fairly solid where entirely unweathered; pure. *Leperditia* sp. throughout; *Camarotoechia? lamellata*, −18.8	13.4	−19.8
Limestone, solid-looking, heavy bedded, gray	5.0	−24.8
Shale, weathered	.5	−25.3
Limestone, fairly solid, gray, in three beds (18, 12, 12 inches) separated by shale	3.5	−28.8
Limestone, gray; weathers into small blocky fragments and has a somewhat nodular appearance	4.0	−32.8
Limestone, thin bedded, gray	2.0	−34.8
	34.8	

This section contains near the top of the Tonoloway formation the zone of *Spirifer keyserensis* which is present at the same horizon at Dalmatia and in Maryland. The lower part of the Keyser member is massive and crinoidal, resembling the heavy crinoidal bed at Mapleton. The zone of *Gypidula coeymanensis* var. *prognosticus*, so persistent and so well marked in Maryland, seems to be developed here, as at Selinsgrove Junction. The upper part of the Keyser is so poorly exposed as to render the identification of the fossil zones difficult, but the presence of the *Leperditia* subzone just beneath the Coeymans is a feature of interest.

CLARK'S MILL, NORTHWEST OF NEW BLOOMFIELD.

The section given below lies along the Newport & Sherman's Valley Railroad a short distance north of McKee station and about 2 miles northwest of New Bloomfield, the county seat of Perry County. The highest exposures are just opposite the old Clark's Mill.

The section was measured and studied in 1885 by E. W. Claypole,[1] who divided it into

[1] Pennsylvania Second Geol. Survey Rept. F2, p. 182, 1885.

the following: Black cherty limestone, 8 feet; Clark's Mill lime shales, 150 feet; Lewistown limestone, 100 feet. His Clark's Mill lime shales he correlated in a general way with the "Delthyris shaly limestone" and "Lower Pentamerus limestone" of New York—that is, with the Coeymans-New Scotland interval. The Lewistown he correlated with the "Waterlime" or "Tentaculite" limestone of New York.

This section was examined in 1913 by C. K. Swartz,[1] who cited Claypole's measurements and recognized in the lower 103 feet the Tonoloway of Maryland and in the upper 150 feet the Keyser of Maryland.

In the following section the beds in the upper 140 feet comprise the entire Keyser member of the Helderberg and are apparently the same as those included by Claypole in his Clark's Mill lime shale. The beds in the lower 62 feet are equivalent to part of the Tonoloway of Maryland. The concealed interval immediately above the Keyser carries weathered *Gypidula* valves on its surface, and it is likely that the Coeymans member of the Helderberg is represented by part of this interval.

Section at Clark's Mill, about 2 miles northwest of New Bloomfield.

	Thickness.	Total thickness.
Concealed by residual clay, filled with white blocky chert, fragments of coarse sandstone, and thin, platy, shaly limestone. Immediately above the top of the Keyser, weathered *Gypidula* valves and segments of a large crinoid column are abundant and indicate the probable presence of the Coeymans member of the Helderberg.		
Helderberg limestone (Keyser limestone member):		
Limestone, fissile, platy, dark gray; fragments ring when dropped; no chert; fresh surface shows distinct lamination	*Feet.* 2.0	*Feet.* 139.7
Limestone, thin bedded, dark gray, with much interbedded black chert; one layer is about 10 inches thick; compact, bluish gray, with conchoidal fracture. *Schuchertella prolifica*, *Meristella praenuntia*, *Tentaculites gyracanthus*, Ostracoda (c), 137.7–136.7	5.8	137.7
Limestone, thin bedded, full of crinoid fragments and other fossils, crystalline. Bryozoa (a), *Schuchertella prolifica* (a), *Meristella praenuntia* (c), *Tentaculites gyracanthus* (a)	1.0	131.9
Concealed by talus	2.7	130.9

[1] Maryland Geol. Survey, Lower Devonian, p. 105, 1913.

Section at Clark's Mill, about 2 miles northwest of New Bloomfield—Continued.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member)—Continued.		
Limestone, thin bedded (1 to 3 inches), a little nodular, bluish gray; some of the layers are compact, with conchoidal fracture; others are subcrystalline, crinoidal, and crammed with fossils; the unit, however, looks homogeneous. *Meristella praenuntia*, *Tentaculites gyracanthus*, Bryozoa, Ostracoda, Pelecypoda, throughout; *Orbiculoidea* sp., *Camarotoechia* sp., 127.1; *Orbiculoidea discus* (a), 123.5; *Pholidops ovata*, 119.1–122.1; *Orthoceras* sp., 121.1; *Whitfieldella* cf. *W. nucleolata*, 113.6, 109.1	*Feet.* 20.1	*Feet.* 128.2
Limestone, thin bedded, blue, crinoidal, subcrystalline, and crammed with fossil fragments. Bryozoa, *Dalmanella clarki*, *Camarotoechia* sp., *Whitfieldella* cf. *W. nucleolata*, *Meristella praenuntia*, *Tentaculites gyracanthus*	1.5	108.1
Concealed	3.0	106.6
Limestone, crinoidal, bluish. *Uncinulus keyserensis?*, *Uncinulus gordoni*, *Uncinulus nucleolatus*, *Whitfieldella* cf. *W. nucleolata*, *Orthoceras* sp	.5	103.6
Concealed. *Lingula* sp., *Orbiculoidea* sp., *Pholidops ovata*, *Dalmanella concinna?*, *Dalmanella clarki* (c), *Schuchertella prolifica*, *Schuchertella swartzi*, *Camarotoechia litchfieldensis*, *Uncinulus nuceolatus*, *Uncinulus keyserensis*, *Rensselaeria keyserensis* (a), *Rensselaeria obtusa* (a), *Beachia proavita*, *Spirifer vanuxemi prognosticus*, *Rhynchospira* sp., *Nucleospira ventricosa?*, *Meristella praenuntia*, *Tentaculites gyracanthus*, *Orthoceras* sp., *Favosites* sp., *Spirorbis* sp., Bryozoa, Pelecypoda, Ostracoda, loose on the surface	4.7	103.1
Limestone, gray, crammed with a ramose bryozoan, *Uncinulus nucleolatus*, *Uncinulus keyserensis*, *Spirifer vanuxemi prognosticus*, Ostracoda	1.0	98.4
Concealed	2.0	97.4
Limestone, compact, hard, bluish. *Pholidops ovata*, *Camarotoechia litchfieldensis*, Ostracoda (a)	.5	95.4
Concealed. Bryozoa, *Pholidops ovata* (c), *Dalmanella concinna*, *Dalmanella clarki*, *Leptaena rhomboidalis*, *Stropheodonta bipartita* (a), *Schuchertella swartzi*, *Camarotoechia litchfieldensis*, *Uncinulus keyserensis*, *Uncinulus mutabilis*, *Atrypa reticularis* (a), *Spirifer octocostatus*, *Spirifer vanuxemi* var. *prognosticus* (a), *Whitfieldella* cf. *W. nucleolata*, *Meristella* sp., *Coelidium pennsylvanicum*, *Holopea antiqua?*, *Cyclonema* sp., *Tentaculites gyracanthus*, *Orthoceras* sp., *Calymene camerata*, Ostracoda (a), loose on the surface	27.6	94.9

Section at Clark's Mill, about 2 miles northwest of New Bloomfield—Continued.

	Thickness.	Total thickness.
Helderberg limestone (Keyser limestone member)—Continued.		
Limestone, thin bedded, dense, bluish; conchoidal fracture. Bryozoa, Ostracoda, throughout; *Dalmanella concinna*, *Leptæna rhomboidalis*, 67.3–66.4; *Stropheodonta bipartita*, *Schuchertella prolifica?*, *Uncinulus keyserensis*, *Spirifer vanuxemi prognosticus*, *Calymene camerata*, 66.4	*Feet.* 4.0	*Feet.* 67.3
Concealed. *Favosites* sp., Stromatoporoidea, Bryozoa, *Dalmanella concinna*, *Leptaena rhomboidalis*, *Strophonella geniculata?*, *Strophonella leavenworthana* var., *Uncinulus keyserensis*, *Spirifer vanuxemi prognosticus*, loose on the surface	20.0	63.3
Limestone, thin bedded, blue, nodular. *Favosites* sp., *Chonetes jerseyensis*, throughout; *Dalmanella* sp., *Schuchertella deckerensis* (a), *Stenoschisma formosa*, *Camarotoechia litchfieldensis* (c), *Spirifer modestus*, Pelecypoda, Ostracoda, 42.3	5.0	43.3
Concealed. *Favosites* sp., Stromatoporoidea, *Chonetes jerseyensis*, *Meristella prænuntia*, *Calymene camerata*, loose on the surface	4.6	38.3
Limestone, very thin bedded, nodular, dark gray. *Camarotoechia litchfieldensis*, 32.6, 31.6; Ostracoda, 30.6	4.2	33.7
Concealed. *Ectomaria minuta*, *Hormotoma* sp., loose on the surface	3.0	29.5
Limestone, thin bedded, much weathered and stained; débris full of fossils. *Sphaerocystites multifasciatus*, 24.5?, 26.5; *Camarotoechia?*, *lamellata*, Stromatoporoidea, *Stenoschisma formosa*, *Camarotoechia litchfieldensis*, *Spirifer modestus*, *Spirifer modestus* var. *plicatus?*, *Rhynchospira globosa* (a), *Leperditia* sp. (a), loose on the surface	6.0	26.5
Limestone, thin bedded, rather nodular, dark gray; upper 3 feet heavier bedded. *Whitfieldella* cf. *W. nucleolata*, 20.5; *Ectomaria minuta*, 20.5?, 17.5; *Leperditia* sp., 20.5, 17.5, 13.9 (a); Ostracoda, 17.5	9.9	20.5
Concealed interval	3.0	10.6
Limestone, thin bedded, very nodular, bluish gray. *Camarotoechia? lamellata*, 6.6, 5.6; *Spirifer vanuxemi*, 6.6; *Rhynchospira globosa*, 6.6, 4.6; *Leperditia* sp., 6.6–3.6; *Rhynchospira* sp., 5.6; Ostracoda, 5.6 (a), 3.6	6.6	7.6
Limestone, single heavy bed, compact, dark gray	1.0	1.0
	139.7	
Tonoloway limestone:		
Limestone, rather massive, dark gray, not nodular. *Leperditia* sp., −1.5	3.0	−3.0

Section at Clark's Mill, about 2 miles northwest of New Bloomfield—Continued.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, fissile, platy, yellowish, banded; fossils very rare; very different from overlying beds; gives a shingle-like talus; dark gray on fresh fracture	*Feet.* 5.9	*Feet.* −8.9
Limestone, single bed, dark gray. *Leperditia* sp., −8.9 to −9.9	1.0	−9.9
Limestone, dark gray, separated into 1-inch courses by silicified seams ⅛ inch thick, which stand out a little in relief. *Leperditia* sp., −11.2 to −12.3	2.6	−12.5
Limestone, single bed, knotty, dark gray; weathers into laminæ	3.6	−16.1
Limestone, platy, shaly; weathers into plates	4.0	−20.1
Shale, contorted, yellow, partly concealed	4.0	−24.1
Limestone, knotty, irregular, yet massive	5.0	−29.1
Concealed	7.5	−36.6
Limestone, very thin bedded, platy, dark gray	8.6	−45.2
Limestone, massive bed, dark gray; breaks into thin plates	6.2	−51.4
Concealed	4.5	−55.9
Limestone, massive, dark gray; breaks into thin plates. *Leperditia* sp., −56.3	6.0	−61.9
Concealed below.		
	61.9	

The Clark's Mill section has the faunas of the *Chonetes jerseyensis* and *Favosites helderbergiae* var. *praecedens* zones well developed and is divisible into a number of subzones.

DALMATIA.

An excellent exposure of part of the Tonoloway formation, the Helderberg, and the Oriskany is to be seen along the Northern Central Railway 1 mile south of Dalmatia. The lower beds are shown in a large abandoned quarry, and most of the Keyser and higher beds have been laid bare by the cuttings of the railway company.

The section was studied by I. C. White[1] in 1883 and referred to by him as the Georgetown section. He recognized in it the Oriskany sandstones; the Stormville shale, 100 feet thick; the Stormville and Bastard limestones, with a combined thickness of 135 feet; the Bossardville beds, with a thickness of 115 feet; and, at the base, the Salina. The sub-

[1] Pennsylvania Second Geol. Survey Rept. G7, p. 93, 1883.

joined section does not include any of White's Oriskany, the uppermost units, referred to the New Scotland, representing part of his Stormville shale. The beds forming the Coeymans and Keyser members of the Helderberg are his Stormville and Bastard limestones. The Tonoloway portion of the section is all included in his Bossardville.

The Tonoloway-Keyser contact is placed at the base of the nodular beds. The Keyser-Coeymans contact is marked sharply by the very sandy limestone forming the Coeymans member. This limestone contains few fossils, but its stratigraphic position and its lithologic agreement with the Coeymans of other sections justify its reference to this member. At the Emrick & Lebo quarry, 4 miles northeast of Dalmatia and about a quarter of a mile south of Mandata (Bull Run), this sandy limestone is about 6 feet thick and is overlain by shale carrying *Spirifer macropleurus*. The Coeymans-New Scotland contact is placed at the base of the concealed unit, which carries loose on its surface numerous New Scotland fossils.

Section 1 mile south of Dalmatia.

	Thickness.	Total thickness.
Helderberg limestone:		
New Scotland limestone member:		
Concealed by wash, filled with yellow-brown ochery shale and much chert. *Strophonella punctulifera*, Pelecypoda	*Feet.* 6.4	*Feet.* 21.6
Shale, ochery yellow, fissile, fine grained. Bryozoa, *Spirifer cyclopteris*, *Anoplotheca concava*	1.5	15.2
Concealed interval; clay and soil filled with fragments of weathered brown ochery shale and sandstone; a little chert observed. *Pholidops ovata* (c), *Dalmanella perelegans* (c), *Stropheodonta beckii*, *Chonetes* cf. *C. hemisphericus*, *Spirifer perlamellosus*, *Spirifer cyclopterus*, *Anoplotheca concava* (a), *Meristella* sp., *Phacops logani?* Ostracoda, loose on the surface	13.7	13.7
	21.6	
Coeymans limestone member:		
Limestone, coarse, dark gray, very sandy; weathers to resemble a brown ferruginous sandstone; contains black chert lentils; no fossils observed	2.0	2.0
	2.0	

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, banded, fine grained, with conchoidal fracture, in 2 to 4 inch layers, separated by same thickness of weathered yellow shale; contains near top some large, irregular curly masses (18 inches in diameter), which look somewhat like *Stromatopora*	*Feet.* 10.3	*Feet.* 139.8
Limestone, blue-gray, conchoidal, fine grained, in four layers (8, 10, 3, 10 inches), separated by platy yellowish limestone	3.3	129.5
Limestone, banded, fine grained, extremely platy; yellow on weathered surface, light gray on fresh fracture; calcite seam at top	5.7	126.2
Limestone, blue-gray, fine grained, conchoidal, thin bedded (6 inches); scattered lentils of black chert (1 inch thick and 18 inches long); calcite sheet at 118.6 and top	2.9	120.5
Limestone, bluish, fine grained; conchoidal fracture; in thin layers (1 to 3 inches), with shale laminae between; calcite sheet at 111.6 and at top. *Meristella* sp., 107.6–116.6; *Tentaculites gyracanthus*, 106.1–112.6; Pelecypoda, 106.1, 107.6	12.1	117.6
Limestone, very impure, dark, shaly; carries irregular lenses (2 to 3 inches in diameter) of pure bluish limestone; in bulk about half of each; weathers to a light-gray color; calcite seam near base and at top. *Meristella praenuntia* (a), 99.6–102.6; Pelecypoda, *Tentaculites gyracanthus*, 99.6–104.6	6.0	105.5
Limestone, pure, thin bedded, fine grained, bluish gray; conchoidal fracture; some fossiliferous lenses. *Meristella* sp., 98.6	1.7	99.5
Limestone, coarse, blue-gray, crystalline, in irregular 2 to 3 inch layers with light-gray shale laminae between; calcite sheet near top. *Uncinulus keyserensis*, *Meristella praenuntia*, *Tentaculites gyracanthus*, and Pelecypoda throughout; Bryozoa, *Camarotoechia litchfieldensis*, *Whitfieldella* cf. *W. nucleolata*, 94.9	3.2	97.8
Limestone, shaly, weathered, impure, dark gray; contains a few pure crystalline streaks; calcite sheet near top. *Meristella* sp., *Tentaculites gyracanthus*, 93.6	1.9	94.6

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, coarse, crystalline, bluish gray, profusely fossiliferous. *Uncinulus keyserensis?*, *Meristella praenuntia* (a), *Tentaculites gyracanthus*, Pelecypoda, Bryozoa, Ostracoda. 92.6	*Feet.* 0.4	*Feet.* 92.7
Limestone, solid, impure, dark gray; weathers yellow; contains many streaks of pure fine-grained limestone; calcite sheet at top. *Whitfieldella? prosseri*, *Meristella praenuntia* (a), *Tentaculites gyracanthus* (a), *Orthoceras* sp., Pelecypoda, 90.6	2.0	92.3
Limestone, coarse, crystalline, blue-gray; weathers light gray; profusely fossiliferous. *Uncinulus keyserensis*, *Meristella praenuntia* (c) throughout; Bryozoa, *Atrypa rugosa?*, *Whitfieldella* cf. *W. nucleolata*, Pelecypoda, 89.6; *Uncinulus nucleolatus*, *Rensselaeria mutabilis* (c), 88.6	2.3	90.3
Limestone, impure, medium gray, fine grained; weathers brown and has a number of thin conchoidal purer lenses which weather light gray; calcite sheet at base; solid unit as a whole. *Tentaculites gyracanthus* throughout; Ostracoda, 85.6	3.9	88.0
Limestone, blue, crystalline, in lenses 1 to 2 inches thick, with irregular shaly layers between; shale weathers yellow; limestone gray. *Meristella piraenuntia*, *Tentaculites gyracanthus*, Ostracoda, throughout; *Rensselaeria mutabilis*, 82.1	2.2	84.1
Limestone, in four layers; blue, conchoidal, fine grained; crystalline fossiliferous streak at 80.6; shale laminae between layers. *Meristella praenuntia*, *Tentaculites gyranthus*, 80.6	2.5	81.9
Shale, calcareous; light gray and yellow on weathered surface, dark gray on fresh fracture; has a diagonal "shear" parting and is interleaved with numerous thin beds of pure blue-gray crystalline limestone. *Rensselaeria mutabilis* (a), 78.8; *Rensselaeria keyserensis*, *Tentaculites gyracanthus*, Pelecypoda, 78.8, 77.3; *Pholidops ovata*, *Dalmanella* sp., *Schuchertella prolifica*, *Rensselaeria* (*Beachia*) *proavita* (a), *Meristella* sp.?, Bryozoa, 77.3	4.0	79.4
Limestone, solid, blue, fine grained; conchoidal fracture; apparently very pure; calcite sheets at top, at base, and in middle	2.6	75.4

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Shale, calcareous; light gray and yellow on weathered surface, dark on fresh fracture. *Spirifer vanuxemi prognosticus*, *Tentaculites gyracanthus*, throughout; Bryozoa, *Orbiculoidea* cf. *O. numula*, *Rensselaeria keyserensis*, *Orthoceras* sp., 71.1; Pelecypoda, 71.1, 70.3; *Pholidops ovata*, Ostracoda, 70.3 (a), 67.0; *Meristella praenuntia?*, *Holopea antiqua?*, *Orbiculoidea* sp., 70.3; *Camarotoechia* sp.?, *Rensselaeria mutabilis*, 67.0	*Feet.* 6.5	*Feet.* 72.8
Limestone, solid but impure; dark gray and fine grained on fresh fracture, but very light gray and yellow on weathered surfaces; calcite seam at top with a slickensided surface. *Orbiculoidea* cf. *O. numula*, *Coelidium dalmatiae*, *Rensselaeria mutabilis*, 65.6; Pelecypoda, 65.6, 63.6; *Orthoceras* sp., 64.6, 63.6; *Meristella* sp.?, Ostracoda, 63.6	3.0	66.3
Shale, calcareous, very platy and papery; weathers yellowish and light gray; contains a number of solid but impure limestone layers (2 to 6 inches thick); shaly parts show much diagonal "shear" parting	7.5	63.3
Shale, calcareous, light gray, with diagonal "shear" parting	.5	55.8
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline fossiliferous seams. *Dalmanella concinna*, *Leptaena rhomboidalis*, *Stropheodonta bipartita*, *Atrypa reticularis*, Ostracoda, throughout; Bryozoa, *Camarotoechia* sp., *Spirifer vanuxemi prognosticus*, *Proetus* sp.?, *Calymene camerata*, 55.1; *Camarotoechia litchfieldensis*, *Uncinulus keyserensis?*, *Meristella* sp., *Merista typa*, 52.2	3.9	55.3
Limestone, single layer, finely crystalline, light bluish; conchoidal fracture; calcite seam at top. *Meristella* sp.?, 51.3	.3	51.4
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline fossiliferous seams. Byrozoa, *Spirifer vanuxemi prognosticus*, throughout; *Leptaena rhomboidalis*, *Stropheodonta bipartita*, *Strophonella geniculata*, *Camarotoechia litchfieldensis*, Pelecypoda, Ostracoda, 48.2	4.0	51.1
Limestone, single layer, finely crystalline, light bluish; conchoidal fracture; ½-inch calcite seam at top. *Spirifer vanuxemi prognosticus*, 46.9	.4	47.1

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, massive, dark gray, crystalline, not distinctly nodular; fossils show on weathered surface sparingly. *Leptaena rhomboidalis*, 45.7	*Feet.* 2.2	*Feet.* 46.7
Limestone, massive, nodular, impure, dark gray, coarsely crystalline layers; calcite seams persistent parallel to bedding at 44.5, 42.4. Bryozoa, 41.6 to 44.4; *Orbiculoidea* sp., *Spirifer vanuxemi prognosticus*, *Uncinulus* sp., *Proetus* sp., 44.4; *Stropheodonta bipartita*, 40.6 to 44.4; *Rensselaeria mutabilis*, 44.4, 42.6; *Uncinulus keyserensis*, 31.7 to 42.6; *Rensselaeria* (*Beachia*) *proavita*, *Whitfieldella* cf. *W. nucleolata*, *Meristella* sp., Pelecypoda, *Calymene camerata*, *Camarotoechia litchfieldensis*, 42.6; *Dalmanella* cf. *D. perelegans*, 41.6; *Atrypa reticularis*, 38.6; *Orthoceras* sp., 37.1	8.1	44.5
Limestone, massive, nodular, impure, medium gray; nodules pure, matrix impure and shaly. *Favosites*, in large heads, abundant in lower 7 feet; *Leptaena rhomboidalis*, 36.4, 34.6; *Dalmanella* sp., *Stenoschisma deckerensis?*, *Atrypa reticularis* (a), *Rhynchospira globosa*, *Coelidium dalmatiae*, 34.6; *Favosites* sp., 30.6–25.6; *Dalmanella concinna*, *Stropheodonta bipartita*, *Stenoschisma formosa*, Pelecypoda, 30.6; *Orthoceras* sp., 27.6; *Schuchertella* sp., *Camarotoechia litchfieldensis*, *Spirifer modestus*, 23.7	12.8	36.4
Limestone, massive, nodular, impure, much like unit above; calcite seams, 16.1, 23.6; layer of *Stromatopora*, 3 to 6 inches, 15.1–15.6; *Dalmanella* sp., *Schuchertella deckerensis*, *Chonetes jerseyensis*, *Stenoschisma deckerensis*, 22.6; *Calymene camerata*, *Camarotoechia litchfieldensis*, 22.6, 16.6; *Spirifer modestus*, 22.6 (a), 13.6?; *Camarotoechia? lamellata*, 13.6–18.1; *Spirifer* sp., 16.6; Ostracoda, 16.6, 13.6; Pelecypoda, 15.6, 13.6; *Spirifer vanuxemi*, 12.6	12.3	23.6
Limestone, massive, nodular, dark gray, impure; ½-inch seam of calcite at base; when weathered looks thin bedded. *Camarotoechia? lamellata*, Ostracoda (c), throughout; *Spirifer vanuxemi*, *Tentaculites gyracanthus*, 8.6; *Camarotoechia litchfieldensis*, *Spirifer modestus?*, 7.6; *Leperditia* sp., 6.6	5.8	11.3

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, massive, nodular, dark gray; conchoidal fracture. *Camarotoechia? lamellata* throughout; Bryozoa, *Spirifer* sp., 5.0	*Feet.* 5.5	*Feet.* 5.5
	139.8	
Tonoloway limestone:		
Limestone, dark gray, pure, crystalline; solid bed; shows a rude columnar character in places; has everywhere one or two ½-inch calcite seams at base. *Spirifer keyserensis*, 1.4; *Leperditia* sp., Ostracoda, −2.4	3.2	−3.2
Limestone, thin bedded (1 to 3 inches); beds do not seem to separate, and unit looks rather massive; dark gray, fine grained, conchoidal in part; crystalline in part; very pure. *Leperditia* throughout; *Camarotoechia lamellata*, −5.4, −11.4, −21.4; *Camarotoechia litchfieldensis*, −5.4, −11.4; *Spirifer keyserensis*, −5.4 to −15.9; Ostracoda, −12.4, −14.9	20.4	−23.6
Limestone, thin bedded (3 to 6 inches), dark gray, in part coarsely crystalline. *Camarotoechia? lamellata*, *Leperditia* sp., Ostracoda, −24.4	1.7	−25.3
Limestone, massive, dark gray, crystalline. *Leperditia* sp., −25.4?, −27.0, −29.0	4.7	−30.0
Limestone, impure-looking, dark gray, banded; much very fine, disseminated pyrite; purer than the next lower unit	2.5	−32.5
Limestone, impure, gritty-looking, dark gray, with a pronounced diagonal parting; looks as if it had been sheared	3.6	−36.1
Limestone, massive, banded, pure, dark gray; shows columnar structure	2.4	−38.5
Limestone, shaly, dirty gray; irregular, diagonal "shear" parting; 1 inch of calcite at base	.6	−39.1
Limestone, massive, banded, pure, gray; shows columnar structure in places. *Leperditia* sp., −39.4, −42.8	4.7	−43.8
Limestone, alternating shaly and pure in 1-inch courses	.9	−44.7
Limestone, massive, dark gray, pure, banded	.8	−45.5
Limestone, same, not banded. *Leperditia* sp., −45.9	.6	−46.1
Limestone, massive, dark gray, pure, banded	1.7	−47.8
Limestone, dirty gray, sandy-looking but contains no sand; shows everywhere an irregular diagonal parting as if it had been sheared	.7	−48.5
Limestone, pure, platy, dark gray	1.0	−49.5
Limestone, very massive, blue-gray; shows no banding	3.2	−52.7

Section 1 mile south of Dalmatia—Continued.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, pure, very platy, laminated; has some geodal calcite layers; shows distinct rude columnar structure in places	*Feet.* 6. 9	*Feet.* −59. 6
Limestone, pure, dark gray, fine grained; conchoidal fracture	1. 0	−60. 6
Limestone, pure, dark gray, very platy and laminated	1. 0	−61. 6
Limestone, light gray, fine grained; conchoidal fracture; has black layers which mottle its fracture surfaces	. 8	−62. 4
Limestone, platy, dark, impure, passing into weathered yellow calcareous shale above	3. 2	−65. 6
Limestone, pure, thin bedded (3 to 6 inches), blue-gray	1. 0	−66. 6
Shale, calcareous, weathered, yellow, with some geodal calcite layers and several thin limestone streaks	6. 7	−73. 3
Limestone, fairly pure, but thin bedded and platy	6. 2	−79. 5
Limestone, impure, banded, platy, light gray; curly layer near base contains small radiating masses of strontianite	2. 2	−81. 7
Shale, weathered, yellow	. 6	−82. 3
Limestone, curly, dull gray, fine grained, with much disseminated pyrite	. 2	−82. 5
Limestone, heavy, blue-gray, pure, fine grained; shows some banding	3. 0	−85. 5
Limestone, impure, shaly-looking; weathers into thin laminae; perhaps a little purer in middle 3 feet	12. 0	−97. 5
Limestone, pure, dark gray, thin bedded (1 to 2 inches)	. 9	−98. 4
Limestone, impure, shaly, dark gray	1. 5	−99. 9
Limestone, fairly pure, dark gray, thin bedded (1 to 2 inches)	2. 5	−102. 4
Concealed by quarry débris.		
	102. 4	

In this section the characteristic faunas of the *Chonetes jerseyensis* and *Favosites helderbergiae* var. *praecedens* zones are well developed, and a number of subzones are recognizable. The Tonoloway formation contains near its top the zone of *Spirifer keyserensis*, which is recognized at the same horizon in Maryland.

SELINSGROVE JUNCTION.

The limestone described by the Second Geological Survey of Pennsylvania as the Lewistown limestone or "Formation No. VI" is exposed along the Northern Central Railway north of Selinsgrove Junction. Susquehanna River cuts across an anticlinal arch at this point, presenting a section which begins 1 mile above the railway station and extends approximately 1½ miles toward the north. Both limbs of the anticline were studied, but only the southern half is described here. The concealed unit forming the center of the arch is probably of Wills Creek age. The succeeding 148 feet of beds contain only *Leperditia*, rare *Rhynchospira*, and *Ectomaria* and have the characteristic lithology of the Maryland Tonoloway, with which they are probably to be correlated. The overlying beds are richly fossiliferous and embrace the Keyser, Coeymans, and New Scotland members of the Helderberg formation. These are succeeded by the Oriskany formation. No indication of the presence of the Becraft member of the Helderberg was seen. The exposures here are excellent and afford the best and most continuous section of these formations observed by the writer.

The two sections were measured by I. C. White,[1] who refers the lowest part to the Salina, and the overlying beds to the Bossardville, Bastard limestone, Stormville limestone, Stormville shales, and Oriskany. It is probable that the upper 114 feet of the Tonoloway formation described in the subjoined section represents White's Bossardville; the beds from the base of the Keyser to the base of the calcareous shales of the New Scotland represent his Bastard and Stormville limestones; and the shaly beds above the New Scotland limestone and extending up to the top of the section represent his Stormville shales. On the north side of the axis there is exposed above the horizons shown in the southern section about 25 feet of coarse cherty ferruginous sandstones, which are probably White's Oriskany beds.

The Helderbergian portion of the section was examined also by C. K. Swartz [2] in 1913. He recognized in it the equivalents of the Maryland Keyser and referred the underlying beds to the Tonoloway.

As fossils are comparatively rare in the beds lying immediately above the New Scotland limestone, the position of the New Scotland-Oriskany contact is open to question. The writer places it tentatively at the base of the lowest distinctly sandy beds.

[1] Pennsylvania Second Geol. Survey Rept. G7, p. 93, 1883.
[2] Maryland Geol. Survey, Lower Devonian, p. 108, 1913.

Section on south side of anticlinal axis at Selinsgrove Junction.

	Thickness.	Total thickness.
Oriskany formation:		
Sandstone, cherty, fine grained, ferruginous	*Feet.* 4.0	*Feet.* 54.4
Concealed	10.9	50.4
Sandstone, cherty, fine grained, ferruginous. *Anoplotheca flabellites*, 39.5, 32.5	7.1	39.4
Concealed.		
Limestone, dark gray, fine grained, very arenaceous; numerous 1-inch chert lentils	12.0	32.4
Shale, dark brown.		
Limestone, dark gray, fine grained, very arenaceous; numerous 1-inch chert lentils. *Spirifer* sp	15.0	20.4
Shale, very sandy; breaks into flat fragments; dark gray to chocolate-brown	5.4	5.4
	54.4	
Helderberg limestone:		
New Scotland limestone member:		
Limestone, very impure, dark gray, mottled with yellow; weathers into small irregular fragments, some of which are siliceous	8.6	57.6
Lime shales, dark gray, with a few thin limestone layers; weathers to thin laminae	35.8	49.0
Limestone massive, crystalline, arenaceous, dark gray. *Lingula* sp., 6.0, 12.0; *Dalmanella perelegans*, *Leptaena rhomboidalis*, *Meristella* sp., 4.3–9.0; *Schuchertella woolworthana*, 6.0–9.0; *Uncinulus nucleolatus*, 9.0; *Eatonia medialis*, 8.9, 9.0; *Spirifer macropleurus*, *Spirifer perlamellosus*, *Phacops logani*, *Dalmanites* sp., 9.0; Pelecypoda, Bryozoa, Ostracoda	9.0	13.2
Limestone, in large nodules (diameter 6 to 8 inches), embedded in a shaly matrix. *Dalmanella perelegans*, *Schuchertella woolworthana*, *Eatonia medialis*, *Anoplotheca concava* (a), 3.7	4.2	4.2
	57.6	
Coeymans limestone member:		
Limestone, fairly massive, coarse, blue-gray, arenaceous, interbedded with layers of black chert 3 to 4 inches thick; joint planes show large imperfect crystals of calcite and quartz. *Pholidops ovata*, *Dalmanella perelegans*, *Stropheodonta leavenworthana*, *Schuchertella woolworthana?*, *Gypidula coeymanensis*, *Atrypa reticularis*, *Leptaena rhomboidalis*, *Spirifer* sp., *Meristella* sp., *Phacops logani*, Pelecypoda, Bryozoa, Ostracoda	3.6	3.6
	3.6	

Section on south side of anticlinal axis at Selinsgrove Junction—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member:		
Limestone, thin bedded, (1 to 3 inches), blue, fine grained. *Leperditia* sp., 201.9	*Feet.* 5.5	*Feet.* 202.3
Limestone, blue, fine grained, with conchoidal fracture; courses 6 to 12 inches, separated by about the same thickness of gray calcareous and arenaceous shale	6.9	196.8
Shale, yellow	1.4	189.9
Limestone, heavy bedded, massive, impure, light gray, indistinctly laminated	18.3	188.5
Limestone, medium bedded, impure, light gray; a few layers very shaly and weathered; toward upper part the bedding planes weather out clearer and rock is laminated; not distinctly separated from underlying unit. *Tentaculites gyracanthus*, 154.9	17.1	170.2
Limestone, thin bedded (1 to 2 inches); some layers crystalline, pure, blue, fossiliferous; others impure and shaly. *Tentaculites gyracanthus* (a), Pelecypoda (a), throughout; *Camarotoechia litchfieldensis?*, *Whitfieldella* cf. *W. nucleolata* (a), *Meristella praenuntia*, Ostracoda, 150.4	3.5	153.1
Limestone, finely crystalline, light bluish gray, in two solid beds separated by 8 inches of shaly limestone. *Tentaculites gyracanthus* scattered throughout the heavy beds; abundant in the shaly layer	3.2	149.6
Limestone, pure, fine grained, thin bedded (3 to 8 inches), blue; breaks with conchoidal fracture, though a few layers are platy and impure; layers are separated by thin shale. *Tentaculites gyracanthus* 139.4–144.9; *Pholidops ovata*, *Meristella praenuntia* (c), *Holopea* sp., *Orthoceras* sp., 141.1; Pelecypoda, 143.9, 144.9; Ostracoda, 144.9	7.8	146.4
Shale, weathered, yellow, filled with small lenses of crystalline blue limestone crowded with *Schuchertella prolifica* (a), *Rensselaeria obtusa*, *Rensselaeria mutabilis* (a), *Pholidops ovata*, *Uncinulus nucleolatus*, *Uncinulus keyserensis?*, *Tentaculites gyracanthus*, *Orthoceras* sp., Pelecypoda, Ostracoda	2.1	138.6
Limestone, medium bedded (10 to 12 inches), fine grained, blue, with conchoidal fracture; platy in parts; a few fossiliferous lenses. *Tentaculites gyracanthus* (c) throughout; *Whitfieldella* cf. *W. nu-*		

Section on south side of anticlinal axis at Selinsgrove Junction—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
cleolata, 132.9; *Rensselaeria mutabilis*, *Rensselaeria keyserensis*, Pelecypoda, Ostracoda, 129.9	*Feet.* 7.8	*Feet.* 136.5
Limestone, very shaly, light gray to yellow, with a few thin pure streaks. *Orbiculoidea* cf. *O. numula*, *Pholidops ovata*, *Rensselaeria mutabilis*, *Orthoceras* sp., Bryozoa, Pelecypoda, Ostracoda, throughout; *Spirifer vanuxemi* var. *prognosticus*, 119.9–125.9; *Meristella praenuntia*, 125.9; *Tentaculites gyracanthus*, 122.9, 125.9; *Uncinulus nucleolatus*, 117.9–124.9; *Nucleospira elegans*, 121.9; *Whitfieldella* cf. *W. nucleolata*, 119.9; *Dalmanella clarki*, *Stenoschisma formosa*, *Camarotoechia litchfieldensis*, *Holopea antiqua*, 110.9; *Calymene camerata* (a), 110.9; *Schuchertella* sp., 110.9, 114.9; *Leperditia* sp., 121.9	19.8	128.7
Limestone in 3 to 6 inch courses separated by about 18 inches of lime shales. The shales are light gray to yellow; the limestones are in part fine grained, in part crystalline. Layer with much pyrite, 103.7. *Dalmanella concinna*, *Stropheodonta bipartita*, *Spirifer vanuxemi* var. *prognosticus*, Pelecypoda, throughout; *Rensselaeria mutabilis*, *Calymene camerata*, *Orthoceras* sp., Ostracoda, 108.9; *Orbiculoidea* cf. *O. numula*, *Spirifer vanuxemi?*, *Cyclonema* sp., *Leperditia* sp., 106.9; *Stenoschisma formosa?*, 104.9; *Schuchertella* sp., 103.9; *Leptaena rhomboidalis*, *Camarotoechia litchfieldensis*, *Atrypa reticularis*, Bryozoa, 102.9	6.6	108.9
Limestone, extremely massive; nodular character not nearly so distinct as in the unit below; coarse crystalline lenses abundant. *Leptaena rhomboidalis*, *Atrypa reticularis*, throughout; *Holopea antiqua*, 101.9; *Dalmanella concinna*, *Proetus* sp., 97.9; *Orthoceras* sp., Bryozoa, 96.4; *Spirifer vanuxemi* var. *prognosticus*, *Schuchertella deckerensis?*, *Goldius barrandi*, 93.9; Pelecypoda, 99.9; Ostracoda, 97.9, 101.9	9.0	102.3
Limestone, extremely massive, nodular, dark; nodules pure; matrix earthy, gray; basal 2 feet has in many places a rude columnar structure and is not nodular; upper 2 feet only faintly nodular. *Dalmanella*		

Section on south side of anticlinal axis at Selinsgrove Junction—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
concinna, *Leptaena rhomboidalis*, *Atrypa reticularis*, 88.9, 81.9; *Stenochisma formosa*, *Camarotoechia litchfieldensis*, 88.9; *Chonetes jerseyensis*, 87.9, 81.9; *Meristella praenuntia?*, 87.9; *Schuchertella deckerensis*, *Gypidula coeymanensis* var. *prognostica*, *Stenoschisma deckerensis*, *Ectomaria* sp., *Proetus protuberans*, 81.9; Bryozoa, 81.9–90.9; Pelecypoda, 85.9, 81.9	*Feet.* 13.6	*Feet.* 93.3
Limestone, impure, nodular; looks sandy but contains no sand	1.2	79.7
Limestone, rather heavy bedded, blue-gray, with conchoidal fracture; nodular character pronounced. *Stropheodonta bipartita*, *Schuchertella deckerensis*, *Chonetes jerseyensis* (c), *Camarotoechia? lamellata*, *Atrypa recticularis*, *Spirifer vanuxemi*, *Orthoceras* cf. *O. perstriatum*, *Calymene camerata*, Pelecypoda, Ostracoda, 77.9	3.4	78.5
Limestone, thin bedded, otherwise like the unit above. *Camarotoechia? lamellata* *Calymene camerata*, *Orthoceras* sp., Ostracoda	3.2	75.1
Limestone, very nodular, thin bedded, fine grained, dark gray. *Orthoceras* sp., 70.9	4.0	71.9
Limestone, very nodular, more or less impure, dark gray. Some benches (52.9–55.9, 58.9–60.9, 63.9–65.9) much more shaly than the remainder and weathers back faster. No other bedding noticeable. Ostracoda and Bryozoa, throughout; *Favosites* sp., 64.9, 60.9; *Stenoschisma formosa*, 63.9?, 60.9; *Schuchertella deckerensis*, 60.9, 51.4; *Schuchertella interstriata?*, *Atrypa reticularis*, *Orthoceras* sp., 60.9; *Calymene camerata*, 60.9, 54.9; *Chonetes jerseyensis*, 54.9, 49.9; *Camarotoechia? lamellata*, 54.9, 51.4; *Camarotoechia litchfieldensis*, 54.9, 49.9; *Rhynchospira formosa*, 53.9, 49.9; *Rhynchospira globosa* var., *Dalmanella* sp., 51.4; *Spirifer modestus*, *Ectomaria minuta*, 49.9; Pelecypoda, 52.9	19.4	67.9
Limestone, nodular, dark gray, fine grained; impure looking on fresh fracture; in places inseparable from the unit below, but apparently not a stromatoporoid bed	3.0	48.5
Limestone, made up entirely of stromatoporoids	6.0	45.5

Section on south side of anticlinal axis at Selinsgrove Junction—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, very nodular, fine grained, thin bedded, bluish gray. Bryozoa throughout; *Camarotoechia? lamellata*, 38.9, 36.9; *Spirifer modestus*, Ostracoda, 38.9; *Schuchertella deckerensis*, 36.9; *Rhynchospira globosa* var., 35.9, 34.9	*Feet.* 6. 0	*Feet.* 39. 5
Limestone, single bed, dark gray, fine grained, with conchoidal fracture; very distinct along exposure; not nodular	. 9	33. 5
Limestone, thin bedded, dark gray, nodular, impure. *Camarotoechia? lamellata*, Ostracoda, 31.9; *Leperditia* sp., Bryozoa, 30.9	2. 5	32. 6
Limestone, massive, blue-gray, somewhat nodular; bounded where measured by prominent bedding planes. *Spirifer vanuxemi* (a), *Rhynchospira globosa* var. (a), Ostracoda, Bryozoa, 27.9, 25.9; *Schuchertella deckerensis* (a), *Chonetes jerseyensis*, *Spirifer modestus*, *Camarotoechia* sp., *Tentaculites gyracanthus*, 25.9; *Orthoceras* sp., 24.9	6. 0	30. 1
Limestone, thin bedded (1-inch courses), with shaly laminæ between the layers; very nodular. Some layers dense, bluish gray, conchoidal; others subcrystalline; others earthy. *Camarotoechia? lamellata*, *Spirifer vanuxemi*, *Rhynchospira globosa* var., *Spirifer modestus*, *Tentaculites gyracanthus*, Ostracoda, Bryozoa, throughout; *Schuchertella deckerensis* (a), 16.9–23.9; *Meristella* sp.?, *Camarotoechia litchfieldensis*, *Spirifer octocostatus?*, *Pholidops ovata*, *Spirorbis* sp., 19.9; Pelecypoda, 23.9, 19.9	15. 1	24. 1
Limestone, like the unit above but somewhat less nodular. *Spirifer modestus?*, Bryozoa, Ostracoda, 7.9; *Camarotoechia? lamellata*, 7.9, 4.4; *Spirifer vanuxemi*, 5.9, 4.4; *Nucleospira* sp., *Leperditia* sp., 5.9	5. 2	9. 0
Limestone like the above two units but less nodular still. *Spirifer vanuxemi*, *Leperditia* sp., throughout	3. 8	3. 8
	202. 3	
Tonoloway limestone:		
Limestone, massive, dark gray, conchoidal, fine grained; quarried for lime. *Ectomaria minuta*, −2.1; *Leperditia* sp., −3.1	4. 8	−4. 8
Limestone, thin bedded, medium gray, fine grained, with conchoidal fracture; quarried. *Leperditia* sp., −5.5	3. 0	−7. 8

Section on south side of anticlinal axis at Selinsgrove Junction—Continued.

	Thickness.	Total thickness.
Tonoloway limestone—Continued.		
Limestone, solid, dark gray, with conchoidal fracture; quarried just behind some old limekilns by a long cavelike opening. *Leperditia* throughout; *Rhynchospira globosa* var., −13.1	*Feet.* 8. 2	*Feet.* −16. 0
Concealed	4. 0	−20. 0
Limestone, banded, dark, impure; has a very noticeable rude columnar structure	14. 4	−34. 4
Limestone, dark gray, fissile, banded; contains large geodal calcite masses. In some parts a fine reticulated structure weathers out, due perhaps to silicification along close joints. *Leperditia* sp., −47.4	17. 0	−51. 4
Limestone, light gray, siliceous, knotty	1. 0	−52. 4
Limestone, rather platy, crystalline, light gray; many stringers and spots of calcite and some small geodes; weathers to thin laminæ	10. 0	−62. 4
Limestone, fairly pure, dark gray, fine grained, conchoidal; in thin lenses separated by very shaly impure layers	6. 5	−68. 9
Limestone, very light gray to yellow; impure; conchoidal fracture; apparently not much weathered	3. 0	−71. 9
Limestone, oolitic, siliceous, dark gray	. 5	−72. 4
Shale, laminated, light gray; thicker layers very light gray on fresh fracture	11. 2	−83. 6
Layer of irregular geodal calcite masses	. 5	−84. 1
Shale, laminated, light gray	9. 8	−93. 9
Limestone, fairly massive, dark gray, fine grained; conchoidal fracture. Sand lens at −98.3. *Leperditia* sp. throughout	8. 2	−102. 1
Limestone, platy, dark gray	1. 0	−103. 1
Limestone, light gray, knotty	3. 0	−106. 1
Limestone, very platy, laminated; light gray on weathered surface; dark, impure, earthy on fresh fracture; some layers finely crystalline	4. 8	−110. 9
Limestone, light gray; banded on weathered surface; dark, conchoidal, resinous on fresh fracture; solid bed; very fine grained	3. 2	−114. 1
Limestone, mostly concealed by talus	10. 0	−124. 1
Limestone, banded, gray; breaks into thin, papery fragments	4. 0	128. 1
Limestone, banded, yellowish	3. 5	−131. 6
Shale, yellow, weathered	2. 0	−133. 6
Limestone, massive, banded, light gray	6. 0	−139. 6
Shale, brown, weathered	1. 8	−141. 4
Limestone, blue, sandy-looking, massive; apparently very impure; breaks into irregular fragments	7. 0	−148. 4
Concealed to the level of the railroad at the axis of the anticline, about 35 feet.		
	148. 4	

The difference between this section and that at Grovania, only 19 miles to the northeast, is striking. The total thickness of the Keyser here is 202 feet; at Grovania, 122 feet. The *Chonetes* zone is well developed in both, but differs greatly in thickness. The *Favosites* zone at Selinsgrove Junction carries an abundance of *Tentaculites gyracanthus, Spirifer vanuxemi* var. *prognosticus,* and *Rensselaeria mutabilis,* but has very few corals and no stromatoporoids; the same zone at Grovania has a profusion of corals and stromatoporoids but almost none of the other forms usually common, carrying only *Rensselaeria mutabilis,* associated with a late form of *Camarotoechia? lamellata.* The Coeymans at Selinsgrove Junction is a sandy cherty limestone; at Grovania it is a dense calcareous sandstone.

GROVANIA.

The section at Grovania was measured in the quarry formerly owned by the Grove brothers, almost on the Columbia-Montour County line, about halfway between Danville and Bloomsburg. This quarry may be identified by the fact that it is the only one in the vicinity which is drained by a tunnel. The exposures are very good and include the upper 40 feet of the Tonoloway, the Keyser, the Coeymans, and, in the tunnel, about 110 feet of shale and limestone representing probably all of the New Scotland, the Becraft (if present), and perhaps part of the Oriskany.

The section was studied in 1883 by I. C. White,[1] who gave a fairly detailed account of it. His description includes the following divisions: Oriskany sandstone; Stormville shale, 100 feet; Stormville conglomerate, 4 feet; Stormville limestone, 111 feet; Bastard limestone, 24 feet; Bossardville limestone, 105 feet. He considered these divisions equivalent to those of the same name in the counties along Delaware River. However, as the fossils cited from the Delaware River area would make his Stormville limestone in part Coeymans and in part New Scotland, and his Stormville conglomerate and shale New Scotland, the correlation is incorrect. The evidence given below demonstrates that White's Stormville conglomerate of the Grovania section is Coeymans in age; his Stormville limestone is upper Keyser; and his Bastard limestone is lower Keyser. The upper part of White's Bossardville is represented by the Tonoloway.

[1] Pennsylvania Second Geol. Survey Rept. G7, p. 88, 1883.

Section at Grovania.

	Thickness.	Total thickness.
Limestones and shales of undetermined age, but probably New Scotland and Oriskany	*Feet.* 110	*Feet.* 110
Helderberg limestone:		
Coeymans limestone member:		
Sandstone, coarse (grains $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter), white; base filled with crinoid stems and other fossils; contains some chert. Bryozoa, *Leptaena rhomboidalis, Strophonella leavenworthana, Strophonella punctilifera, Schuchertella woolworthana, Gypidula coeymanensis* (a), *Atrypa reticularis, Stropheodonta arata, Phacops logani,* Ostracoda, Pelecypoda, 1.0	3.0	3.0
	3.0	
Keyser limestone member:		
Limestone, irregular, crinoidal, dark blue	1.6	122.5
Limestone, compact, light blue, heavy bedded; conchoidal fracture	5.5	120.9
Limestone, laminated, light gray to yellowish, platy. Has some solid 6-inch layers of light-gray rock, but for the most part is rather shaly. Barren of fossils.	36.4	115.4
Limestone; a peculiar pebbly stromatoporoid makes up whole of rock	3.0	79.0
Limestone, blue, pure, with many transverse calcite seams; massive and somewhat nodular; composed almost entirely of stromatoporoids; has $\frac{1}{2}$-inch layer of shale at top	3.4	76.0
Shale, yellow	.2	72.6
Limestone, composed almost entirely of stromatoporoids	5.6	72.4
Shale, blue-black, with one or two limestone layers. Limestone at 65.1 is arenaceous. *Camarotoechia? lamellata,* 65.1, 63.1 (a); *Rensselaeria mutabilis* (a), 65.1; *Atrypa rugosa?,* 63.1, 62.1; *Favosites* sp., *Spirorbis laxus, Pholidops ovata* (c), *Schuchertella* sp.?, *Camarotoechia litchfieldensis?, Rensselaeria keyserensis* (a), *Spirifer vanuxemi prognosticus, Whitfieldella* cf. *W. nucleolata,* Ostracoda (a), 62.1	4.6	66.8
Limestone, crystalline, blue, pure. *Favosites* sp	1.3	62.2
Limestone, crystalline, blue, pure; many transverse calcite seams	.8	60.9

Section at Grovania—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, crystalline, blue, pure, massive; weathers thin bedded; has much black shale. Stromatoporoids throughout; *Favosites* sp., *Halysites catenulatus* (a), 57.1, *Camarotoechia litchfieldensis*, 55.1	*Feet.* 8.0	*Feet.* 60.1
Limestone, crystalline, blue, pure, massive; numerous transverse thin calcite seams; weathers thin bedded. *Halysites catenulatus* throughout, abundant at 51.1–48.1; *Favosites* sp., *Cladopora rectilineata*, *Uncinulus nucleolatus?*, 44.1	10.0	52.1
Limestone, heavy bedded, light gray; has great masses of vein calcite. *Favosites* sp., *Cladopora rectilineata* (a), *Halysites catenulatus* (a), Bryozoa, *Camarotoechia litchfieldensis*, *Rhynchospira globosa?*, 42.1	6.0	42.1
Limestone, crinoidal, relatively impure	.6	36.1
Limestone, light gray, nodular; much shalier than the beds beneath; weathers easily; "Bastard" limestone of the quarrymen. *Rhipidomella emarginata* 31.2; *Stropheodonta bipartita*, *Stenoschisma formosa*, 32.1–19.9; *Spirifer vanuxemi* var. *prognosticus*, 31.1, 24.0; *Orthoceras* sp., 31.1–23.0; *Leptaena rhomboidalis*, *Atrypa reticularis*, 28.1–13.4; *Favosites* sp., 26.0, 25.0; stromatoporoids, 25.0; *Uncinulus nucleolatus?*, *Eotomaria* sp., *Schuchertella deckerensis*, Pelecypoda, Bryozoa, 25.0–23.0; *Orthostrophia strophomenoides*, *Spirifer octocostatus*, 25.0–17.9; *Dalmanella concinna*, *Chonetes jerseyensis*, *Camarotoechia? lamellata*, 25.0–12.3; *Coelidium pennsylvanicum*, 25.0; *Stenoschisma deckerensis*, *Merista typa*, 24.0, 23.0; *Calymene camerata*, 24.0, 12.3; *Spirorbis laxus*, *Camarotoechia litchfieldensis*, *Tremanotus profundus?*, *Loxonema fitchii?*, 23.0; *Strophonella leavenworthana* var., *Leperditia* sp., 22.0, 13.4; *Whitfieldella* cf. *W. nucleolata*, 22.0; *Euomphalus?* sp., 15.9, 13.4; *Dalmanella clarki*, *Uncinulus convexorus?*, *Wilsonia globosa*, 13.4; *Spirifer modestus*, *Spirifer vanuxemi?*, *Rhynchospira globosa* var., *Proetus pachydermatus*, *Proetus protuberans*, 12.3	23.6	35.5
Shale, irregular	.3	11.9

Section at Grovania—Continued.

	Thickness.	Total thickness.
Helderberg limestone—Continued.		
Keyser limestone member—Contd.		
Limestone, irregularly bedded, somewhat nodular, dark gray; courses often separated by shale laminae. *Favosites* sp., 11.1; *Schuchertella* sp., 11.1, 7.6; *Camarotoechia* sp.?, *Atrypa reticularis*, *Proetus protuberans*, 11.1; *Leperditia* sp., 11.1–1.6; *Camarotoechia? lamellata*, *Rhynchospira globosa* var., 9.6; Ostracoda, 8.6	*Feet.* 11.6	*Feet.* 11.6
	122.5	
Tonoloway limestone:		
Limestone, dark gray, pure; conchoidal fracture; many transverse calcite seams; when unweathered is a massive unit though 1-inch bedding is shown in the upper part and 6-inch bedding near the base; it is not nodular or platy; shows a persistent thin shaly layer at −8.0. Ostracoda, −2.1	12.0	−12.0
Limestone, fissile, platy, dark gray; joints have yellow discolored borders. *Leperditia* sp. (a), −17.0	10.0	−22.0
Limestone, fissile, platy, much weathered. *Leperditia* sp., −26.0	6.0	−28.0
Limestone, solid, dark gray, banded in parts	6.6	−34.6
Limestone, fissile, platy, much weathered, yellow; fresh surface is dark gray. *Leperditia* sp., −35.9, −37.9	4.3	−38.9
Concealed.		
	38.9	

The Grovania section resembles the Tyrone sections very closely, but differs from all the others studied in Pennsylvania and from the Maryland sections. The Tonoloway is identical in lithology with that in the other sections, though its fauna, so far as it is known, includes only ostracodes. The *Chonetes jerseyensis* zone of the Keyser is well developed and carries a characteristic fauna. The *Favosites helderbergiae* var. *praecedens* zone of the Keyser is peculiar in that its lower part is made up of thick beds of coralline limestone and stromatoporoids. It has also a thin zone of *Rensselaeria mutabilis*, but it lacks most of the other characteristic brachiopods of the upper Keyser and contains no *Tentaculites gyracanthus*. The Coeymans is here a sandstone, as it is in the easternmost Maryland sections.

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STRATIGRAPHY OF THE HANNA BASIN, WYOMING

BY

C. F. BOWEN

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ILLUSTRATIONS.

STRATIGRAPHY OF THE HANNA BASIN, WYOMING.

By C. F. Bowen.

INTRODUCTION.

Carbon County, Wyo., has attracted the attention of geologists since the days of the territorial surveys under King, Hayden, and Powell. During this earlier work all the rocks (except the North Park formation) overlying the uppermost beds of marine origin were grouped in a single formation, for which the name Laramie was proposed.

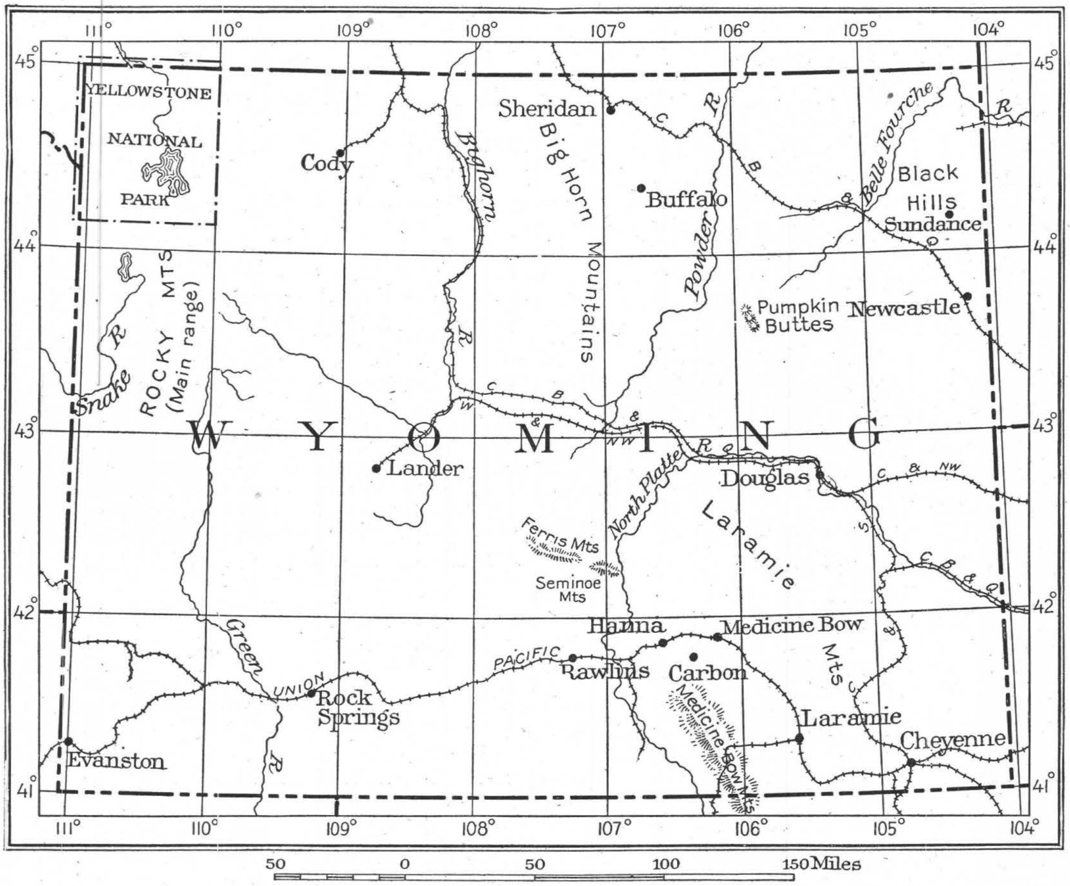

FIGURE 31.—Key map showing location of Hanna Basin, Wyo.

As the result of his work in the Hanna Basin (see fig. 31) in 1906, Veatch[1] subdivided this group of rocks into two formations, which he designated "Lower Laramie" and "Upper Laramie," and made the statement that the two were separated by an unconformity that involved the removal of 20,000 feet of rocks.

[1] Veatch, A. C., Coal in east-central Carbon County, Wyo.: U. S. Geol. Survey Bull. 316, p. 246, 1906; The origin and definition of the term Laramie: Jour. Geology, vol. 15, pp. 526-549, 1907.

Veatch's upper formation became the type of the "Upper Laramie formation," and the flora which it yielded was adopted as a standard for purposes of comparison in other fields.

It is the purpose of the present paper (1) to show that the "Upper Laramie" as defined by Veatch consists of two formations separated by a marked unconformity; (2) to show that this unconformity is the one which he regarded as representing the erosion of 20,000 feet and referred to the base of the "Upper Laramie formation"; (3) to present the facts so far as they can now be interpreted for and against the existence of an unconformity at the horizon indicated by Veatch; and (4) to offer some suggestions as to the source of the material which goes to make up the enormous thickness of continental deposits of this era.

STRATIGRAPHY.

GENERAL SECTION.

The formations exposed in or immediately adjacent to the area under consideration range in age from Cambrian (?) to probably Miocene. Those in the upper part of the section—that is above the base of Veatch's "Lower Laramie"—are of chief interest and will be described somewhat in detail; the underlying formations will be referred to but briefly. The sequence and general character of the Mesozoic and Cenozoic formations are shown in the following table:

Mesozoic and Cenozoic formations in Hanna Basin, Wyo.

System.	Formation.	Thickness (feet).	Characteristics.
Quaternary.	Alluvium.		Worked-over material from surrounding formations.
	Terrace gravel.	0–25±	Waterworn pebbles of older sedimentary and crystalline rocks.
Tertiary.	North Park formation.	0–400±	Whitish unconsolidated sand and clay with thin intercalated beds of limestone in some places; conglomeratic at base.
....	Unconformity...........		
	Hanna formation.	7,000±	Alternating beds of dark-gray, yellowish, and carbonaceous shale; white, gray, and brown sandstones, massive to thin bedded and commonly cross-bedded; conglomerates and conglomeratic sandstones containing pebbles of chert, granite, quartzite, sandstone, Mowry shale, Cloverly conglomerate, etc. (these conglomerates are distributed throughout the section but are most abundant in the lower half), and numerous beds of coal. Contains fossil bones of vertebrates, fresh-water shells, and an abundance of leaves.
....	Unconformity............		
Tertiary (?).	Ferris formation.	6,500±	Light-colored, dark-gray, and carbonaceous shale; buff to brown sandstone; in places extremely cross-bedded and showing great irregularity of deposition and numerous beds of coal. Pockets, lenses, and thin beds of conglomerate composed of pebbles of older rocks are distributed through a zone about 1,000 feet thick at the base of the formation. Contains fresh-water invertebrates, land plants, and bones of vertebrates.
Cretaceous.	Medicine Bow formation.	6,200±	Light-colored to gray carbonaceous shale; gray to brown sandstone showing cross-bedding, ripple marks, and other features of irregular deposition; and thin irregular beds of coal. Fresh and brackish water, invertebrates, land plants, and bones of vertebrates.
	Lewis shale.	3,300±	Predominantly dark-gray shale with thin intercalated beds of shaly sandstone and some beds of light-colored massive to heavy-bedded sandstone. Near the top of the formation is a persistent ledge-making gray sandstone about 270 feet thick. Marine.

Mesozoic and Cenozoic formations in Hanna Basin, Wyo.—Continued.

System.	Formation.	Thickness (feet).	Characteristics.
Cretaceous.	Mesaverde formation.	2,700	An upper member of whitish sandstone alternating with gray and carbonaceous shale with a conspicuous resistant white sandstone at the top; contains thin irregular beds of coal in some places. A middle member of brown to gray sandstone, gray carbonaceous shale, and thin irregular beds of coal; differs from upper member in its prevailingly brown color; fresh and brackish water fauna. A lower member of gray to white sandstone and gray shale; contains a marine fauna and is not coal bearing.
	Steele shale.	4,000±	Dark-gray shale with intercalated beds of sandstone and shaly sandstone, some of which form conspicuous ledges near top of formation. Shale contains concretions of calcareous sandstone, dark limestone, and white crystalline calcite. Marine fauna.
	Niobrara formation.	370±	Calcareous shale with considerable intercalated white crystalline calcite at top and bottom.
	Carlile shale.	200	Dark-gray to black shale with some thin sandy layers.
	Frontier formation.	700	An upper member composed of thick beds of sandstone alternating with thinner beds of shale and a lower member composed of dark-gray shale.
	Mowry shale.	170	Fissile shale, dark brown on fresh surface but weathering to silver gray or white.
	Thermopolis shale.	140	Dark-gray shale with thin sandy layers.
	Cloverly formation.	231	An upper member of sandstone, a middle member of shale, and a lower member of conglomeratic sandstone.
Cretaceous (?).	Morrison formation.	350	Shale, mostly gray or greenish, alternating with sandy shale and sandstone. Contains bones of dinosaurs.
Jurassic.	Sundance formation.	85	Chiefly green, olive, and drab shales with a few thin intercalated beds of sandstone.
Triassic.	Chugwater formation.	1,000−	Chiefly red shale with intercalated red, buff, and yellow sandstone.

For stratigraphic study the most important of the formations given in the table are the Mowry shale, the Frontier, and the Mesaverde, because they possess characteristics which render them valuable as horizon markers. This is especially true of the silver-gray fish-scale shale of the Mowry.

MEDICINE BOW FORMATION.

Above the highest marine formation—the Lewis shale—is a mass of continental deposits, divisible into four formations having a maximum thickness of more than 20,000 feet. For the lowest of these formations the name

Medicine Bow is here proposed, because the formation is best exposed and most easily studied along both sides of North Platte River at the mouth of the Medicine Bow. The Medicine Bow formation is the equivalent of the "Lower Laramie" as defined by Veatch. The latter term is not applicable, for the "Upper Laramie," in the sense in which that term was originally used, is not of Laramie age. As the relation of the Medicine Bow formation to the Laramie of the Denver Basin can not be determined by field relations, and as paleontologists are not agreed as to the relation of the fossil remains found in the two formations, the use of the unqualified term "Laramie" is not advisable, and it is thought that confusion may be avoided by the use of an entirely new name for the formation hitherto called "Lower Laramie."

The Medicine Bow formation rests conformably on the Lewis and consists of an alternating succession of shale and massive to thin-bedded, ripple-marked, and cross-bedded sandstones, with several beds of coal in the lower third of the formation. The massive and thick-bedded sandstones are commonly somewhat coarser than the thin-bedded varieties and in some places contain clay balls and an occasional pebble the size of a pea.

Microscopic examination shows that the sandstone is composed of fragments of quartz, quartzite, feldspar, chert, schist, volcanic rocks, limestone, and other minor constituents. In other words, it has been derived from both sedimentary and igneous rocks. The grains show considerable variation in the degree of sorting and rounding, but on the whole are decidedly angular. One section showed well-rounded grains, 20 per cent; subangular grains, 35 per cent; angular grains, 45 per cent. These proportions suggest that the grains are chiefly the result of mechanical disintegration and rapid transportation with little or no subsequent reworking.

The formation contains remains of fresh and brackish water invertebrates, land plants, and bones of vertebrates. The plants are regarded by F. H. Knowlton as of the same age as the plants of the Laramie of the Denver Basin. The invertebrates are considered by T. W. Stanton to belong to the fauna of the Lance formation. The bones belong in part to the ceratopsians, but no specimens have been found that are sufficiently diagnostic for even generic determination.

FERRIS FORMATION.

The Medicine Bow formation is terminated above by a conglomeratic zone taken as the base of the Ferris formation, so named because it is best exposed from the old Ferris ranch, on North Platte River, eastward to the top of the hill north of "Middle Ditch" at its junction with "Big Ditch." As defined the Ferris formation is approximately equivalent to the lower half of the "Upper Laramie" of Veatch. The conglomerate at the base of the Ferris formation ranges through an interval of about 1,000 feet, in which massive sandstone, more or less conglomeratic, alternates with non-conglomeratic sandstone and shale. The conglomerate is sparingly developed at the base of the zone but increases in amount upward. It is succeeded by an alternating series of sandstone and shale containing numerous beds of coal. The maximum thickness of the formation is about 6,500 feet.

Both the matrix and the pebbles of the conglomerate consist of materials of the same kind as make up the sandstone of the underlying Medicine Bow formation. The pebbles consist mainly of chert and white quartz or quartzite; then follow in about the order named red and gray quartzite, porphyries, and conglomerate, with subordinate amounts of other constituents. Three facts impress the student of this conglomerate: (1) It is made up of only the most resistant kinds of rock; (2) it is lacking in several kinds of rock now exposed in the surrounding mountains—for example, granite, limestone, sandstone, Cloverly conglomerate, and Mowry shale; (3) it contains materials that seem to be foreign to this region, namely, quartzite, porphyry (quartz latite), and rhyolite. These features lead to the inference that the conglomerate and also the associated sandstone were derived from some distant source rather than from the near-by mountains. This inference has an important bearing on the unconformities discussed on pages 231–234.

The Ferris formation contains fresh-water invertebrates, land plants, and bones of vertebrates. The shells and plants, which are found chiefly above the conglomerate zone, are regarded as of Fort Union age, whereas the vertebrate remains, thus far found only in the conglomeratic zone, consist of bones of turtles, indeterminable fragments of ceratopsians, and a few specimens that have been identified by C. W. Gilmore as *Triceratops*. The bones of *Triceratops* tend to show that the basal part of the formation should be correlated with the Lance of Wyoming and Montana and the Denver formation of the Denver Basin. There is, however, no conclusive proof of an unconformity below the bone horizon in the Hanna Basin, as there is said to be in the Denver Basin.

HANNA FORMATION.

For the upper part of the "Upper Laramie" as defined by Veatch the name Hanna formation is proposed, because the formation is well exposed to the west and north of the town of Hanna and yields all the coal mined at that place. The Hanna formation rests unconformably on the Ferris formation. A conglomeratic sandstone marks its base, above which conglomerate, sandstone, shale, and coal beds alternate to the top of the formation, some 7,000 feet above the base.

This formation differs from the Ferris in being highly feldspathic, in being conglomeratic throughout, and in the fact that the conglomerate contains an abundance of local material, notably granite, Mowry shale, and Cloverly conglomerate. The relative abundance of these constituents varies from place to place in accordance with the character of the surrounding rocks. Thus near outcrops of the Mowry shale and the underlying Cloverly those rocks constitute most of the pebbles, near outcrops of granite that rock is the most abundant material in the conglomerate, and in the center of the basin granite, sandstone, and conglomerate pebbles are associated with chert, white quartz, quartzite, etc.

This formation contains an abundance of plant remains, all of which are referred to the Fort Union by Mr. Knowlton. The invertebrates are also regarded by Mr. Stanton as chiefly indicative of Fort Union age, though species found near the top are said to resemble the Wasatch fauna. Only a few fragmentary remains of vertebrates have thus far been found in this formation. They include fish scales, fragments of turtle shells, and a fragmentary mammalian jaw identified by J. W. Gidley as a creodont, probably *Claenodon*, which may belong to either the Fort Union or Wasatch.

NORTH PARK FORMATION.

The North Park formation rests unconformably on the underlying rocks. This formation consists of conglomerate, unconsolidated sand and marl, and local thin beds of limestone. A peculiarity of the formation is that in many places its surface is thickly strewn with boulders of white, vitreous quartzite as much as 2 feet in diameter, but none of these have ever been found actually embedded in the formation.

No fossils have been found in the North Park, and its age is therefore largely a matter of conjecture, but it is thought to be Miocene.

STRUCTURE.

FOLDING AND FAULTING.

Folding is the dominant structural feature of the Hanna Basin, though faulting has occurred to some extent. A characteristic of the folds is that they are all oversteepened toward the west or southwest.

All the rocks up to and including the Ferris formation seem to have been equally deformed and were folded, faulted, and deeply eroded before the deposition of the Hanna formation. After the deposition of this formation there was another disturbance, which followed chiefly the lines of the earlier movements and served to emphasize the features of structure already produced. By this disturbance the Hanna formation was tilted in some places into a vertical position and was locally faulted. A third disturbance seems to have taken place subsequent to the deposition of the North Park formation, for this formation is now tilted in some places 40° or more.

UNCONFORMITIES.

Perhaps the most interesting structural problem in the field relates to the occurrence and magnitude of the unconformities. There are certainly two and possibly three unconformities present. The highest of these is at the base of the North Park formation, which overlaps all other formations in the field.

The next lower unconformity is that at the base of the Hanna formation, formerly assigned to the base of the Ferris formation. It represents the removal of more rather than less than the 20,000 feet assigned by Veatch.

The existence of this unconformity is demonstrated by the following field relations: (1) There is a marked angular discordance between the underlying and overlying formations; (2) the Hanna formation transgresses all the underlying formations at least down to the Cloverly and possibly down to the granite; (3) the Hanna formation has been less intensely deformed than the underlying formations; (4) the conglomerate at the base of the Hanna formation has clearly been derived from all the underlying rocks and is chiefly of local origin.

That this unconformity is the one assigned by Veatch to the base of his "Upper Laramie" is evident from the following considerations: (1) It is the most conspicuous break in the field; (2) it is the only unconformity present at some of the typical places observed by Veatch, the lower beds being there cut by overlap; (3) the Ferris formation nowhere transgresses the "Lower Laramie" and overlaps older rocks, as was postulated by Veatch; (4) all the rocks between the Medicine Bow ("Lower Laramie") and North Park were included by Veatch in a single formation.

Veatch's mistake was a natural one to make in rapid reconnaissance work. In the eastern part of the basin, where the unconformity is most evident, the conglomerate of the Ferris formation is either cut out by overlap or is directly overlain by the conglomerate of the Hanna formation, all the intervening strata being eroded. These relations were not detected in a rapid examination, but are perfectly clear when studied and mapped in detail.

On the west side of the basin the two conglomerates are separated by a stratigraphic interval of nearly 6,000 feet and by a horizontal distance of 5 to 7 miles. In that area Veatch appears to have recognized only the lower of the two conglomerates and to have unhesitatingly correlated it with the unconformity he saw farther east.

The next question that arises is regarding the significance of the conglomerate at the base of the Ferris formation. It has been held that, because this conglomerate is made up in part of pebbles containing Paleozoic fossils, it necessarily represents a period of uplift and erosion between the deposition of the Medicine Bow and that of the Ferris formation ("Upper Laramie" and "Lower Laramie") sufficient to expose the Paleozoic rocks. This would naturally follow if it could be proved that Paleozoic rocks did not contribute materials to the underlying formation or that the pebbles of the conglomerate came from a different source than the sand and clay of the underlying formation. As previously stated, microscopic study shows that the constituents of this conglomerate are all represented in the sandstone of the Medicine Bow formation. This seems to indicate that both were derived from the same source and that Paleozoic rocks contributed material to the Medicine Bow formation, as well as to the conglomerate above it. It is therefore not necessary to assume a great interval of uplift and erosion between the periods of deposition of the two formations to account for the Paleozoic pebbles in this conglomerate any more than it is necessary to assume a great interval of uplift and erosion to account for each of the successive conglomerates in the Hanna formation, or the conglomerates of earlier formations, such as the Beckwith in Uinta County and the Frontier (?) at Coalville, Utah. The presence of Paleozoic pebbles in these conglomerates, as well as in the Cloverly, is proof that the Paleozoic formations had been exposed somewhere in the region at least since the beginning of the Cretaceous period. That is, in so far as the evidence furnished by the conglomerate alone is concerned, it seems to the writer that there is no more argument for assuming an unconformity between the Ferris and Medicine Bow formations than there is for assuming an unconformity at the base of each of the conglomerates in the Beckwith, Frontier, and Hanna formations. Each of these conglomerates contains pebbles of Paleozoic rocks.

It is recognized, however, that a conglomerate indicates a more or less pronounced change in conditions of sedimentation. This change could be accomplished by a rejuvenation of the streams of an already existing land mass, by climatic changes, or by a combination of these and possibly other causes. The point made here is that the existence of a conglomerate is not positive proof of a great unconformity. This is especially true of a conglomerate occurring in the midst of a great mass of continental deposits that have the same lithologic character throughout—conditions entirely different from those presented by a conglomerate that separates two marine deposits or one deposit of marine origin and another of continental origin.

The field relations of the Ferris conglomerate and the underlying formation show (1) that the two have been equally deformed; (2) that there is no angular discordance between them either in the Hanna Basin or in other areas where both are present; (3) that the Ferris formation is nowhere known to transgress the Medicine Bow formation and overlap older rocks; (4) that, as previously indicated, the conglomerate seems to have been derived from the same source as the Medicine Bow; (5) that there appears to be a gradual transition from the Medicine Bow formation to the Ferris formation. The contact between the two is not sharply defined, coarse sandstone of the Medicine Bow being followed by grits in which a few small pebbles occur, and these giving place higher up to pockets, lenses, and thin beds of conglomerate, which are finally succeeded by thick beds of sandstone that are conglomeratic throughout. Interbedded in this transition zone are several beds of dark-gray shale, some of which attain a thickness of 30 feet.

This transition zone is very significant, occurring in all areas where both the Medicine Bow and Ferris formations or their equivalents are present. In the southern part of the Great Divide Basin it is, according to Smith,[1] 800 feet thick and consists chiefly of clay with interbedded thin rusty-brown sandstone, which becomes increasingly conglomeratic toward the top. In the northern part of the Great Divide Basin, according to the same author, the transition zone is still thicker.

Similar conditions in the Little Snake River field are described by Ball and Stebinger.[2]

This thick transition zone between the assumed unconformity and the principal conglomeratic zone supposed to represent it seems to the writer to be a fatal objection to the idea of an unconformity. It is difficult to conceive of a basal conglomerate occurring several hundred feet above the base it is assumed to represent. These conditions lead to the inference that no unconformity exists between the two formations.

The arguments in favor of an unconformity are (1) the conglomerate at the base of the Ferris formation, which, if the above reasoning is sound, has no weight; (2) a considerable thinning of the Medicine Bow formation in some places, which is partly offset by the fact that the Lewis and Mesaverde show just as great variations in thickness within as short distances; and (3) the fact that at the base of the Evanston formation of Uinta County, correlated with the Hanna at Carbon, there is an unconformity which has been assumed to represent the interval between the Medicine Bow ("Lower Laramie") and Ferris ("Upper Laramie") epochs.

The question now arises whether the Evanston formation should be correlated with the Ferris or with the Hanna formation. There are three lines of evidence which suggest that it should be correlated with the Hanna. (1) The flora of the Evanston is said to correspond to that obtained from the old town of Carbon, which in all probability came chiefly if not entirely from the Hanna formation and therefore tends to support the correlation of the Evanston with that formation; (2) the Evanston is conformable with the overlying Wasatch, a relation which is not known to exist between the Wasatch and older rocks in any other place in southern Wyoming; (3) the relation of the Evanston to the Adaville ("Lower Laramie") is largely a matter of inference, for it nowhere rests on the Adaville, and some of those most familiar with the Evanston section now believe that the Adaville formation, formerly thought to represent the "Lower Laramie," is really Mesaverde.

It seems to the writer, therefore, that the weight of evidence so far as it can now be interpreted is opposed to the existence of a great unconformity at the base of the Ferris formation, but it is freely admitted that more detailed field work over wider areas is necessary to decide this question. It is of course possible that a considerable unconformity near the margin of the ancient land mass from which the sediments were derived may give place to

[1] Smith, E. E., The eastern part of the Great Divide Basin coal field, Wyo.: U. S. Geol. Survey Bull. 341, p. 224, 1907.

[2] Ball, M. W., and Stebinger, Eugene, The eastern part of the Little Snake River coal field, Wyo.: U. S. Geol. Survey Bull. 381, p. 190, 1910.

apparent conformable relations at a considerable distance from that place. But it is still a fact that unconformity between the Fort Union and Wasatch is the most widespread and significant break that had been produced up to that time since the beginning of the Cretaceous period.

SOURCE OF THE MATERIAL.

The source of the enormous amount of sediment represented in these continental deposits is an interesting problem.

For the Hanna formation it can be stated with considerable confidence that the material was derived from all the underlying formations and is of more or less local origin.

For the underlying formations the case is not so simple. Even if it could be demonstrated that the Ferris formation is of local derivation, it would still be necessary to explain the source of the 6,200 feet of the Medicine Bow formation to which the immediately underlying rocks did not contribute. A study of at least all the Cretaceous formations is therefore necessary to throw light on the problem.

A few suggestions may be offered by comparing the sections in the accompanying chart (Pl. LXVI). These sections extend from the east side of the Hanna Basin westward through Rawlins, Rock Springs, and Evanston to Coalville, Utah. In constructing them the Mowry shale was taken as a datum plane. To consider first the sandstone formations, these sections show that from east to west the Mesaverde and Frontier thicken regularly, the materials become coarser with pronounced development of conglomerate in the Frontier and with slight indications of conglomerate in the upper part of the Mesaverde, and there is a marked development of coal in both formations.

The 700-foot interval represented by the Morrison and Cloverly near Medicine Bow is represented by the several thousand feet of Bear River and the upper part of the Beckwith in Uinta County. Although individual units of this group can not be exactly correlated, their upper and lower limits are definitely fixed, the upper by the Mowry shale and the lower by the Jurassic (Sundance and Twin Creek) formations, which are correlated with each other by their marine faunas.

The Beckwith includes many beds of coarse sandstone and conglomerate containing pebbles of Paleozoic rocks, and the Bear River is coal bearing. There is no coal in this interval in the Medicine Bow area, and the conglomerate of the Cloverly is composed almost entirely of small pebbles of black chert rarely exceeding half an inch in diameter. These pebbles show by their fineness and thorough assortment that they have been transported for long distances.

Of the shale formations the Lewis thins from east to west—that is, in the direction in which the sandstones thicken. The Mowry and the Hilliard and Steele shales, however, do not. The westward thickening of the Mowry is doubtless due to the fact that it is coarser and contains a considerable amount of interbedded sandstone in its western part. The Hilliard also carries large lenses of sandstone in Uinta County, but its apparent thickening toward the west may be due to the difficulty of accurately determining its thickness because of lack of exposures, inability to measure dips except in the overlying and underlying formations, and the possibility that its boundaries have not been drawn at the same horizon in the several fields.

The evidence of these sections seems to indicate that all the Cretaceous formations up to the top of the Lewis were derived from a western source.

As the Medicine Bow formation, or its equivalent the "Lower Laramie," rests conformably on the Lewis and shows some tendency to become coarser westward, as indicated by its slightly conglomeratic character in places in the Rock Springs field, the inference is that it was derived from the same source as the underlying formations.

The fact that the Ferris formation seems to be more closely related to the Medicine Bow both lithologically and structurally than to the overlying formation, together with the evidence that the conglomerate came from some distant source, would seem to indicate that this formation also came from the west. This view is somewhat strengthened by the fact that pebbles of quartzite occurring in the conglomerate are similar to the quartzite in the Uinta Mountains.

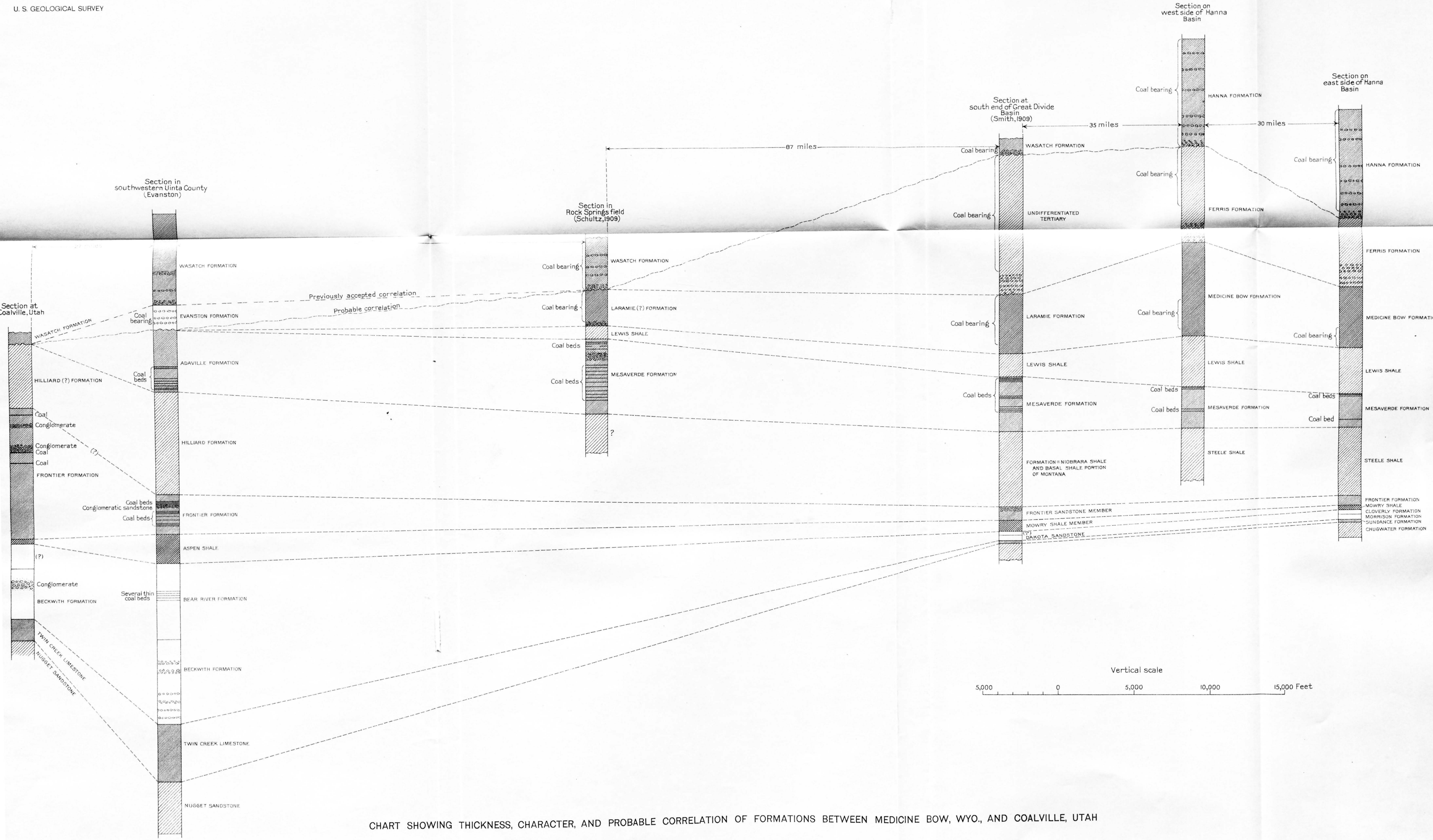

CHART SHOWING THICKNESS, CHARACTER, AND PROBABLE CORRELATION OF FORMATIONS BETWEEN MEDICINE BOW, WYO., AND COALVILLE, UTAH

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

CONCLUSION.

By way of summary it may be said that the great break, as indicated by structural and field relations, occurs at the base of the Hanna formation; that this formation is the equivalent of the Wasatch of the Great Divide Basin and Rock Springs fields; that the structural and field relations do not suggest an unconformity at the base of the Ferris formation; that Paleozoic rocks contributed to the sedimentary formations from at least the beginning of Cretaceous time; and that the sediments seem to have been derived from the west or southwest.

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