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THIRD ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

U.S.

SECRETARY OF THE INTERIOR

1881-'82

U.S. GEOLOGICAL SURVEY
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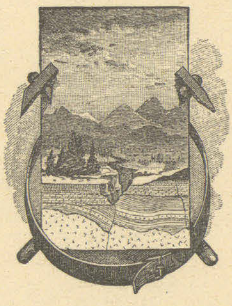
J. W. POWELL

DIRECTOR



WASHINGTON
GOVERNMENT PRINTING OFFICE
1883

REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 1, 1882.

SIR:

I have the honor to transmit herewith my report of the operations of the Geological Survey for the fiscal year ended June 30, 1882.

I am, with great respect,
Your obedient servant,
J. W. POWELL,
Director.

To the Honorable
The SECRETARY OF THE INTERIOR.

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THIRD ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY.

By J. W. Powell, *Director*.

INTRODUCTION.

In the first and second years of the Survey, each of the chief geologic assistants conducted a field investigation and began the preparation of its results for publication. Preliminary outlines of their memoirs accompanied my last report. During the fiscal year just closed they have continued the office studies necessary to the best presentation of their work, and have carried forward the preparation of manuscripts and illustrations. This work is now nearly completed. Probably all their monographs would ere this have been published had it not been found necessary to divert a share of their attention to the supervision of new field work, both geologic and geographic, by their assistants.

While the energies of the corps have been thus largely directed to office work incidental to the publication of researches already completed, a considerable number of new investigations have also been initiated, and the mapping of regions selected for future geologic work has been prosecuted.

The present organization inherited from its predecessors a large amount of good topographic material pertaining to the Colorado Plateau region, a district embracing portions of Utah, Colorado, New Mexico, and Arizona. For the study of certain important geologic problems this region is unrivaled, and it has been determined, therefore, to complement the data in hand and prepare a topographic map of the region as a basis for future geologic researches. To this end a base line was measured near Fort Wingate, New Mexico, and geodetic and topographic work has been initiated under the direction of Mr. Gilbert Thompson.

In Colorado the field work for a topographic map of the Ten Mile mining district has been finished, and the map completed, ready for the use of the geologist.

In northern Nevada the mapping of a considerable tract has been commenced for the purpose of complementing material gathered by the Survey of the Fortieth Parallel and the Surveys West of the One Hundredth Meridian. This will furnish the Survey a trustworthy map of northern and central Nevada, and enable it to exhibit the geologic history of the great ancient lake, Lahontan, the investigation of which is in progress.

Mr. Arnold Hague, who is preparing a memoir on the geology of the Eureka District, Nevada, has during the year devoted a few weeks of field work to the re-examination of some points of especial interest; and the study of the ore-deposits of the same locality, intrusted to Mr. J. S. Curtis, has been brought to a close, so far as field work is concerned.

In the study of the Quaternary lakes of the Great Basin, the principal field work has been performed by Mr. I. C. Russell. He has completed his reconnaissance of Lake Lahontan, and has made a preliminary examination of the southeastern portion of Oregon.

Under the direction of Mr. S. F. Emmons the investigation of the mining and general geology of the Ten Mile district in Colorado, and of the vicinity of Golden, Colorado, has been begun, and attention has been given to the soils in the neighborhood of Denver.

Mr. L. F. Ward spent the summer of 1881 in the collection of fossil plants in Colorado and Arizona. Dr. C. A. White began at the same time the collection of a parallel suite of invertebrate fossils, but was unexpectedly called to an investigation of the problem of artesian water on the Plains, and deferred his paleontologic work until another season.

Prof. T. C. Chamberlin continued, under the auspices of the Survey, a work he had begun as State geologist of Wisconsin, examining and tracing the glacial moraines of eastern Dakota and the associated features of the drift.

Among the more profound questions of geologic science are several whose solution requires a knowledge of the chemical and physical properties of rocks and rock-forming materials under extreme conditions of temperature and pressure. These questions are intimately involved in the great dynamic problems of American geology, and the subject calls urgently for special experimentation. The work has been undertaken, under the direction of Mr. Clarence King, by Dr. Carl Barus, and is now in progress.

Detailed information in regard to the various departments of the work will be found in the accompanying reports of my principal assistants.

Important progress has been made in the organization of office work, especially that pertaining to the preparation of illustrations and the publication of reports. A technical working library is urgently needed, and steps have been taken toward its acquisition. Only the most imperative wants, however, have been met by purchase, since it is hoped that the system of interchange provided for by law will ultimately afford the Survey, in exchange for its publications, nearly all that is desired.

The continued courtesies of the National Museum and of the American Museum of Natural History in New York City have not only afforded the Survey important laboratory facilities, but have enabled it to practice notable economy in the matter of rent. The principal office has been maintained in a suite of rooms furnished by the National Museum, and several members of the corps have occupied well-equipped work and study rooms placed at their disposal by the American Museum.

FINANCIAL STATEMENT.

Amount appropriated by Congress for work of the U. S. Geological Survey for the fiscal year ending June 30, 1882	$156,000 00
Expended during fiscal year	142,558 76
Remaining on hand July 1, 1882, to meet outstanding liabilities	13,441 24

The following is a classification of the expenditures:

1.	Salary of Director	$6,000 00
2.	Services of assistants and employés	104,516 20
3.	Rent of offices	3,403 66
4.	Repairs of offices	278 99
5.	Office furniture	2,738 75
6.	Fuel	320 50
7.	Gas	435 37
8.	Ice	79 91
9.	Telegrams	283 13
10.	Rent of telephones	127 28
11.	Rent of post-office boxes	65 20
12.	Stationery	1,481 69
13.	Books (includes maps, &c.)	2,899 11
14.	Instruments purchased	1,661 90
15.	Instruments repaired	578 50
16.	Laboratory supplies	908 53
17.	Photographic material	2,574 58
18.	Transportation of assistants and property (freight, $1,188.36; persons, $1,934.49)	3,122 85
19.	Traveling expenses	4,481 16
20.	Purchase of horses	80 00
21.	Purchase of mules	270 00
22.	Camp and field equipage	611 75
23.	Subsistence	2,160 21
24.	Forage	1,319 01
25.	Pasturage	372 54
26.	Tollage and ferriage	17 45
27.	Storage	417 50
28.	Apprehension and delivery of lost public property	5 00
29.	Minor office supplies	117 32
30.	Repairing office furniture	73 55
31.	Amount of bonded railroad accounts for transportation of freight and assistants	1,157 12
		142,558 76

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

ADMINISTRATIVE REPORTS

OF

CHIEFS OF DIVISIONS

AND

HEADS OF INDEPENDENT PARTIES

ACCOMPANYING THE ANNUAL REPORT OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1882.

REPORTS OF HEADS OF DIVISIONS.

REPORT OF MR. CLARENCE KING.

Mr. King being absent from the country on account of ill-health, the following report upon the work under his charge has been prepared at his request by one of his colleagues, from information furnished by Dr. Carl Barus.

PHYSICAL CONSTANTS OF ROCKS.

During the past year a critical study has been made of previous investigations on this subject, with a view to a selection of the best experimental methods. Besides the ordinary laboratory furniture, more delicate instruments have been selected and purchased, and special apparatus has been designed and constructed. Quarters for a laboratory in the American Museum of Natural History have been placed at the disposal of the Survey, which, in addition to other advantages, possess the desideratum of a floor of rock in place; and preliminary operations have begun. Considerable time, however, must yet be spent in completing such preparations as are involved in the commencement of all physical researches.

In June the progress of the work was temporarily though very appreciably retarded by the untimely resignation of Dr. V. Strouhal, who had been appointed to associate with Dr. Barus in the prosecution of the physical researches in question. Upon him, at the time, the duties of testing and purchasing the part of an approved inventory of apparatus which it was found expedient to import from Europe, were immediately incumbent. In Dr. Strouhal (at present professor-in-ordinary of physics at the University of Prague) the Survey has lost an observer whose unusual proficiency and ability, both in physical and astronomical experimentation, would have rendered his services of great value throughout the course of the investigation, and especially in its later portions. In this emergency we were fortunate in securing the services of Dr. William Hallock, Fellow of Columbia College. Dr. Hallock being at the time associated with Dr. Strouhal in Europe, a transfer of instructions and duties could thus be expeditiously made, the former continuing the work from the point where the latter had left it.

The instruments and material, though chosen with especial reference to the class of experiments contemplated, will, nevertheless, as a whole, meet the requirements of a fairly complete physical laboratory. It was the endeavor of those in charge to select pieces of acknowledged excellence only. The following list comprises the more important instruments, etc., which either have been or are about to be received:

Balance, 250 g., 0.1 mg., Rueprecht, Vienna.
Balance, 100 g., 0.01 mg., Bunge, Hamburg.
Balance ordinary, 2–5 kg., 2–5 mg.
Set of weights, 1 kg–1 mg., Rueprecht.
Set of weights, 100 g–1 mg., Bunge.
Fairbanks scales.
100 grammes, standard, Fromment, Paris.
Meter, standard, Fromment.
Cathetometer, Grünow, New York.
Spherometer.
Chronometer, Bröcking, Hamburg.

Rood's Sprengel's air-pump, Grünow.
Bessel Hagen's mercury air-pump, Müller, Berlin.
Air-pump, ordinary.
Fortin's barometer, with Wild's improvement, Fuess, Berlin.

Three normal thermometers, —1°–101°, $\frac{1}{10}$°, Baudin, Paris.
Two normal thermometers, —1°–101°, $\frac{1}{5}$°, Baudin.
Two thermometers, 20°–200°, —$\frac{1}{1}$°, Baudin
Assortment ordinary thermometers.
Air thermometer, Grünow, New York.
Hygrometers.

Large telescope with scale adjustment, Hartmann, Würzburg.
Three small telescopes with scale adjustment, Hartmann.
Total reflectometer, Apel, Göttingen.
Laboratory theodolite, Meyerstein, Göttingen.
Small spectrometer, Meyerstein.
Microscope with stage micrometer, Grünow.
Prisms, mirrors, nicols, lenses, etc.

Rheostat, 1–10,000 ohms (remodeled by Grünow).
Rheostat, 1–10,000 ohms, Elliott Bros., London.
Two rheostats, 0.1–4,000 ohms, for shunting, Hartmann.

Assortment of Weber's commutators.
Standard ohms.
Two Kohlrausch's Wheatstone's bridge, Hartmann.
Earth inductor.

Two Thomson's astatic reflecting galvanometer, Elliott Bros.
Wiedemann's reflecting galvanometer, Grünow.

Two Kohlrausch's reflecting galvanometer, Hartmann.
Tangent compass.
Thomson's quadrant electrometer, White, Glasgow.
Electro-dynamometer, Siemens and Halske, Berlin.
Small magnetometer, Hartmann.

Lathe, with assortment of tools.
Carpenter's bench, with assortment of tools.
Forge, anvil, vise, tools.
Jeweler's rolling-mill.
Burners, blast-lamps, gasometers, &c.

Glass apparatus (flasks, beakers, burettes, &c.).
Porcelain apparatus (dishes, &c.).
Chemicals, batteries, &c., &c.
Additions will be made from time to time as occasion requires.

The proposed experiments on the physical constants of rocks may be conveniently considered under the following three heads:

(*a.*) Phenomena of fusion. These would comprehend temperature of fusion, specific volume of the solid and of the liquid material respectively at this temperature, heat-expansion, compressibility, latent heat of fusion, specific heats—all considered with especial reference to their variation with pressure.

(*b.*) Phenomena of elasticity and viscosity considered, as before, with especial reference to their dependence on temperature and pressure.

(*c.*) Phenomena of heat-conductivity under analogous circumstances.

The difficulties presented are great, and in some instances insuperable; for if the results are to be applicable to the solution of geological problems, experiments must be made at the highest attainable pressures, as well as at elevated temperatures. The observers will therefore confine themselves for a considerable period to narrowly circumscribed portions of the investigation. Among such, an empirical study of the variation of melting point with pressure for a number of typical rocks would come first in interest and in value. Fortunately, too, this is the portion of the work which, when considered from an experimental standpoint, presents the least formidable aspect, and which finally, from theoretical grounds, recommends itself as a point of departure. Side by side with it, moreover, certain features of the viscosity question may be conveniently attended to. Until considerable progress has been made experimentally, but little aid can be derived from thermo-dynamics.

The problem presented is, therefore, the measurement of the relation between the small increments of temperature superimposed upon very great values of this quantity, and the corresponding very large increments of superincumbent pressure to which the former are due, the substance being supposed to remain constantly at a melting point. Insomuch as high temperatures and pressures are to be dealt with, it is obvious that only small quantities of the material to be examined can be experimented upon; in other words, that the space raised to the temperature of fusion of the sample must comprise but a minute portion of, or, as it were, be local in comparison with, the necessarily small space within which an intense pressure is brought to bear. It furthermore follows that the only means for the measurement of temperature probably available under the circumstances will be of a thermo-electric kind. It is believed, however, that if proper care be taken to guard against the many errors incident to this work, and means be devised by which the constants of the couple can be readily checked, results not unworthy of reliance may be attained. There will be reason to recur to this matter again after the main features of a method adapted to the problem just enunciated have been briefly sketched.

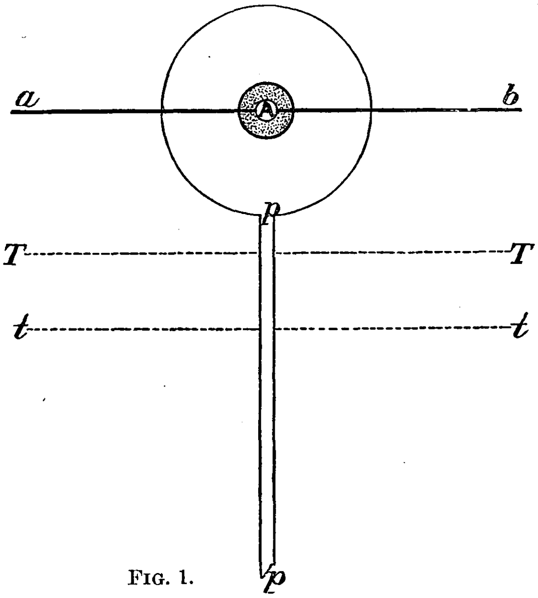

FIG. 1.

Within a strong receiver communicating with the tube *pp*, the material to be examined, A, in form of a spherule, is appropriately secured. The latter is immediately surrounded by an adhering envelope of very thin platinum foil, which again lies within a thick jacketing of some refractory non-conductor (CaO, MgO, ...).[1] Thick wires, *a* and *b*, in part of platinum, meeting the platinum covering (crucible) at points diametrically opposite, make it an integrant part of a galvanic circuit, insulated throughout from the receiver. This circuit furnishes a means of fusing the specimen. It is not necessary to retain the closed form of crucible; ordinary open forms will be at times convenient, insomuch as appliances may then be easily devised by which a galvanic arc can be used for fusion in place of the incandescent crucible, the variation of resistance of the fused contents of the latter measured, etc. These facilities are of importance.

As a means of securing a requisite amount of pressure, the method adopted by Pictet[2] suggests itself. To apply it the receiver would be

[1] *Deville & Debray*, "Ann. de chim. et de Phys." (3), LVI, 1859, page 396, found, in the case of a lime crucible whose walls were 2^{cm}. thick, that while the interior contained melted platinum, the exterior surface was raised to a maximum temperature no higher than 150° C.

[2] *Pictet*, "Mémoire sur la liquefaction de l'oxigène, &c.," Geneva, 1878.

filled with a salt,[1] from which great quantities of gas are easily generated by the application of a moderate amount of heat. Notwithstanding its simplicity, however, there attach to it, when used for the present purpose, a number of serious inconveniences, chief among which is the fact that the maximum pressure attainable, apart from extraneous obstacles (strength of receivers, application of heat, etc.), is limited by causes inherent in the method itself. An air compressor being even more unsatisfactory, the following plan presents some interest: As a medium for the transmission of pressure a liquid[2] having a *low* critical temperature is presupposed. The receiver and the part of the tube *pp* above the plane *TT* are to be kept permanently at a temperature higher, the part of the tube *pp* below the plane *tt* at a temperature decidedly lower, than the critical point of the pressure-medium chosen. If the receiver be conceived to have been exhausted at the outstart, and the liquid in question then gradually introduced through *pp*, finally, by the aid of a powerful forcing-screw propelling a closely fitting soft copper piston[3] in an upward direction, pressures ranging from zero to a maximum depending only on the strength of materials, power applied, etc., would be attainable.[4] The obvious advantages of acting mechanically on the pressure-medium while in the liquid state, and of bringing the pressure to bear on the crucible by means of the same medium in the gaseous state, are to an extent vitiated by the necessity for an especial and preliminary investigation of the effect produced by absorption of gas under pressure[5] on the temperature of fusion of the sample. There would be difficulty in distinguishing between the effect possibly due to the latter cause and that to be ascribed to pressure. In the hypothetical case, for instance, where water is used in the way described as a medium for transmitting pressure, we should partially realize the conditions of an aqueo-igneous fusion. If the closed crucible be surrounded by a series of consecutive thick shells of non-conducting material, suitably supported and arranged in the order of their melting points, the innermost of which layers is viscous at the temperature of fusion of the sample, the outer liquid at ordinary temperatures, it is possible that pressure may be directly applied to the crucible by compressing the outermost liquid. Such a disposition would avoid the intervention of a gas—at the expense, however, of the maximum of temperature available for fusion. Both projects will be tried. It is hoped that they will also suffice for the investigation of the variation of structure produced by cooling rocks under pressure.

[1] $KClO_3$, H_4NNO_2, $HCOOK + KOH$, &c. In the above apparatus a pressure of 500 atm. would be a high estimate of the maximum attainable by this method.

[2] $(C_2H_5)_2O$, CN, SO_2, &c.

[3] By means of this device *Mousson*, to whom it is due, believes to have attained a pressure of 13,000 atm. (Pogg. Ann., CV, p. 161); Hannay (Chem. News, xli, 1880, p. 103) has proposed a convenient apparatus for smaller pressures.

[4] *Hannay*, Chem. News, xliv, 1881, page 3.

[5] A method similar to the above is proposed by Sir William Thomson, for the study of critical points, in Nature, xxiii, 1880, p. 87.

The measurement of high pressures has of late attracted some attention. Pictet[1] obtained results with powerful aneroids. Cailletet[2] was able to utilize a mechanical device due to Depretz. Dewar[3] based measurements of pressure on the melting point of ice. Amagat,[4] availing himself of his results on the compression of gases, has adapted the closed manometer to high pressures. To Tait[5] a new manometer, based on Hooke's law, is due. None of these pieces of apparatus, however, has been applied to the measurement of pressures so high as those which will be called for in the present series of experiments. An extension, therefore, of the methods of manometry in the direction specified, urges itself. An endeavor will moreover be made to utilize a closed manometer read optically, as well as an apparatus based on the compressibility of water, for the definition of high pressures. It is intended at the same time to investigate the effects of great compression on the electrical qualities of metals, etc. The whole of the pressure apparatus would be appropriately attached to the colder parts of the tube *pp* in the above figure.

On whatever plan the observations are conducted, whether by producing an approximately constant pressure in the receiver and varying the temperature of the crucible gradually and in such a way as to pass through the melting point of the sample under experiment, or by maintaining an approximately constant temperature and gradually varying the pressure, it is of the utmost importance to devise a method of recognizing the precise time of incipient fusion or solidification. In the first, and probably the more practical, of the cases just mentioned, the ordinary phenomenon of a temperature temporarily stationary while fusion is in progress would perhaps answer. By preliminary trials the connections (zero method) of the thermo-element are first to be adjusted to a temperature corresponding as nearly as is conveniently possible to the particular melting point of the material chosen; the definite measurement will then be made by correcting this approximate temperature by the aid of a method of graphic interpolation; the galvanometer needle being for this purpose fitted with means for tracing its excursions on sensitized paper. Again, substances possessing a definite melting point usually experience a marked change of specific resistance on passing from the solid to the liquid state.[6] The application of this peculiarity also to the purpose in question therefore suggests itself. In this case—the melting point being as before approximately known—the needles of both galvanometers (*i. e.*, that belonging to the circuit for measuring resistance and that of the thermo-element) would be allowed to trace their deflections side by side on the same sheet of sensitized paper.

[1] *Pictet*, l. c.
[2] *Cailletet*, Ann. de Chim. et de Phys. (5), xix, 1880, p. 386.
[3] *Dewar*, Proc. Roy. Soc. Lond., xxx, 1880, pp. 533–538.
[4] *Amagat*, Beibl. (3), p. 414.
[5] *Tait*, Proc. Roy. Soc. Edinbg., x, 1880, p. 572.
[6] *Cf. Mousson*, "Physik," 2d ed., iii, p. 311.

A few words on the measurement of temperature are still to be added. Becquerel[1] very highly recommends his platinum-palladium couple, principally as presenting, in addition to sensitiveness at high temperatures, a constancy in its indications sufficient to permit the observer immediately to compare results obtained within very large intervals of time and use. Nevertheless, an especial research with reference to the choice of metals is desirable—indeed necessary,[2] and in connection therewith a study of the thermo-electric effect of superficial layers differing in composition from the body of the wires forming the couple, of the effect of silicification, etc. It is obvious that both the crucible and the thermo-element will be gradually corroded and finally destroyed by the cause last mentioned. At high pressures, moreover, there is danger of the formation of an alloy[3] at the thermo-electric junctures of the (originally tied) wires, in which case the couple would become useless at a temperature below that of the melting point of the constituent metals. Preparation has been made for the repetition of such of Deville and Troost's[4] high-temperature experiments as will be auxiliary to or necessary for the calibration of the thermo-element. Both the forms of porcelain air-thermometer and the methods of measurement of these observers will be applied, as well as Crafts and F. Meier's[5] modification of V. Meyer's ingenious vapor-density contrivance, including, of course, a determination of the expansion of the porcelain employed at high temperatures. Insomuch as the ultimate object of the work is that of devising some means by which the constants of the thermo-element may be readily and satisfactorily checked, there will also be tried a number of other devices for thermometry, among them the vapor-tension thermometers recently again urged by Thomson.[6]

In giving the brief review above, the object was more that of defining the character and scope of the researches to be made than of presenting determinate experimental methods. The particular section referring to the calibration of the thermo-element alone has been projected with requisite detail and the apparatus in part constructed; the others will, however, impart direction to the corresponding integrant parts of the work on melting point and pressure, and in the main probably be adhered to. Owing to the great practical difficulties encountered on all sides, the general plan of research must necessarily be progressive. It is intended to commence with easily fusible material (wax, etc., salts) as well as with comparatively low pressures; and passing onward from these, so to develop and modify the methods adopted as to render them finally applicable to material and pressures possessing immediate geological interest.

[1] *E. Becquerel*, Ann. de Chim. et de Phys., (3), lxiii, 1863, p. 142.

[2] Nichols, Am. Journal (3), xxii, 1881, p. 368.

[3] *Spring*, Chem. Ber., xv, 1882, p. 595.

[4] *Deville and Troost*, Comptes-rend., xc, 1880, p. 727, 773; lix, 1864, p. 162; lvii, 1854, p. 897.

[5] *Crafts and Meier*, Comptes-rend., xc, 1880, p. 606.

[6] *Sir W. Thomson*, Proc. Roy. Soc. Edinbg., cvi, 1880, p. 432.

REPORT OF MR. ARNOLD HAGUE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE PACIFIC,
New York, July 15, 1882.

SIR: I have the honor to submit the following report of operations by the Division of the Pacific for the year ending June 30, 1882.

During the fiscal year just closed the only field work undertaken by any member of this division was a journey which I made to Eureka, Nev., in the months of July and August, 1881, mention of which was made in my last annual letter, written after returning from the field. The trip, which proved a successful one, was undertaken for the purpose of examining some disputed points in the geology of the Eureka district suggested by a comparison of observations and cross-sections after leaving the field; and, also, to re-examine certain localities bearing directly upon the important question of a non-conformity at the top of the Eureka quartzite, midway in the Silurian beds. Pressed as I was for time, in order to prepare the geological maps for publication at an early date as possible, I left the field with regret, leaving many interesting questions remaining unanswered, and returned immediately to office work in New York.

All office work on the topographical and geological maps is about finished, and the sheets are now in the hands of the lithographers. The first proofs have nearly all been revised, and are far advanced towards publication. The small geological map presenting the mountains of Eureka on a single atlas sheet, has already been printed in color, making a beautiful map. It is now complete and only awaits publication. The double sheet of cross-sections, drawn to a natural scale across the map from west to east and forming the last plate of the atlas, has been finished and is in the hands of the engraver. But little work therefore remains to be done, except revising the proofs and finally printing the twelve sheets that make up the atlas.

Mr. C. D. Walcott's full report upon the paleontology of the Eureka district, a brief sketch of which, indicating its scope and importance, appeared in my last letter, was completed in the spring and is now ready for the printer. It embraces a rich fauna from the Cambrian, Silurian, Devonian, and Carboniferous. Over three hundred careful drawings of fossils, illustrating the new species, have been arranged on thirteen plates, which have already been engraved in a most satisfactory manner.

Mr. Joseph P. Iddings has submitted the special monograph on which he has been engaged, upon the microscopic petrography of the crystalline rocks of the Eureka district, presenting a systematic classification of all the rock-sections in the collection. His paper will be accompanied by six plates, all of which have been prepared and are ready for publication.

The difficulty of producing good illustrations of the thin rock-sections required in petrographic investigation has been realized by all who have endeavored to represent correctly sections of fine-grained rock as seen with a high magnifying power under polarized light. Such sections have usually been reproduced from hand-drawings, and then more or less accurately colored. Attempts to illustrate the more important microscopic objects by means of microphotographs have encountered many difficulties, and only after laborious experiments and repeated trials have any of the minute structural peculiarities of rocks been adequately represented. To produce a satisfactory result requires considerable skill in photography, a knowledge of the use of the microscope, the best of lenses, and a thinness and evenness in the rock-section which has only been attained of late years. Indeed, it is useless to attempt to reproduce by photography, thick, uneven microscopical preparations.

Up to the present time the most acceptable illustrations of rock structure by microphotography that have been published are those given by Professors Fouqué and Michel-Levy, of Paris, in their elaborate work on "Minéralogie Micrographique des Roches Éruptives Françaises."

For a long time I have been desirous of seeing portrayed clearly, and at the same time with the accuracy of a photograph, the structural peculiarities of igneous rocks, and the mode of occurrence of certain minute crystals found in microcrystalline ground mass. Dr. J. W. S. Arnold, of New York, well known for his very successful microphotographs of medical preparations, undertook at my request the task of making the necessary pictures under polarized light. After experimenting for months he has produced a number of photographic negatives, which not only exceed my expectations but are unsurpassed by any published work of the kind. They present the delicate structure of various types of crystalline and microcrystalline rocks, highly magnified, in a manner that the most untrained observer can appreciate and understand far better than any lengthy description.

At the present time I am occupied, at your request, in preparing a summary of my report upon the geology of the Eureka district, to accompany your forthcoming Annual Report, and will therefore present here no further comments upon its contents.

Since early spring Mr. Iddings's entire time, and a large share of my own, has been given to an examination of the collection of acidic volcanic rocks from the Great Basin, brought in by geologists attached to the Geological Exploration of the Fortieth Parallel.

The results of our work we hope to present for publication in the course of a few months. They embrace both a geological and microscopical review of all material at hand, including not only the rocks reported upon by Professor Zirkel in his "Microscopical Petrography," but also a large amount of material from which no microscopic thin sections had been prepared at the time of the publication of the reports of the Exploration. From these rocks I have had prepared between three and four hundred thin sections, representing a great variety of volcanic products, and an area of country more than four hundred miles in width. A study of these sections has added very considerably to our stock of knowledge in this branch of geology.

One object of our investigation is to correct what appears to us as a very grave mistake in the elaborate work of Professor Zirkel, above quoted. Throughout his report he is frequently committing the error of calling the feldspars in certain rocks "sanidin", when careful observation shows that the recognizable individuals are determinable as belonging to triclinic species. This, it will be admitted, is a serious error in a system in which volcanic rocks are classified according to the prevailing feldspars present. From observing that very many of the feldspars were wrongly determined we were led to investigate with considerable care the question of the mineral composition of the acidic volcanic rocks in the Great Basin. As the results of these investigations are of interest to all engaged in petrographic studies, I wish here to state briefly the more important facts brought out by our work.

We find that in the Great Basin, over the area covered by the Fortieth Parallel Exploration, there are, at least so far as it is represented by the collections, strictly speaking, no normal trachytes. The rocks which have been so classed are, in nearly all cases, andesites. In other words, there are among the Tertiary and Post-Tertiary rocks which have been classed as trachytes, in none of which the feldspar is orthoclase, an essential ingredient in every trachyte. The feldspars are invariably plagioclase.

It has been recognized, of course, that in many trachytes triclinic species occasionally equaled the monoclinic feldspar, and still more rarely that triclinic forms far outnumbered the monoclinic, but orthoclase was always supposed to be present in considerable quantity. All our observations show conclusively that these rocks, in all cases where it is possible to determine the feldspars, are plagioclase rocks, and that sanidin, if present, is an exceedingly rare mineral in all of these so-called trachytes. This result seems all the more remarkable, as rhyolite, an orthoclase rock, is by far the most abundant of all the acidic volcanic rocks in the Great Basin. Rhyolite covers very large areas. It occurs forming the highest of the volcanic peaks, as well as in low hills skirting the ranges. It occurs in numerous small outbreaks and ridges, irregularly scattered over the Basin. Indeed, there are few ranges between the Wasatch and the Sierra in which volcanic action plays an important part where outbursts of rhyolite are not found.

A study of these results leads to the broad, general statement that among the products of volcanic action in the Great Basin, at least over the area examined by the Exploration of the Fortieth Parallel, the occurrence of orthoclase rocks is dependent upon the percentage of silica in the rock. Orthoclase secretions in the groundmass are unquestionably an exceptional occurrence in those rocks which do not carry the high percentage of silica found in rhyolites. In other words, they are seldom observed in rocks in which the amount of silica falls much below 68 per cent. Segregated crystals of sanidin may occur in a fine groundmass, rich in glass, without quartz secretions; the rock in most other respects presenting the characteristic structure and mode of occurrence of rhyolite. In general, however, secretions of sanidin and quartz occur together. An abundant development of free quartz is usually accompanied by a large amount of sanidin crystals, but in varying proportions.

In the autumn of 1870, the geologists attached to the Geological Exploration of the Fortieth Parallel visited a number of the volcanic cones of California, Oregon, and Washington Territory for the purpose of making preliminary surveys of the extinct craters with a view to future detailed investigation. Mr. Clarence King visited the two most prominent cones of California, Mount Shasta and Lassen's Peak. Mr. S. F. Emmons proceeded to Washington Territory and explored, from base to summit, the grandest of all the volcanoes of the Northwest, Mount Rainier; while the writer devoted all the time at his command to an examination of Mount Hood, just south of the Columbia River, in Oregon. Although they brought back most interesting material, especially in the way of lithological collections, the scientific results of their journeys were never published, with the exception of an announcement in the *American Journal of Science* for March, 1871, of the existence of actual glaciers upon the slopes of Mount Shasta, Mount Hood, and Mount Rainier.

After studying the so-called trachytes from the Great Basin and finding that among them there were none with a mineral composition which would permit of their being classed as trachytes, we took up the examination of the rocks from these four prominent volcanoes with a view of learning to what extent they might be found to agree with the rocks from Nevada and Utah.

Our work as yet has been confined mainly to a preliminary examination, but the results of our investigation we hope to have ready for publication in the course of a few months. I only desire to make here the announcement that the great cones of Mount Rainier, Mount Hood, Mount Shasta, and Lassen's Peak, which play so important a part in the geology of the Sierra Nevada and Cascade Ranges, are andesite volcanoes. While the rocks present a wide range in physical habit and structure, and suggest most interesting fields of research in their mode of occurrence, position, and relative age, they are all in mineral composition plagioclase rocks. Their essential ingredients are one or more species of triclinic feldspar, associated in varying proportions with hornblende, augite, and mica. Highly acidic varieties with secretions of quartz do not play, apparently, an important part in the more northern volcanoes, but on Lassen's Peak, in California, most interesting dacites occur among the later outflows.

In the entire collection from the four volcanoes, including rocks from the earlier as well as from the more recent flows, there is not a single specimen that can be called a trachyte in the strict sense in which the term is now used by most petrographers and geologists who employ the searching tests of the microscope in the determination of crystalline rocks.

Before closing this letter I desire to express my thanks to the Trustees of the American Museum of Natural History for the facilities which they have afforded us during the past year in carrying out our investigations and in preparing the results for publication. The rooms which they placed at our disposal have met not only all our requirements, but are unsurpassed for purposes of scientific work.

Very respectfully, your obedient servant,

ARNOLD HAGUE.

Hon. J. W. POWELL,

Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. G. K. GILBERT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE GREAT BASIN,
Washington, D. C., June 30, 1882.

SIR: I have the honor to present the following report of operations in the Division of the Great Basin during the year ending to-day.

At the close of the last fiscal year my professional force consisted of Mr. I. C. Russell, assistant geologist; Mr. Gilbert Thompson, topographer; and Mr. Albert L. Webster, assistant topographer. There were also in my service one packer, one cook, and one janitor. Mr. Russell was in the field in Nevada, Messrs. Thompson and Webster were engaged in office work in Salt Lake City, and I was in Washington, where I had been ordered for the purpose of preparing a report upon Lake Bonneville.

During the fiscal year I have remained continuously in Washington. Messrs. Thompson and Webster completed their office work in Salt Lake City, and on August 1 were transferred to other duty in the Survey. Mr. Russell continued in the field until October 24, when he disbanded his party, sending his herd of animals to Ruby Valley, Nevada, and himself returning to Salt Lake City. There he prosecuted studies growing out of his field work, and in December he was ordered to Washington to continue them. Last spring he took the field once more, leaving Washington April 24, and going into camp at Winnemucca, Nev., on May 18. He is now in charge of a small party in Southern Oregon. Mr. Willard D. Johnson was employed as assistant topographer on April 28, entering the service at Salt Lake City. At the same time Mr. E. R. Trowbridge joined the corps as a voluntary assistant. These two gentlemen proceeded to Ruby Valley and thence traveled with the herd of animals to Winnemucca, where they reported to Mr. Russell. They are now with him in Oregon. Mr. Webster was a second time detailed to this division on May 1, being then in Washington, D. C. On May 14 he left for the field, proceeding via Salt Lake City to Winnemucca, where he went into camp on June 6. He is now in charge of a small party in Northern Nevada.

My force now consists of Messrs. Russell, Webster, Johnson, and Trowbridge, with one stenographer, three packers, two cooks, and one janitor.

During the year chemical analyses have been made for me by Prof. O D. Allen, of New Haven, Conn., and Prof. S. A. Lattimore, of Rochester, N. Y., and through the courtesy of the Director of the National Museum similar work has recently been undertaken by Mr. F. W. Taylor.

An office has been continuously maintained at Salt Lake City, but for part of the year it was occupied only by the janitor. Arrangement has been made to continue it during the following fiscal year, but in a different building, one selected as offering better facilities for the chemical work which should soon be undertaken by a permanent assistant of the division.

The field work has been a continuance of the work which was begun in the survey of Lake Bonneville. Its results will be a contribution to the Quaternary history of the Great Basin, and especially to our knowledge of the system of lakes which at that time characterized its surface. Mr. Russell last year completed his reconnaissance of the basin of the ancient lake Lahontan, tracing its periphery throughout and constructing a preliminary map of it. His first field work this year has consisted of a reconnaissance through that portion of the Great Basin which lies in Southern Oregon. It is anticipated that this will be completed about the middle of July, and he is instructed then to proceed to localities of special interest in the Lahontan Basin, and devote the remainder of the season to their study. It is part of his work to map, sound, and determine the saline contents of the lakes which now occupy the lowest points of the Lahontan Basin, and he is equipped with apparatus for this purpose. The geographic work begun by Mr. Webster, and which will be continued throughout the field season, consists in the mapping of a belt of country in Northern Nevada, of which existing maps are not sufficiently accurate for the delineation of the Quaternary geology. The remainder of the basin of Lake Lahontan has already been well mapped by various surveys of the government, and when Mr. Webster's work is completed a map of Lake Lahontan, with the topography of the surrounding country, will be compiled.

The accompanying map plate shows the limits of the Great Basin, so far as they are known, and indicates by dotted lines the probable course of the boundary where it has not been determined. The areas tinted blue are definitely known to have been covered by bodies of water in Quaternary times, and the abundance of these in the region to which our investigation has extended is such as to lead us to anticipate that a final map will show the entire district of the Great Basin to have been dotted with them. A few localities where lakes are known to have existed, but where their boundaries have not yet been determined, are indicated by blue rulings.

The office work has consisted, first, of the completion of a series of maps and engravings illustrative of the history of Lake Bonneville; second, of the continuance of the preparation of a report upon Lake Bonneville; third, of the preparation of a preliminary report upon Lake Lahontan; fourth, of the assemblage of the literature of the Great Basin and of other interior basins and salt lakes; fifth, of the completion and publication of a memoir on the use of the barometer; and, sixth, of the compilation from various sources of map material necessary to the intelligent continuance of the work in the Great Basin. My own time has been largely occupied by various minor duties connected with the general work of the office, and especially by investigations connected with the paper on hypsometry. This paper assumed a greater importance than had been anticipated, and, as a result, the preparation of the report upon Lake Bonneville, which would otherwise have been completed, has not been greatly advanced.

In the preparation of illustrations I have been greatly assisted by Mr. Holmes and his corps of draughtsmen; and Mr. Thompson, although not at the time a member of my division, kindly compiled a preliminary map of the Lahontan Basin and a preliminary map of the Colorado and and San Bernardino deserts.

I am, with great respect, your obedient servant,

G. K. GILBERT,
Geologist in charge.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

Julius Bien & Co. lith.

PROGRESS MAP OF THE GREAT BASIN

REPORT OF MR. T. C. CHAMBERLIN.

UNITED STATES GEOLOGICAL SURVEY,
Beloit, Wis., July 14, 1882.

SIR: I have the honor to submit herewith a report of the work committed to my charge for the year ending June 30, 1882.

In your letter of instructions bearing the date of June 17, 1881, you assigned as the subject of my investigation for the coming year the terminal moraine that enters the United States on the north border of the Territory of Dakota and stretches thence southward and eastward, in sinuous course, presumably to the Atlantic. I was instructed to devote my investigations principally to the portion lying in the Territory of Dakota, and to such other portions as had not been previously traced, giving to still other portions such examination as might be necessary to determine the relations of the several parts, and the proper delineation of the whole on a map. Collateral deposits, intimately associated with the moraine in history, were also designated as subjects of study.

The method pursued in the execution of the task assigned me deserves brief consideration, as this line of investigation is one of recent development, and its special phases and working hypotheses lie somewhat without the usual practice of field operations. By previous investigations it had been ascertained that the formation under consideration consisted, not of a single moraine, but of a group of three or more concentric and rudely parallel ones, that sometimes coalesce and sometimes separate, so as to occupy a belt occasionally twenty or thirty miles in width. It had further been shown that the individual moraines, instead of consisting of single sharp ridges, as has too often been the mental picture of a terminal moraine fashioned after the lateral moraines of Alpine glaciers, consist of a broad belt of irregular, tumultuous hills and hollows, giving rise to a peculiar knob-and-basin topography. Contrary to previous conceptions, the massiveness of the moraine finds its development in great width rather than in abrupt and conspicuous height. To its departure from prevalent preconceptions in this and other respects, is to be attributed its long escape from general recognition. It had further been ascertained that throughout a considerable portion of its course, instead of pursuing a direct or moderately undulatory course, it is disposed in great loops, formed at the margins of ice tongues, between which re-entrant portions formed extensive intermediate moraines. It had also been learned that these ice tongues occupied the great valleys of the interior, and manifestly owed their origin to topographical influences. It had further been shown that the direction of ice movement within each of these lobes coincided in the center with the axis of the lobe, but diverged laterally toward the margin in a most remarkable manner, so that the motion on opposite sides of the ice tongue was in nearly opposite directions and, immediately adjacent to the moraine, essentially at right angles to it. These and other cognate results of previous study, which need not here be specified, determined the working hypotheses upon which the survey was prosecuted.

By careful study of the topographical features of the territory involved, of its drainage systems, and of other available data, such different hypotheses as to the disposal of the moraine as seemed to be harmonious with surface features, and conformable to the laws of its disposal already determined, were framed, and made aids and stimulants in the prosecution of the work. But an effort was made to hold them merely as working hypotheses for the guidance and assistance they might render, and entirely subject to rejection or modification, as might be demanded by the results of observation. Furthermore, the working plan adopted was such as to check and correct the possible misleading influences of an erroneous hypothesis. To work without hypotheses in an investigation of this kind, is to neglect a most valuable aid. To be unmindful of their possible misleading influences, and to neglect corrective measures, is to open the way to error.

The most obvious and seemingly natural method of investigation would have been to attempt to trace the moraine lineally. But this was rejected on the basis of previous experience, because of its liability to error, growing out of the complexity of the range, the frequent spurs which diverge from it, and the existence of subordinate moraines, by which an observer might easily be misled in an attempt at a merely linear tracing of the moraine. Furthermore, the study of the moraine itself is scarcely more important than that of the overflow deposits and older drift on the exterior, and of the newer till and subaqueous formations within it, and a really comprehensive study of it involves the determination of the character of the glacial lobes that produced it and of their erosive and distributive work, as manifested by the resulting drift exhibited throughout the areas occupied by them. The method pursued, therefore, was that of extensive preliminary reconnaissances of the entire area involved, which embraced a frequent crossing, not only of the entire morainic belt, but of a considerable adjacent area upon the exterior, and of the entire lobate area within the moraine. With this was associated a system of broad zigzagging of the morainic belt, for the purpose of the closer determination of the course and relation of the associated moraines, accompanied by local study in detail, and linear tracing of the belts. The complete plan, as projected, involves the following of the system down to as detailed investigation and delineation as may be possible. The limits of a single season and of the means at disposal manifestly confined this detailed work to selected localities, where special study was essential to a correct interpretation of the results of the reconnaissance and more general studies.

In pursuance of this method, three lines of observation were carried entirely across the glaciated territory lying between the Mississippi and

Missouri rivers, which involved the traversing of the tracts occupied by the glaciers of the Red, Minnesota, and Dakota River valleys, and of the moraines which border them on the east and west, as well as the interesting series lying between them. The southernmost of these was made along the line of the Chicago, Milwaukee and Saint Paul Railroad, from McGregor, Iowa, on the Mississippi, to Chamberlin, on the Missouri; the second along the line of the Chicago and Northwestern Railroad, from Saint Paul, on the Mississippi, to Pierre, on the Missouri; the third along the line of the North Pacific, from Brainard, on the Mississippi, to Bismarck, on the Missouri. This last line was extended westward beyond the limit of the drift, which was found to extend about 28 miles west of the Missouri, and to be characterized at its margin by an extraordinary abundance of granitic bowlders.

That portion of the morainic belt which was presumed to cross the lower Dakota Valley and lie between the Dakota and Missouri rivers, was assigned for special study to Professor J. E. Todd, while the writer devoted himself to the portion lying east of the Dakota (James) River. The moraines of this region, as far north as the head of the *coteau*, together with the general character of the associated deposits of the adjacent territory, were successfully determined by the 6th of August.

Professor Todd, parting from the writer at Canton, in southeastern Dakota, on the 19th day of July, reconnoitered the country southwest to the Missouri River, and thence northwesterly to Mitchell, in the Dakota River valley. From this point he traversed the plateau to the Missouri River, examined the Bijou Hills, and thence recrossed the plateau northeasterly to Huron, examining the Wessington Hills and adjacent region. From this point he reconnoitered the country northward on the west side of the James River and adjacent to it, extending observations west in the Elm Creek Valley as far as the *Coteau de Missouri*. From Ordway he passed somewhat directly northward to Jamestown for consultation with the writer, according to previous appointment. As the result of this conference, on August 13, it was thought advisable that Professor Todd, instead of a further examination of the Missouri *Coteau*, as first planned, should spend the rest of his available time in examining a chain of morainic hills which, in a previous reconnaissance had been observed lying between the Shyenne and the James Rivers, south of the Northern Pacific Railroad, and in exploring as far as practicable the somewhat critical area lying between them and the head of the *Coteau de Prairie* which had been the northern limit of my connected observations. Professor Todd explored this region and reached the head of the *Coteau* on August 19, from which point he returned along the western edge of the *Coteau de Prairie* to Canton, where his work closed on August 30.

Between August 27 and September 1, I examined a portion of the western moraine of the Green Bay glacier, in Waupaca, Shawano, and Marathon Counties, in the great northern forest of Wisconsin, which had previously been difficultly accessible, but had recently been opened by the extension of the Lake Shore and Western Railroad.

Meantime, Professor L. C. Wooster, under instructions from the writer, had been engaged in the exploration of the moraine in Michigan, which had never been specially studied beyond a general reconnaissance by the writer several years since. Upon the basis of these previous observations, a working hypothesis was framed, which presumed the existence of a glacier traversing the valley occupied by the outlet of Lake Huron, the western end of Lake Erie, and the Maumee Valley; of another occupying the Saginaw Valley; of another in the Lake Michigan basin, and of a minor one, less confidently assumed, occupying the deep valley of Great Traverse Bay. This hypothesis, in all its essentials, was verified.

Commencing work on July 1, Professor Wooster traced the intermediate moraine occupying the high land between the Saginaw Valley and the Erie-Huron Valley, from Washtenaw County, through Livingston, Oakland, Le Pere, and Sanilac, to Huron County. He then determined successively the general position and character of the moraines flanking the Saginaw glacier on the west, through Kalamazoo, Barry, Ionia, Kent, Montcalm, Mecosta, Isabella, Clair, Roscommon, and Ogemaw counties; those marginal to the Traverse Bay glacier; and that of the Michigan glacier through Leelenaw, Benzie, Wexford, and Osceola counties, to its union with the Saginaw moraine in Mecosta County; and, finally, in the early days of August, determined in part the moraine marginal to the extreme southern point of the Saginaw glacier.

From September 7 to October 1, the writer was engaged in the study of the moraines of New York and of Eastern Ohio, with some supplementary observations in the adjacent States, with a view to the correct interpretation of previous observations, and the determination of the eastward extension of the moraine, and its relations to the marginal moraine previously traced along the southern coast of New England, and across New Jersey, by Messrs. Cook, Smock, and Upham. The work in New York was mainly expended upon the tract occupied by the remarkable linear lakes extending from Chautauqua on the west to Otsego on the east, and in the region of the Catskills. A large extent of territory was embraced in zigzag lines of observation, and, locally, studied in detail, developing the existence of numerous interesting morainic accumulations. Indeed, the richness of phenomena was such that with the time at disposal I was unable satisfactorily to determine their connections and relations, and the work was reluctantly left in an unsatisfactory condition.

The remarkable series of glacial striæ in the Grand River region of Eastern Ohio, observed by Mr. M. C. Read, and published in the Ohio Geological Report, coinciding so closely with the divergent method of glacial movement previously determined to be a characteristic of the glacial lobes which formed the moraine under consideration, suggested that a glacial tongue probably occupied the Grand River Valley, and that its margin must have been marked by a morainic loop analogous to those previously determined in the western region. A short time was devoted to the tracing of this loop, but imperative circumstances compelling my return from the field on October 1, the tracing was left incomplete, though it had reached the stage of approximate demonstration.

This work was resumed on the 8th day of May, and completed a few days later. Considerable importance attaches to this determination, not only in that it demonstrates a persistence of the lobate character of the glacial margin, and the wide applicability of the law of divergent flow, but in that the southern extremity of this morainic loop lies on the margin of the drift area, and brings to light the significant fact that a terminal moraine, which, in the interior region, is at points some hundreds of miles back from the margin of the drift area, here approaches and coincides with it, indicating that the earlier and later glacial frontages were not concentric. In connection with this work, some further observations were made upon the moraines of the Scioto, Maumee, and Michigan lobes.

On the 15th day of last June I resumed work in Dakota, by making a reconnaissance of the northern portion of the Territory, with a view to determining its general drift features, and to the more intelligent direction of the detailed work of the season. The region eastward from Fort Totten to the Red River Valley, and that south from the same point to the Northern Pacific Railroad, was traversed. A short excursion was also made westward from Fort Totten. The moraines near the Shyenne, in Barnes County, were also further studied and traced northward to T. 143.

A portion of the winter months was devoted to the study of results and the preparation of a report, but in accordance with previous arrangements a considerable portion of the time was devoted to the completion of the publications of the Wisconsin survey, of which time so devoted due report and proper deduction of compensation have been made.

Very respectfully, your obedient servant,

T. C. CHAMBERLIN.

Hon. J. W. POWELL,

Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. S. F. EMMONS.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
Washington, D. C., August 5, 1882.

SIR: I have the honor to submit herewith a report of operations in the Division of the Rocky Mountains, under my charge, during the fiscal year ending June 30, 1882.

Owing to the limited amount of funds available, no field work has been undertaken during the year, beyond that outlined in my previous report. This consisted in an examination of the Ten-mile district, Summit County, Colorado, on the same plan as the Leadville report, to which it will form a supplement, and a study of the region round the basaltic mesas at Golden, Colo., which it is intended should eventually include an economical examination of the entire Denver coal-basin. These fields of work were chosen more because, being within easy reach of the Denver office, and a portion of the necessary topography being already prepared, they could be carried on by my present corps of assistants with but little additional expense over and above their regular salaries, than because of their intrinsic importance.

Owing to the great altitude of the Ten-mile district, whose mines are all situated at an elevation of from 11,000 to 13,000 feet, field work can be carried on there only during a comparatively short summer season. The topographical map of this district was commenced by Mr. A. D. Wilson, in the fall of 1880, but field work was brought to a close before its completion by a heavy fall of snow on 25th September. The field work of this map was completed by Assistant-Topographer Morris Bien in the fall of 1881, and he was then transferred to New York to prepare drawings and correct proofs for the illustration of the report on Leadville. This map is now completed, and ready to be geologically colored as soon as field work can be resumed.

Geological-Assistant Ernest Jacob was occupied during the same season in the examination of the geology of this district until further field work was rendered impossible by snow. He was then transferred to New York, to assist in the preparation of the report on Leadville. Owing to the severe physical and mental strain of continuous labor in Leadville district during two years, his health failed him, and he was ganted leave of absence without pay in March 1881, for the balance of the fiscal year.

As soon as the funds for the coming year are available, field-work will be resumed, and it is expected that the report will be ready for publication before the close of the calendar year.

The examination of the Golden region was carried on by Assistant-Geologist C. W. Cross during the summer and fall, and at times during winter when the weather was such as to admit of out-door work to advantage. The succession of Tertiary and Cretaceous rocks, and the relations of the former to the basaltic flows, have been satisfactorily made out. A most valuable collection of zeolitic minerals has been obtained from the basaltic rocks, and a careful examination, both mineralogical and chemical, has been made by Mr. Cross and Mr. W. F. Hillebrand. Their investigations have also disclosed valuable clays, besides the coal-beds which were known to exist in this region. The soils in the neighborhood of Denver have also been examined. In order to carry out the plan of making a map of Denver coal-basin, which shall show the depths and location of available coal-beds, it will be necessary that a new survey shall be made. The alternative is therefore presented of confining the report to the immediate region of Golden, which will deprive it of a large part of its economic value, or of delaying its publication till the coming spring if it be found that the expense of a new survey can be assumed.

I have been personally engaged in office-work during the entire year. Leaving Denver on the 15th August, I remained in New York till 1st January, occupied in superintending the preparation of maps and illustrations for the Leadville report; in preparing statistics of the production of the precious metals in my district for the Census Bulletin; and in writing the abstract of my report on the Geology and Mining Industry of Leadville for your last annual report. Since the 1st January I have been in Washington preparing the text of my report on Leadville, and exercising an advisory supervision over the work of my assistants.

It is impossible to say what work can be undertaken during the coming year until it is ascertained what funds may be allotted to this division. The possible field of work is almost bewildering from the multitude of points of scientific interest and economical importance which it presents. The remarkable silver deposits of the Silver Cliff region; the great sulphuret veins of Gilpin and Clear Creek Counties; the unique telluride ores of Boulder County; the varied and complicated ore bodies of San Juan and Gunnison; the important gold veins of the Black Hills of Dakota; and the, as yet little known, mining fields of Montana and New Mexico, all demand careful examination.

The scientific examination of any or all of these regions will not only prove of great value to the theoretical study of ore deposits, but will practically advance the interests of mining industry by pointing out the true methods of systematic development. As, owing to the amount of time and money involved in the preparation of the monographs of these districts, not more than one or two can be undertaken at a time, I would respectfully recommend that if the collection of mineral statistics, which has already been commenced by the Survey under the auspices of the Census Bureau, be continued as one of the features of its work, preliminary reports be prepared from time to time with the aid of material gathered by those engaged in the statistical work, and published in a relatively cheap form as Bulletins of the Survey.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. G. F. BECKER.

DIVISION OF MINING GEOLOGY,
DISTRICT OF THE GREAT BASIN,
New York, September 12, 1882.

SIR: During the past fiscal year I have been chiefly engaged in completing the details of the investigations connected with my mono, graph on the Geology of the Comstock Lode and the Washoe District- and in preparing the manuscript for the press. A summary of this memoir was transmitted to you on October 20 of last year and appeared in your annual report. This summary fairly represents the contents of the volume, which was transmitted in manuscript on May 6 of this year. Printing was begun about the end of June, and the report will probably all be in type about October 1.

Much of my time during the year has been given to the compilation and discussion of the Census of the Precious Metal industries. This portion of the Census investigations was originally placed in charge of the Hon. Clarence King, then Director of the Geological Survey, Mr. Emmons and myself each having charge of the conduct of the inquiry in our respective districts.

In April of this year Mr. King was obliged to resign his charge of this work through ill-health, and on May 1 I was appointed to continue it. The reports are now in an advanced stage of preparation, especially that on Technology and Production, which will be ready for publication during the autumn. This volume will embrace statistics and discussions of the following topics: *first*, the geographical and geological distribution of the mines, and the relations of the mining districts to the mountain system of the country. The nature of the ores, gangue-minerals, inclosing rocks, and the character of the ore deposits, so far as the information collected serves, will be noted; special geological details will be given of a number of important or typical mines, and some attempt will be made to indicate the relations of natural districts to the general geology of the country. In this connection a list or directory of the mines concerning which information has been received will be given; *second*, data relative to the investments in mines, showing the capital stock, the cost of plant so far as can be estimated, the assessments, dividends, and the market value of shares during the census year; *third*, the methods employed in mining, milling, and smelting, embracing tabulations of many technical matters and such discussions as appear profitable; *fourth*, the labor, power, and material supplies consumed in mining; and *fifth*, the production of the mines, including the contents of a bulletin already published, with such additional tables and remarks as were not ready for the press at the date of issue of that pamphlet. A bulletin issued last winter shows the production of the precious metals in the United States during the census year by States and Territories, and also by counties and districts so far as the data were thoroughly trustworthy; but no segregations of production on general information were permitted to appear, except where the method employed was specially explained. The subjects of the other volumes in preparation, Mining Law, and Mining Civilization, are somewhat remote from the purposes of the Survey, and need not be enlarged upon here.

Mr. J. S. Curtis has spent the past year under my general direction in studying the ore deposits of Eureka, as a supplement to the general geology of the district, a summary of which by Mr. Arnold Hague appears in this volume. Mr. Curtis's work is practically completed, but as much office work remains to be done before he can reach definite conclusions on all points, it is not yet time to foreshadow his results as a whole. One of the interesting points bearing upon the nature and origin of the deposits is the metallic contents of the inclosing limestone. Numerous assays made with specially prepared reagents, and with the utmost care, show that while traces of silver can be readily detected in the limestone, the quantity of silver is in inverse ratio to the distance from ore. It appears not improbable that prospecting on Ruby Hill might be materially assisted by assays which, in some cases, at all events, would indicate the proximity of unsuspected ore bodies. It is impossible to account for the presence and peculiar distribution of this silver in the limestone, except upon the supposition that it is an impregnation. The ores were therefore not derived from the limestone, but either from the quartzite adjoining the limestone or from some other source. Unfortunately, only the limestone is opened up by mine-workings to any considerable extent, and much difficulty will be experienced in drawing sufficiently broad conclusions from the unsatisfactory exposures of quartzite, granite, etc.

The beautiful masses of aragonite crystals which cover the roofs of the caves above the ore bodies on Ruby Hill are familiar to all who have visited these mines. Mr. Curtis has detected the fact that these crystals are still in process of rapid formation, and is conducting accurate measurements to ascertain the rate of growth, as well as the physical and chemical conditions attending their formation.

The mines of Prospect Mountain are of far less commercial importance than those of Ruby Hill. They are, however, also being examined with care, mainly in the hope that phenomena there observed will throw light upon the obscurer points of the geology of Ruby Hill, and for this hope there seems considerable justification.

Mr. Curtis's report will be accompanied by maps and sections, and will record a large amount of accurate observations. Certain questions connected with ore deposits in limestone have heretofore eluded solution, and the report on the Eureka mines is hardly likely to clear up all the obscurities of the subject, but it is believed that it will prove a material contribution to our knowledge of that important class of occurrences. It will be ready for the press during the present year.

Very respectfully, your obedient servant,

G. F. BECKER,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. LESTER F. WARD.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., August 17, 1882.

SIR: I have the honor to report that from July 1 until July 26, 1881, I was principally engaged in collecting the titles of works on vegetable paleontology for the Survey.

On July 26, pursuant to instructions, I left Washington and proceeded to Greeley, Colo., where I arrived July 30, and where I found Dr. C. A. White in waiting, who reported to me as directed. On the following day, accompanied by Mr. William Cleburne, Dr. White and myself proceeded to Golden, Colo., where we made such general observations of the geology and paleontology of that region as it was possible to do under the circumstances. Returning to Greeley on August 2, we learned by telegram of the probability that Dr. White would be appointed commissioner for the location of artesian wells on the Great Plains, which necessitated an entire change in my plans for the summer's work.

While awaiting developments respecting the above-named appointment, it was decided to accompany Mr. Cleburne to a point on the Platte River, some fifty miles below Greeley, where fossils were reported in a recent railroad cut. Accordingly we left Greeley, and on August 4 visited the point named. No vegetable fossils were exposed, the formation being Cretaceous.

Leaving Mr. Cleburne at this point, Dr. White and myself, with the

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assistance of Prof. Lawrence Bruner, proceeded with the same outfit with which we started from Greeley, to a place some fourteen miles north of Fremont Orchard (Girardot's Ranch), known as Girardot's Coal Mine, where the Laramie Group is well exposed, and where abundance of fucoids (*Halymenites*) occur above shell-beds. Having examined this locality and made collections, the party returned to Greeley on the 6th.

Being obliged to wait still further for orders, two outfits were employed, and Dr. White proceeded to Crow Creek, while I, accompanied still by Professor Bruner, visited a bluff near the mouth of Saint Vrain River, a short distance from Platteville, Colorado, where the base of the Laramie Group is exposed, as also the extreme Upper Cretaceous. Nothing of a vegetable character excepting fucoids and some silicified wood was found in this locality. I therefore decided to visit two points in the vicinity of Fort Collins, known as Fossil Creek Spring and Cañon, which were reported to yield fossil plants.

These localities were examined on the 9th and 10th of August. They were found to be Cretaceous strata (Fox Hills Group), containing abundant remains of *Inoceramus*, *Baculites*, &c. From this point I again returned to Greeley on the 11th. Dr. White had also returned from Crow Creek, and had then received definite instructions to proceed to the investigation of artesian wells. Two boxes of fossils were prepared for shipment from Greeley, the result of collections up to that time. It was then decided to proceed to Denver and await further instructions as well as funds. While waiting at Denver, taking Professor Bruner, who offered his services without compensation, I visited Golden and made more careful observations than it had been possible to do on a previous occasion, remaining there during the 15th, 16th, and 17th, and returning on the 18th, having collected and left ready for shipment five boxes of fossil plants chiefly from the slope of South Table Mountain.

Having received the necessary funds to proceed, though unaccompanied by further instructions, and Dr. White having left my party permanently, I was compelled to adopt such a plan for the remainder of my field season as upon the whole seemed best. I arranged with Prof. Lawrence Bruner, who was employed as assistant entomologist of the Department of Agriculture, to accompany me in the interest of the Department of Agriculture, since the field which he desired to examine corresponded with that in which I alone could operate, namely, the various points of interest in the nearer vicinity of the Union Pacific Railroad.

I therefore proceeded to visit in succession the principal localities along that road at which collections of fossil plants had been made. The first of these was reported to be Rock Station, Wyoming, where we arrived on the 26th. A few species had been reported from this locality, but on examination I was soon satisfied that none had been found in the vicinity of the station—the horizon being evidently Upper

Cretaceous, or Fox Hills Group, and containing *Inoceramus*, *Ammonites*, and other characteristic Cretaceous fossils. Little better success was had at Medicine Bow, where Cretaceous strata still prevailed, as revealed at one spot by the presence of *Baculites*, *Scaphytes*, &c.

The next locality visited was at Carbon Station. Here, for the first time, vegetable remains were found. The plant-beds lie immediately over the coal-beds, and fossils may be easily obtained. We remained at Carbon until August 29, and prepared for shipment five boxes of fossil plants.

From Carbon I proceeded, still accompanied by Professor Bruner, to Black Butte Station, now reduced to a side track, where three days were spent, and four boxes of fossils obtained, containing many very excellent specimens, the locality being one of unusual interest.

On September 1 I reached Point of Rocks, and remained there until the 3d, making collections. While there I received valuable assistance from Mr. Levy, station agent at Point of Rocks Station. The geology and paleontology of this region especially merits the closest attention. A species of *Salisburia*, which may be the same as that found near Fort Ellis (*S. polymorpha*), occurs at one point in considerable abundance. Many of the specimens obtained at Point of Rocks when shown to Dr. J. S. Newberry, a short time since, were regarded by him as new to American paleontology. Two boxes of specimens were shipped from Point of Rocks.

Green River City was the next point visited, but as little could be done without securing an outfit and proceeding some distance from the railroad, and as time was limited, I remained here only two days, with small success.

Accounts which I had received from Mr. Wm. Cleburne, chief engineer of the Union Pacific Railroad, and from Mr. J. Budd, superintendent of construction, relative to rich fossil deposits discovered along the line of the Oregon branch, now in process of construction from Granger, Wy., up Hams Fork and through Hodge's Pass, induced me to abandon further operations in the vicinity of Green River and to endeavor to reach the localities designated by these gentlemen. Accordingly on the 7th instant I proceeded to Granger, and on the following day took the construction train of the Oregon branch to the terminus, some 26 miles distant. Here an outfit was obtained from the ranch of Mr. Charles F. Roberson, and I proceeded to the tunnel now being cut through a ridge forming the divide between the Green and Bear River drainages. The coal formation was reached before leaving Hams Fork to enter the Pass, and continues some five miles west of the divide, the strata dipping to the west and representing an immense thickness of coal deposits. Fossil plants were found at nearly all horizons above the coal beds, and at two places they were exceedingly abundant, yielding specimens of superior perfection and interest. Large collections were made. On the 11th a point seven miles west of the tunnel was visited, known as Bell's Fish Cliff. Here the Green River formation again appears, and the cliff resembles in most respects those in the vicinity of Green River City; but Messrs. John and Jesse Bell, who have collected fossils here by blasting, have discovered very large palm and other leaves and vegetable remains. Owing to lack of facilities for detaching rocks I was unable to obtain any very perfect specimens, but succeeded in finding fragments of gigantic palm leaves, and a few specimens of other forms of vegetation. Returning on the 13th to Mr. Roberson's ranch I retained the same outfit, and on the 14th and 15th visited two remarkable localities known as "Petrified Forests." The first one examined lies some four miles west of Hams Fork, at a point about twenty-five miles above Granger. It is a very interesting spot and demands a more detailed description than can be given here. The other lies about six miles east of Hams Fork, opposite a point about thirteen miles above Granger. This forest is much more extensive than the former and presents some remarkable features. Both deserve a more careful study than I was able to give them, but the material which I have brought from them may add something to what is already known respecting the nature of these petrifactions.

Reaching Granger on the 16th, I found that a limit to my season's operations had been reached, and accordingly, after preparing for shipment the fourteen boxes of specimens obtained on the last expedition, I proceeded to Ogden for the purpose of preparing my report and making other necessary preparations for returning to Washington.

During the entire expedition I was accompanied, as above stated, by Prof. Lawrence Bruner, who is an accomplished collector and a keen observer of geological and paleontological facts, as well as those of his own specialty—entomology—and to him I am indebted for much valuable assistance.

Returning, I reached Washington on October 1, and reported in person.

From October 1, 1881, until January 1, 1882, I was employed in the office of the Survey, performing literary work connected with the publications of the office, and editing and publishing Bulletin No. 22 of the United States National Museum, previously prepared by myself. On the first of the present year the fossil plants already in the National Museum, which had been catalogued by Professor Lesquereux, and by him sent to the Museum in the boxes, were turned over to me for classification, and from that time until June 18 I was engaged upon this work. From June 19 to the end of the fiscal year I was engaged chiefly in unpacking the 31 boxes of fossil plants collected by me during the previous field season and in the study of those fossils, preparatory to their ultimate determination.

I am, very respectfully,

LESTER F. WARD.

Hon. J. W. POWELL,

Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. J. HOWARD GORE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE COLORADO,
Washington, D. C., December 11, 1881.

SIR: In your letter of instructions of July 1, 1881, I was directed to proceed to Fort Wingate, N. Mex., and there measure a base-line for trigonometric expansion and determine its geographical position.

No instrument of precision for base-measurement was in the possession of the Survey, and it would have been necessary to have incurred the expense of a purchase, had it not been for an offer from the late chief of the United States Coast and Geodetic Survey, Hon. Carlile P. Patterson, of a pair of four-meter bars, with all the accessories. Four-meter bars were preferred to those six meters long, since they are more easily transported and are less liable to injury by careless handling. By consulting those familiar with the resources of that section which was to form the field of operations, I ascertained what articles were necessary to secure before starting. These were purchased, and all arrangements were made for starting on July 5, but the tragedy of the Saturday previous and its uncertain results caused an unavoidable delay.

In consequence of favorable predictions, I was instructed to start on July 25, and arrived at Fort Wingate, N. Mex. August 2, accompanied by my assistants, Mr. Richard U. Goode and Mr. E. V. McElhone. The former had acquired considerable experience in topographic work during his two years' connection with the Survey. The clerical accuracy of the latter while engaged in the office gave evidence of his fitness as a recorder.

At Fort Wingate I expected to meet Mr. Gilbert Thompson, topographer, who was coming overland from Salt Lake City, Utah, with camp equipage, wagons, animals, and laborers. The heavy rains of an unusually protracted rainy season rendered the time of his arrival so uncertain that I obtained from Colonel Bradley, commanding officer of the post, a tent and fixtures and riding animals.

A wash-out on the Atlantic and Pacific Railroad detained our instruments, which did not come until August 11. We anxiously unpacked and inspected them, to see what injury they had sustained during a journey of 2,600 miles. A feeling of gratification was experienced upon finding them in excellent order. Mr. McElhone immediately prepared his barometers for observations, of which he made eight each day.

In selecting a site for our base an extensive reconnaissance was necessary. The peculiar topography of this section rendered the selection of a location especially difficult. The only approximately-level ground within many miles of Fort Wingate is along the valley of the Rio Puerco, a stream, empty or full according to the weather, which runs westerly to the Little Colorado. The valley, nowhere more than four or five miles wide, is traversed back and forth by this watercourse, and throughout its whole length is skirted on the south by an unbroken mountain range, varying in height from 300 to 800 feet above the plain below. On the north is a continuous line of mesas, with their perpendicular walls on the south, while northward they slope at a greater or less inclination. The condition usually desired for a base, that it shall form the diagonal of a polygon whose vertices are situated on opposite sides of the base, it was here found impossible to secure. It would have compelled us to pursue a course near the middle of the valley and parallel to it. This would require the building of several bridges over the Rio Puerco, whose banks are too precipitous and high to allow any other method of crossing. Besides this, the mesas on the north do not present any eminences which could be sighted from stations either north or south of them. Knowing that the base was for Mr. Gilbert Thompson's expansion, we thought it desirable to have several sites located, so as to give him his choice upon his arrival, which we expected daily. For this purpose Mr. Goode and myself spent every favorable day reconnoitering. The rainy season, more protracted and extensive than any previous one within the recollection of the oldest inhabitant, so seriously affected our progress that we had only three locations in view when Mr. Thompson and party reached our headquarters, August 27. Fortunately the rains had ceased the day before. A line running along the side of the valley close to the mesas on the north was selected. This afforded an excellent expansion, forming one side of a polygon, and while not as long as base lines frequently are, it is longer than any of the other sides of the triangles of which it forms a part, and is consequently of ample length. As all the details had been carefully arranged beforehand, and all minor preparations made, work on the line was commenced the next day with the assistance of members of the Salt Lake City party detailed for that purpose, and was prosecuted with the utmost care and rapidity. The whole distance was carefully aligned by setting up temporary signals about a fourth of a mile apart; then all the weeds and bushes were removed, making an unobstructed road-way about five feet wide. The line was measured first with a tape-line, and wooden stubs placed at every 80 meters, approximately. A line of levels was run by Mr. Goode from a railroad bench-mark to the eastern extremity, and thence over the whole course, using the stubs previously set as bench-marks. The care with which Mr. Goode executed this work, as well as all other which he undertook, deserves favorable mention. The whole line was measured once with the base apparatus, and a segment of about one-third the whole length, situated near the middle, was remeasured. The rough measurements agreed so well, even before applying the corrections for inclination, that it was not deemed necessary to measure the entire length a second time, but with this remeasured segment as a base, the length of the other two segments were determined by triangulation, so that by using each segment as a base we have a double check upon each of the others. In addition to this, I measured a distance of 80 meters seven times, in order to determine the probable error. Latitude observations were made at each extremity of the line by determining the altitude of *Δ ursa minoris*. Azimuth marks were erected at each end of the base, whose azimuths were determined by a series of nine observations for each. The method adopted is different from the one usually employed for azimuth determinations, but possesses some advantages, which will be discussed in my report on "Methods and Results." Before each observation local time was determined, so as to know the chronometer correction.

By carrying on latitude and azimuth observations while the base-measurement was in progress we were able to finish on September 30. My assistants reported to Mr. Thompson, and I, in pursuance of your orders, returned promptly to Washington.

I accept this as a suitable opportunity for expressing our obligations to Colonel (General) Bradley, commanding officer at Fort Wingate, for assistance which materially expedited our work, and for favors which added to our comfort while sojourning near the post.

Very respectfully, your obedient servant,

J. HOWARD GORE.

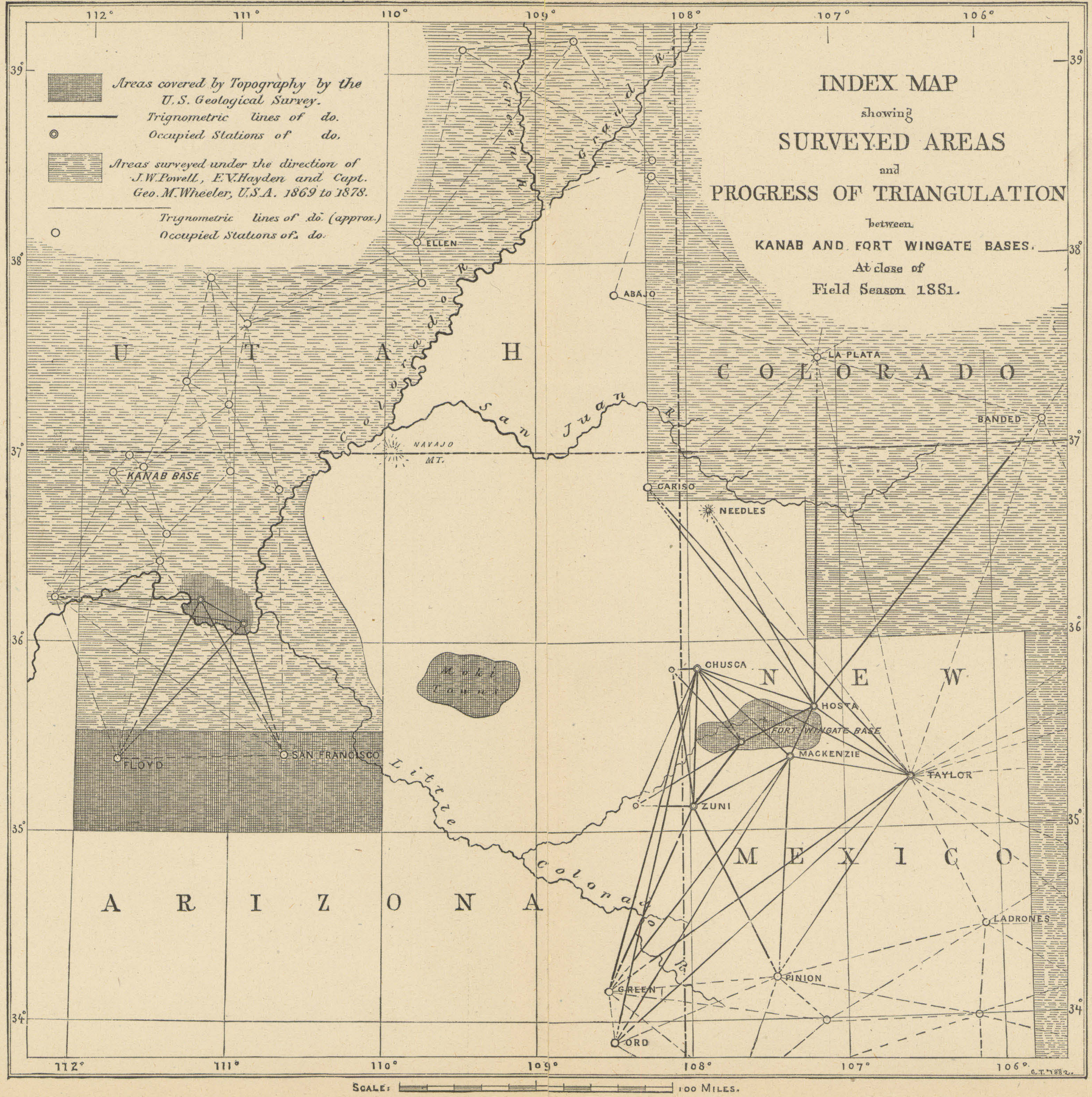
Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. GILBERT THOMPSON,

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE COLORADO,
Washington, D. C., June 30, 1882.

SIR: I have the honor the submit the following report of work performed by your direction, and under my charge, from July 5, 1881, to date, accompanied by one illustration and an index map showing surveyed areas and progress of work:

On July 5, 1881, I received orders from the Director to organize and outfit a party at Salt Lake City, Utah, with which to proceed, via Kanab, Utah, to Fort Wingate, N. Mex., where I was to report to him for the purpose of taking charge of topographic work at that place and in that vicinity. Mr. A. L. Webster was to accompany me. I was required, however, to complete all drawings in hand illustrating the monograph on Lake Bonneville, by G. K. Gilbert, geologist, in whose division I was at that time, and if it was not possible for me to leave with the party, I was to join it at some point on the way, or to proceed to Fort Wingate


INDEX MAP
showing
SURVEYED AREAS
and
PROGRESS OF TRIANGULATION
between
KANAB AND FORT WINGATE BASES.
At close of
Field Season 1881.
Areas covered by Topography by the U.S. Geological Survey.
Trignometric lines of do.
Occupied Stations of do.
Areas surveyed under the direction of J.W. Powell, F.V. Hayden and Capt. Geo. M. Wheeler, U.S.A. 1869 to 1878.
Trignometric lines of do. (approx.)
Occupied Stations of do.
U T A H
C O L O R A D O
N E W M E X I C O
A R I Z O N A
ELLEN
ABAJO
LA PLATA
BANDED
NAVAJO MT.
San Juan R.
KANAB BASE
CARISO
NEEDLES
CHUSCA
HOSTA
FORT WINGATE BASE
MACKENZIE
TAYLOR
ZUNI
Moki Towns
FLOYD
SAN FRANCISCO
Little Colorado R.
LADRONES
PINION
GREEN
ORD
112° 111° 110° 109° 108° 107° 106°
39° 38° 37° 36° 35° 34°
SCALE: 100 MILES.

by rail. At Kanab, I was to engage more men, and add to my outfit all property and animals of the Survey at that place. That point, as a base of operations, was then to be abandoned.

The report of the season's work, in pursuance of such orders, is naturally divided into three parts:

I. Organization of party and journey to Fort Wingate, N. Mex.

II. Operations of parties under my charge at that place and vicinity.

III. Results of office reductions of field work.

PART I.—ORGANIZATION OF PARTY AND JOURNEY TO FORT WINGATE, N. MEX., JULY 5, TO AUGUST 29, 1881.

Owing to the great demand for labor consequent upon the rapid extension of railroads in Colorado and Utah, I had great difficulty in engaging the necessary complement of men for the season's work. Mr. Joseph Hamblin was engaged at Kanab, and was directed to employ men, get the property together, and have the animals shod. Fortunately, Mr. J. K. Hillers was sent to me, by order of the Director, to assist and take charge of the party until I might be able to join it; he arrived July 17.

The party as it started from Salt Lake City was composed of Mr. Hillers and five men, having two wagons, one horse, and eighteen mules for transportation. The equipment consisted of a good assortment of instruments such as are required in triangulation and topographic work, as well as for general transportation and camp use, together with four hundred rations for the journey.

Mr. Hillers arrived at Kanab August 1, without experiencing any accident or drawback, having followed the route along the Sevier River. The distance traveled was 320 miles. He set immediately about collecting Survey property and making necessary preparations. Having completed my drawings, Mr. Webster and myself proceeded by the Utah Southern Railroad and by special conveyance to Kanab, arriving August 7, the fourth day from Salt Lake City.

Finding everything in readiness to move the following morning, August 8, we left Kanab, having with us all serviceable property and animals of the Survey, except such as remained, by order of Capt. C. E. Dutton, in the hands of William T. Stewart.

The party, now complete, consisted of Gilbert Thompson, topographer, in charge; A. L. Webster, assistant topographer; J. K. Hillers, photographer; G. W. Schutt, assistant; Dan Ensign, Joseph Brown, Wiliam Lewis, A. F. Denney, teamsters; William McBride, W. J. Crouch, cooks; and S. B. Bootes, helper; having for transportation four wagons and thirty-four animals, several of which had been hired.

I will not occupy space by an itinerary of the journey, but simply put on record such matters of general interest or facts of value as were observed.

August 12. An intensely hot day. We crossed the Colorado at the mouth of the Paria, and were nearly broken down when over the "Point." In the distance of one and a half miles an ascent and descent of 800 feet is encountered. It was fortunate for our animals that we were able to obtain hay of the ferryman, as they were all of necessity tied up at the previous camp.

August 14. We laid over at McClellan tanks, finding here the first good grass since starting. During the day and night heavy rains fell.

August 18. Made a nooning at the falls of the Little Colorado. The river was very high and of the consistency of liquid red mud, and the singular appearance was presented of an endless avalanche of blocks of mud enveloped in clouds of dust. The fall has been produced by a lava flow from the westward, which filled the river channel at this point and extended entirely across. The effect of this was to retard erosion above, while the channel continued to be cut away below. It consists of a rapid and two sharp falls, the height, as determined by Mr. R. U. Goode in 1879, by means of triangulation, being about 150 feet. It still resembles the illustration first furnished of it, in Capt. L. Sitgreaves' report,[1] except that the upper and lower falls were then apparently nearer together. Probably at one time there was only one fall.

The Little Colorado is a poor resource for the traveler, as at flood the water, if it can be entitled to the name, is so full of sediment as to be scarcely serviceable in any way whatsoever, and when at its lowest stage it is simply a succession of salt and alkaline pools. In 1873 even these disappeared, and the Mormon emigrants to this country were forced back and their proposed settlements abandoned. This section of country is desolate in the extreme, and surrounded, as it is, with variously-colored mesas, well deserves the name of the Painted Desert, the San Francisco Mountains, with their heavily-wooded summits, affording the only relief to the eye, wearied with the glare of the immediate surroundings.

On account of the high and turbulent flood we were unable to cross at the ford to the Prescott road, and remained on the north side, following the wagon tracks of a party which had recently passed.

It is shown by the lines of driftwood far away from the river that at times there must occur extensive inundations, resulting most probably from jams of logs in the narrow portions of the river's course. At such times this part of the valley must have the appearance of a series of extensive lakes.

We arrived at the Mormon settlement at Sunset Crossing on the evening of August 20. This day I observed a water-spout from its formation to its disappearance. Its form and appearance can be best understood from the accompanying illustration. Nearly as interesting to me

[1] Report of an expedition down the Zuni and Colorado Rivers, by Capt. L. Sitgreaves, Corps Topographical Engineers, U. S. A., 1853.

was the beginning of a second one, which, however, never reached the earth.

When we moved out, August 22, we encountered the results of the water-spout at the Cottonwood Wash. We effected a crossing by making an approach; then, putting the team animals across on the solid ground,

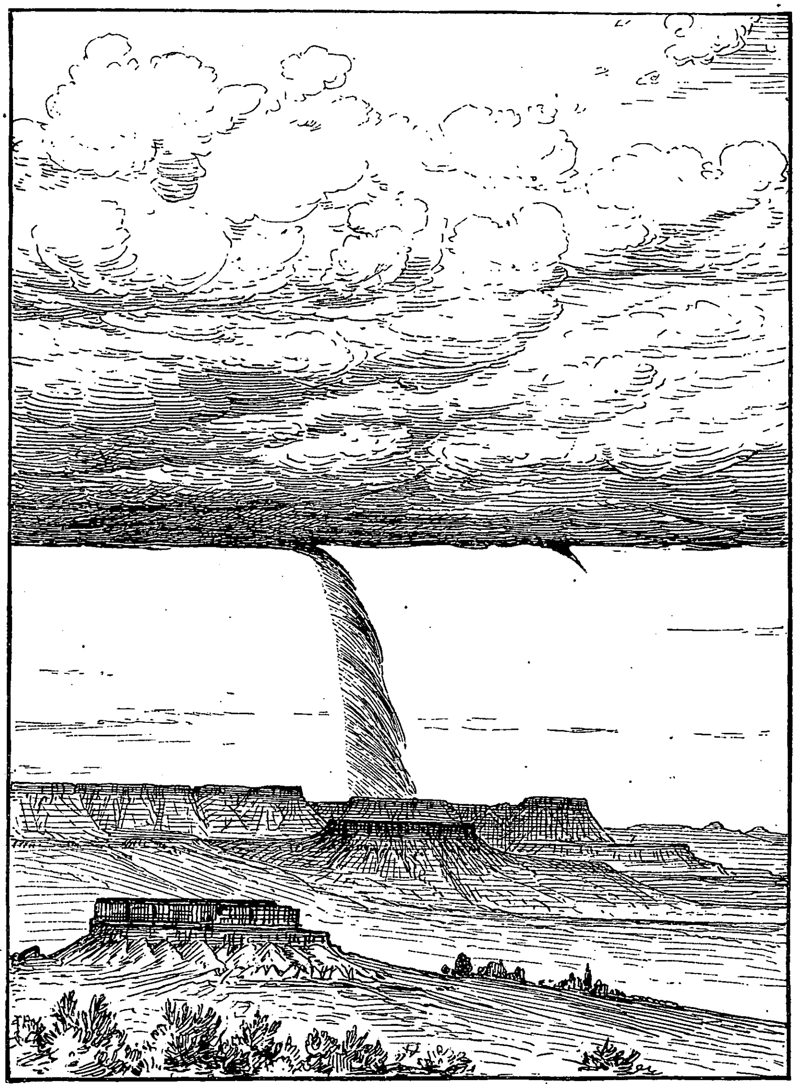


FIG. 2.—Waterspout.

we took a strong rope of a length greater than the width of the wash, and drew each wagon, half floating, through the quicksands and swift current. Three hours' work put our whole train across, including that of Lieutenant Burke's party, and without being obliged to unload the wagons.

From this point our travel was without special interest. We left the Little Colorado at the Puerco, which we followed. Our first glimpse of civilization was a locomotive, hot and helpless, between two wash-outs. We were very fortunate, for although there had been an extraordinary amount of rainfall we made each day our stated march, the storms only serving to furnish us with pools of pure water to camp by and with luxuriant grass for the animals.

On August 28, about 3 p. m., we arrived at Fort Wingate, after a journey of 710 miles, without accident or any loss of property, the animals being in much better condition than at starting. The animals from Salt Lake City had traveled 890 miles. The total time was forty days, or thirty-seven of actual travel. I wish here to render my thanks to Mr. Hillers and all the other members of the party for their universal good-will and cheerfulness throughout this long journey.

We met with a hearty greeting from Professor Gore and his party. I immediately paid my compliments to the commanding officer, General Luther P. Bradley, who offered me every assistance in his power for the prosecution of the work. The main camp was established northward from the fort, under some oaks, where it remained until the close of the season. Mr. J. K. Hillers and Mr. G. W. Shutt from this time on were engaged in their special duties with their own or other parties.

PART II.—OPERATIONS OF PARTIES AT FORT WINGATE AND VICINITY, AUGUST 30 TO DECEMBER 24, 1881.

In the absence of the Director, on account of severe illness, it was agreed that I should take general charge until his arrival or future orders. After resting one day, topographic work was begun the 30th of August.

Professor Gore had been so delayed by the unusual rains in the measurement of the base, even his preliminary work having been swept away, that I arranged that a full party should be immediately organized for that portion of the work. Further particulars in regard to it I properly leave to his report.

September 1 I received a telegraphic order from the Director to "take general charge of topographic work until his arrival," &c.

In 1873, as a topographer in a party of the Surveys West of the 100th Meridian, Lieut. R. L. Hoxie, Corps of Engineers U. S. A., in charge, I surveyed a line from Salt Lake City, through the Moki towns, to this place, from here to Camp Apache, and thence by the Rio Grande to Santa Fé. In 1874 I also worked up a section of country westward from

Santa Fé as far as Mount Taylor, which peak I occupied for the purposes of triangulation. Therefore I was somewhat familiar with this section of country, and during the monotony of some of the days of our recent journey I had laid out in my mind a scheme for the season's work for presentation to the Director upon my arrival. His absence left no fair alternative to me except to begin, subject to any change he might in future direct. In brief, my plan was to form a figure of triangulation, of which Mount Taylor, Chusca Knoll, Zuñi Butte, and a central one at any favorable point on the Zuñi Mountains, were the outer ones, connected in a proper manner with the base; at the same time obtaining as much detailed topography as possible.

To those accustomed to carrying on a triangulation upon "natural points," the area between longitude 108° and 110° and latitude 35° and 36° presents insuperable obstacles, there being but one sharp, prominent point, Chusca Knoll. This and Mount Taylor give one line of some 80 miles in length, and further progress can be achieved only by the aid of artificial stations.

The ultimate object I had in view to be accomplished by this scheme was the connection of the Kanab base with that of Fort Wingate, as well as the formation of the necessary basis for the topographic details. With a little amplification this scheme would close up the vacant area between the triangulation of Surveys West of the 100th Meridian in the southern portion of Arizona and along the Rio Grande, the Colorado survey of Dr. Hayden on the north, and that developed from the Kanab base in Utah to the westward. This may be much easier understood by reference to the index map accompanying this report, in which the relation of the Fort Wingate base and its development to that of other government surveys are clearly shown. A large portion of this area has never been mapped. The mighty Navajo Mountain, at the junction of the Colorado and San Juan Rivers, as far as is known, has never been approached or ascended by a white man, and whenever an archæologic map of the United States is published, this section, with its ruins and inhabited Indian towns, ancient and deep-worn trails, will be one of its most interesting features.

While the base was being measured I employed myself in the selection of points and building of signals for triangulation and plane-table work. I made topographic sketches at each of these, reading the desired angles with a gradienter. I was almost single-handed at first, but finally employed a number of good men for this work.

At the request of Mr. James Stevenson, of the Bureau of Ethnology, I sent Mr. A. L. Webster with him to map the Moki towns. For this work he was furnished with a plane-table and other necessary instruments. He was directed to make the field work, if possible, on such a scale and with such degree of accuracy that a re-survey would not be required, should that section be ever embodied in an atlas sheet. He left on September 13 and returned October 3, having successfully accomplished all that was desired, some 350 square miles having been mapped on a scale of 1½ miles to the inch. It is worthy of note that to save time on his return, in order to assist me, he rode ahead of the party and traveled alone some 115 miles.

On September 28 the base measurement was completed, with the exception of a few details. I then organized parties for building triangulation stations and running necessary lines of levels.

After having made topographic sketches at each of the base stations I carefully plotted and prepared a plane-table sheet in the vicinity of the base on a scale of 1 inch to 1 mile. Although the scale for publication is 4 miles to 1 inch, in consideration of the fact that it would include the military reservation as well as the complex details of the mesas to the northward, I considered this none too large.

It is a cardinal principle in the collection of topographic details to adjust the scale of field work according to their intricacy, for if they are not correctly obtained primarily they can never be correctly published, no matter how small the scale of publication may be. There are areas in the West where the field work may be done on the same scale as that of its publication.

October 10 I detailed to Mr. Webster a permanent party, and he began plane-table work, which he continued until the close of the season.

Regular hourly observations were then commenced at the barometric base station, Mr. E. V. McElhone being the observer; and his faithfulness and conscientious care in such character of work is beyond ordinary commendation. Each field party was furnished with a cistern barometer.

Mr. R. U. Goode completed the required lines of levels by October 10, and was given a party to finish the construction of the remaining triangulation stations, the first to be built by him being MacKenzie station, on the Zuñi Mountains, if they can be dignified as such. This station is the central one of my proposed figure, and, to be visible, was built nearly forty feet in height. To construct this and clear away the heavy pine timber obstructing the lines of sight occupied this party about ten days.

On October 11 I left on a triangulation trip to the westward, including Zuñi Butte. Mr. Hillers and myself combined our parties. On the route he secured some valuable negatives, one being of the shrine of the war gods of the Zuñi Indians, situated upon the top of Zuñi Butte.

I understand they have a similar shrine at each quarter of the compass for the protection of their town, this being the one at the north. Without infringing, I trust, on the prerogatives of the assistants of the Bureau of Ethnology, I will draw attention to a few facts in this connection. This shrine faces to the east, and is semicircular in form. When a new war chief is chosen, his insignia or representative is placed here with appropriate ceremonies, and his predecessor's is taken up and left leaning against the wall, while its predecessor is laid back upon a pile of ancestors, being then literally a dead god. Of these I counted eighty-five, and they were all of the same pattern, although in different stages of decay; and grotesque and simple as was the faith here revealed, yet the reflection forced itself upon the mind that some of these were placed there with prayer and ceremony long before the white man had found a new world.

After stopping over one day at the pueblo of Zuñi, we returned to Fort Wingate. I then prepared a plane-table sheet for Mr. Goode, of the section westward of Mr. Webster's. I detailed to him a permanent party for such work, which he began November 4, after having completed the construction of Powell station, and which was continued by him until the close of the season.

November 6 and 7 I occupied Mount Taylor, camping at the very top, and experienced very inclement weather. This is a noble mountain, commanding an immense area of country, and with the aid of this point a great triangle can be measured with sides approximately as follows:

	Miles.
Taylor–Truchas	115
Taylor–Sierra Blanca	165
Truchas–Sierra Blanca	160

Mount Taylor is held in veneration by the Pueblo Indians, and is called by them the "*mother of the rain.*" In the spring its summit is the scene of their sacred dances, invoking the blessing of plentiful harvests, and their votive offerings are to be found thickly strewn around.

By December 11 I had finished the occupation of the remaining triangulation stations, fifteen in all having been occupied by me for this purpose. The longest line developed from the base was about 80 miles in length, and some 1,500 square miles were covered inside of lines connecting occupied stations.

The weather becoming disagreeable and wintry, the plane-table parties were called into the main camp, Mr. Webster having covered in all 630 square miles and Mr. Goode 145.

Throughout the field season we were delayed very much by unusual rains and early snowfall, yet the snow went away very rapidly, and we were continually tempted by the succeeding beautiful days to continue work, the most serious impediment being the freezing up of the water pools.

By the kindness of Dr. Washington Matthews, surgeon at Fort Wingate, I am able to present in a tabular form the amount of rainfall as observed at this point for ten years:

Rainfall (in inches) at Fort Wingate, N. Mex.

Year.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Total for year.
1870–'71	3.88	3.23	0.73	1.50	0.15	2.21	2.65	5.05	0.58	1.80	0.31	0.00	22.09
1871–'72	2.37	1.20	2.80	1.20	1.33	2.29	3.30	1.59	0.63	1.99	3.00	2.25	23.95
1872–'73	1.10	3.15	0.50	2.75	0.00	0.50	0.75	11.25	0.00	0.15	0.20	3.15	23.50
1873–'74	0.26	2.65	3.60	0.50	0.55	2.00	1.85	0.44	0.55	0.07	0.30	0.03	12.80
1874–'75	1.94	1.25	0.00	0.48	0.22	0.47	0.35	1.07	0.91	0.15	0.50	0.33	7.67
1875–'76	1.23	1.01	3.19	0.10	1.55	0.37	0.75	0.48	1.55	0.22	0.24	0.17	10.86
1876–'77	2.32	2.34	1.54	0.80	0.61	0.21	0.91	0.29	0.51	2.70	1.47	0.66	14.36
1877–'78	1.06	0.36	0.87	0.53	0.24	1.76	1.68	1.32	1.88	2.50	0.52	1.18	13.90
1878–'79	3.78	5.90	0.90	0.00	2.12	5.90	0.53	1.36	0.70	0.23	0.00	0.00	21.42
1879–'80	0.37	0.29	0.80	0.68	0.51	0.90	0.72	0.21	0.96	0.72	0.04	0.19	6.39
1880–'81	3.55	1.49	0.31	1.81	0.20	0.86	0.16	0.05	0.99	0.42	0.18	0.00	10.02
1881–'82	3.48	3.18	2.55	......	......	......	......	......	......	......	......	......	......

The parties were disbanded, the property boxed and stored at the quartermaster storehouse at the fort, and Mr. Webster and myself left for Washington, D. C., on December 24. Mr. Webster stopped over at Santa Fé for the purpose of making comparison of barometers at the office of the United States Signal Service.

Before closing this portion of my report, I desire to render my special acknowledgments to General Luther P. Bradley, the commanding officer at Fort Wingate, for his kindness and courtesy, and also to Lieut. John S. Bishop, quartermaster. To Mr. Hopkins, post-trader, I am indebted for many favors in the obtaining of supplies and the transaction of business. Messrs. Webster, Goode, and McElhone deserve my thanks for their zeal and interest in the work, and I desire especially to recommend Mr. Webster to your notice as possessing qualities deserving of advancement.

PART III.—RESULTS OF OFFICE REDUCTIONS OF FIELD WORK.

After arrival at Washington, I was made, January 10, acting chief topographer, and, beside my duties as such, have reduced the triangulation as far as possible by means of least squares, and brought the material into shape for publication as far as practicable—Mr. Webster and Mr. Goode reducing their plane-table sheets to representation with one-hundred-foot contours. Mr. E. V. McElhone has computed the barometric observations, besides cataloguing note-books and manuscript maps.

Information has been collected for reference and field use during the next field season; in all some thirty maps have been furnished, two of which were original compilations, and one a large index-map showing progress of work to date for office use. Much time was saved in copying maps by the use of photography and the blue-print process, Mr. Hillers showing himself quite skillful in this branch of the art. Mr. S. H. Bodfish assisted in the compilation, in addition to special work upon which he was engaged. Mr. J. H. Renshawe has been mainly employed in preparing atlas sheets for publication, the material for which had been already obtained.

I close my report by the following statistics of field and office work:

Square miles covered by triangulation	1,500
Square miles covered by topography	775
Triangulation stations occupied	15
Number of observations	3,500
Barometric observations	1,380
Points determined by barometric observations	320

Theodolite used, No. 172, Kübel, maker.

I am, very respectfully, your obedient servant,

GILBERT THOMPSON,

Topographer, United States Geological Survey.

Hon. J. W. POWELL,

Director U. S. Geological Survey, Washington, D. C.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

PAPERS ACCOMPANYING THE ANNUAL REPORT

OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1882.

BIRDS WITH TEETH.

BY

PROFESSOR O. C. MARSH.

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BIRDS WITH TEETH.

By Professor O. C. Marsh.

INTRODUCTION.

The absence of teeth has long been regarded as one of the distinctive characters of Birds; since teeth are present in some members of all the other classes of vertebrate animals.

All existing Birds have the jaws covered with a horny sheath, which is usually smooth. In some groups, this beak covering is more or less serrated, and in a very few forms the elevations correspond to slight projections of the bone beneath, but no true teeth have yet been found. Anatomists have indeed detected in the young of some recent birds certain germs which resemble those of embryonic teeth, but in most cases these were apparently portions of the undeveloped horny beak. That such germs may exist, however, in some embryonic birds, is rendered probable by recent discoveries in this country, where the remains of birds with well-developed teeth have been found, differing widely from all recent Birds. These fortunate discoveries have led the writer to investigate all the known forms of the oldest Birds, and it is the object of the present article to give a *résumé* of the results thus obtained.

The remains of Birds are among the rarest of fossils, and very few have been discovered, except in the more recent formations. According to present evidence, the oldest known Birds were embedded in deposits of Jurassic age, which in Europe have yielded three individuals belonging to the genus *Archæopteryx*, so well preserved that the more important characters can be determined. The only other remains of Birds found in the Mesozoic strata of the Old World are a few specimens from the Cretaceous, which are too fragmentary to throw much light on the extinct forms they represent.

The earliest traces of Birds hitherto discovered in this country are from the Jurassic beds of Wyoming, where the single genus *Laopteryx* has recently been found, represented only by fragmentary specimens. There is at present no evidence whatever that any of the three-toed impressions in the Triassic, described as the foot-prints of Birds, were made by Birds; and the proof now seems conclusive that nearly all of them are the tracks of Dinosaurian reptiles, remains of which have been found in the same strata.

In the Cretaceous beds of the Atlantic coast, and especially in the green-sand regions of New Jersey, various remains of Birds have been found, and described by the writer. These fossils, though often in excellent preservation, occur mainly as isolated bones, and hence their near affinities have not yet been determined with certainty. It is probable that these birds possessed teeth, but the fact has not yet been fully established.

Along the eastern slope of the Rocky Mountains, and especially on the adjoining plains in Kansas and Colorado, there is a series of Cretaceous strata remarkably rich in vertebrate fossils. The deposits are all marine, and, away from the mountains, they lie nearly horizontal. They have suffered much from erosion, and are still wasting away, especially along the river valleys. These beds consist mainly of a fine, yellow chalk and calcareous shale, both admirably adapted to preserve delicate specimens; and here have been found the toothed Birds on which the present article is mainly based.

The geological horizon of these *Odontornithes* is in the Middle Cretaceous, and corresponds to the strata named by the writer the "Pteranodon beds." The latter are included in subdivision number three, of Meek and Hayden's section. The accompanying fossils are Mosasauroid reptiles, which are very abundant; Plesiosaurs, allied to Pliosaurus; Pterodactyles, of the genus *Pteranodon;* and many Fishes. With these occur Rudistes, and occasionally Ammonites, Belemnites, and various other Cretaceous invertebrates.

The first Bird remains discovered in this region were found by the writer in 1870, near the Smoky Hill River, in Western Kansas. Explorations in the same region were continued by the writer for several years subsequently, resulting in the discovery of remains of more than one hundred different individuals of Birds with Teeth; and these are all now deposited in the museum of Yale College.

A study of this extensive series of Bird remains brings to light the existence in this class of two widely separated types, which lived together during the Cretaceous period, in the same region, and yet differed more from each other than do any two recent Birds. Both of these types possessed teeth, a character hitherto unknown in the class of Birds; and hence they have been placed by the writer in a separate subclass, the *Odontornithes.** One of these groups includes very large swimming Birds, without wings, and with the teeth in grooves (*Odontolcæ*), and is represented by the genus *Hesperornis.* The other contains small Birds endowed with great power of flight, and having teeth set in sockets (*Odontotormæ*), and biconcave vertebræ; a type best illustrated by the genus *Ichthyornis.* Other characters, scarcely less important, appear in

* See *Odontornithes:* A Monograph on the Extinct Toothed Birds of North America; with thirty-four plates and forty woodcuts. By OTHNIEL CHARLES MARSH, Professor of Palæontology in Yale College. 4to, pp. i–xv, 201. Exploration of the 40th Parallel, Vol. VII. Washington, D. C., 1880.

each group; and we have thus a vivid picture of two primitive forms of Bird structure, as unexpected as they are suggestive. A comparison of these two forms with each other, and with some recent Birds, promises to clear away many difficulties in the genealogy of the class, now a closed type.

The fossil Birds now known from the Cretaceous deposits of this country have been described by the writer under nine genera and twenty species, represented at present by the remains of about one hundred and fifty different individuals. This is evidence of a rich and varied avian fauna in America during Mesozoic time, and likewise indicates what we may expect from future discoveries.

In the later formations, remains of Birds are more abundant; but all belong apparently to modern types, and hence present fewer points of interest than the older forms which are discussed in the present article.

It is now generally admitted by those who have made a study of the vertebrates, that Birds are closely related to Reptiles, and there can be little doubt that they originally descended from the latter class. The close affinity of Dinosaurian Reptiles with some recent Birds, especially the Ostriches, is remarkable, and the evidence of their still nearer connection with their contemporaries, the Mesozoic Birds, amounts almost to a demonstration.

The classes of Birds and Reptiles as now living are indeed separated so widely, that a few years since this was thought to be the most important break in the animal series, and one that could not be closed. Since then, the gap has been virtually filled by the discovery of bird-like Reptiles and reptilian Birds, and the two classes are now generally regarded as members of one large group, which has been named by Huxley the *Sauropsida.*

The oldest Bird known from Europe, *Archæopteryx*, was found in the lithographic slates of Bavaria, which are of upper Jurassic age. *Laopteryx*, the oldest known American Bird, and recently described by the writer,* is from nearly the same geological horizon in the Rocky Mountains. It has recently been ascertained beyond question that *Archæopteryx* possessed teeth, and there is strong evidence that *Laopteryx* was also thus provided. The first specimen of *Archæopteryx* discovered was a single feather, and to this the generic name was given by Von Meyer, in 1862. Later, a nearly perfect skeleton was found near the same locality; and this was described by Professor Owen, in 1863,† and is now in the British Museum. Quite recently, another skeleton has been brought to light in the same beds, and is now in the Royal Museum at Berlin. These three specimens of *Archæopteryx* are the only remains of the genus known. They indicate a Bird rather smaller than a Crow.

When first discovered, *Archæopteryx*, notwithstanding its feathers, was thought by some anatomists to be a Reptile, mainly because it differed

* See American Journal of Science, vol. XXI, p. 341, April, 1881.

† Philosophical Transactions, p. 33. London, 1863.

from all known Birds in having a very long reptilian tail, and the bones of the hand separate from each other. This view is held by some authors at the present time, but the best authorities are now agreed that *Archæopteryx* is a Bird.

DESCRIPTION OF HESPERORNIS.

It is fortunate for science that *Hesperornis*, the type of the order *Odontolcæ*, should now be represented by remains as complete as any fossil skeleton yet discovered, even in the later formations. Nearly all the bones of the specimens obtained were almost as perfect as in life, when first found in the matrix, although the more delicate parts were sometimes unavoidably broken in removal, and occasionally small fragments were lost. Many of the bones were near their natural position when discovered, and in such cases a special effort was made to preserve this position, or retain a record of it by drawings.

In its more important characters, the skull of *Hesperornis* (figure 7) resembles that of the *Ratitæ*, or Ostrich tribe of Birds, and we shall find other striking evidences of affinity with this group in various portions of the skeleton. The base of the skull shows nearly all the cranial characters which Huxley, in his valuable memoir on the Classification of Birds, lays down to distinguish the *Ratitæ*. The foramina in the base of the skull have the same general position as in recent Struthious Birds.

The palatines resemble those of the Ostrich. They are long, slender bones, extending from their union with the pterygoids, parallel with the axis of the skull, and joining the premaxillaries. The vomers in *Hesperornis* are separate, as in lizards and a few existing Birds.

The bones of the brain case are ankylosed, but in other parts of the skull the sutures are distinct, and many of them open, as in the Ostrich and other *Ratitæ*. The orbits are large, and placed near together. There are well marked glandular depressions extending along the roof of the orbits, as in *Colymbus* and some other recent aquatic Birds.

The premaxillaries are elongate, and separate throughout their posterior two-thirds. Their extremities touched the frontals. Their sides are deeply excavated for the anterior nares, and in front they are ankylosed, and form a long pointed beak, the end of which is somewhat decurved. This extremity, back to the nasal openings, has its surface pitted with irregular vascular foramina, indicating, apparently, that it was once covered with a horny bill, as in modern Birds.

THE TEETH.

The various cranial characters above described may nearly all be found in recent Birds, if we search through different groups; but in *Hesperornis* the stout maxillary bones were armed with well developed teeth, a feature unknown in this class before the discovery of the remains described in the present article. These teeth were set in a deep,

Fig. 3.

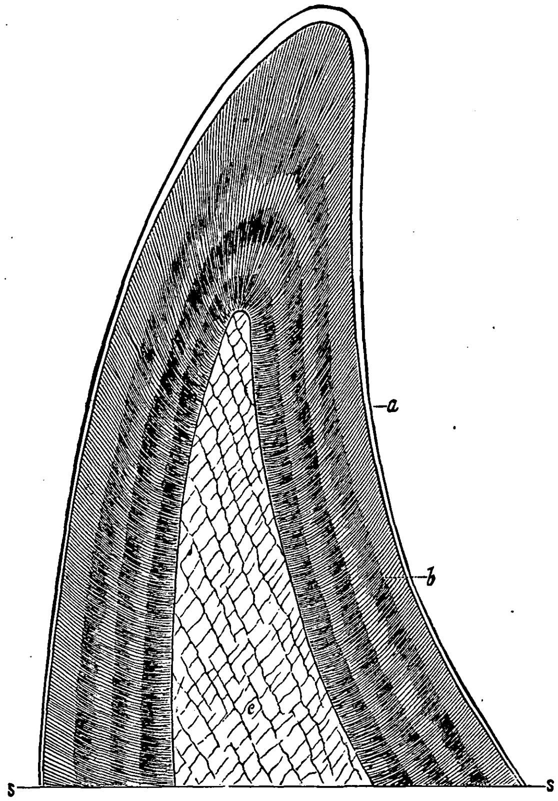

Fig. 4.

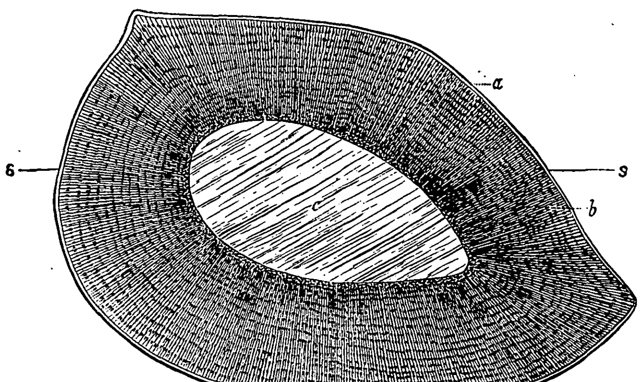

Fig. 5.

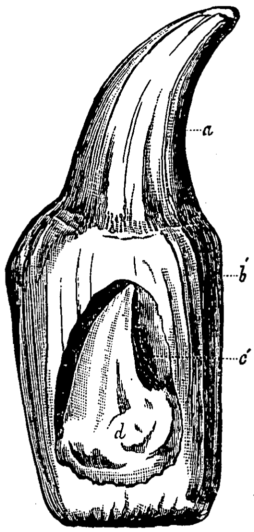

Fig. 6.

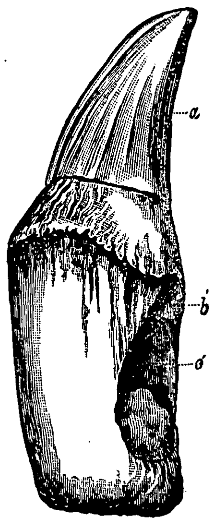

Fig. 3.—Vertical section of tooth of *Hesperornis regalis*, Marsh.
Fig. 4.—Horizontal section of same tooth; both enlarged thirty-two diameters.
Fig. 5.—Tooth of *Hesperornis regalis*; enlarged eight diameters.
Fig. 6.—Tooth of *Mosasaurus princeps*, Marsh; half natural size.
a, enamel of crown; *b*, dentine; *c*, pulp cavity in crown; *b′*, root of tooth; *c′*, absorbed cavity in root; *d*, young tooth; *ss*, intersection of horizontal and vertical sections.

continuous alveolar groove, with only faint indications of separate sockets (figure 10). They resemble most nearly, in form and structure, the teeth of reptiles. There were no palatal teeth, and none in the premaxillaries.

The teeth of *Hesperornis* are true teeth, with their distinctive characters as well marked as in those of any reptile. In the upper jaw, they are confined to the maxillary bone alone, the premaxillary being entirely edentulous. In the lower jaw, the teeth extend from very near the anterior extremity of the ramus along the entire upper border of the dentary bone.

The teeth above and below were implanted in a continuous groove, somewhat like those of *Ichthyosaurus*. From the sides of the groove, slight projections extend between the teeth, thus forming faint indications of sockets; but these projections are not sufficient to materially lessen the width or depth of the groove.

The teeth were evidently held in position by cartilage, which permitted some fore and aft movement; but lateral motion was much restricted by the depth and narrowness of the groove, and the large size of the fangs. With the decay of this cartilage after death, the teeth readily lost their erect position, and became more or less displaced.

The teeth of *Hesperornis* were gradually replaced by successional teeth, and this took place in a manner very similar to that in some Reptiles. The germ of the young tooth was formed on the inner side of the fang of the tooth in use (figure 5), and, as it increased in size, a pit for its reception was here gradually made by absorption. The old tooth at last became undermined, and was expelled by the new one, which occupied the same position, the number of teeth thus remaining the same.

The teeth of *Hesperornis* have conical pointed crowns, covered with smooth enamel, and supported on stout fangs. In form of crown and base, they closely resemble the teeth of Mosasauroid Reptiles, one of which is represented for comparison in figure 6. The outer and inner surfaces of the crown are separated by sharp ridges, which are without serrations. The outer side is nearly plane, and the inner surface strongly convex.

The crowns of the teeth are mainly composed of firm dentine, invested with a layer of enamel. The relative proportions of these are shown in figures 3 and 4. The layer of enamel gradually increases in thickness from the base of the tooth to the apex, as shown in figure 3. It is also somewhat thicker over the anterior cutting edge than in the other portions of the base of the crown, as indicated in figure 4. The line of junction between the enamel and the dentine is everywhere sharply defined. The enamel is dense and hard, the calcification having proceeded so far, in the specimens examined, that the constituent fibers could not be distinguished. The external surface of the enamel is nearly smooth, but marked by delicate striæ. There is no indication of cement on the coronal surfaces.

The dentine which forms the mass of the crown shows a well marked structure in both the vertical and horizontal sections, figures 3 and 4. It is firm and compact, and the calcigerous tubes are well defined. Near the base of the crown, they radiate horizontally, and in transverse section appear nearly straight, as shown in figure 4. Higher up in the crown, these tubes curve upward, diverging from the axis of the tooth less and less, until beneath the apex they become nearly parallel. In the dentine there are distinct concentric lines of growth. These are seen near together and numerous in transverse section (figure 4), while those which appear in the vertical section, figure 3, are fewer in number, and more strongly marked.

The pulp cavity was large, and in the specimen above represented was filled with calcite. The coronal walls of this cavity are smooth, and well defined. The fang consists of osteo-dentine.

The teeth of *Hesperornis*, taken by themselves, appear to resemble more nearly the detached teeth of Mosasauroid Reptiles (figure 6), than any others known, not excepting the teeth of *Ichthyornis*. The teeth in the latter have compressed crowns, and are implanted in distinct sockets. In all their main features, the teeth of *Hesperornis* are essentially reptilian, and no anatomist would hesitate to refer them to that class, had they been found alone. Combined with the other reptilian characters of *Hesperornis*, noted elsewhere in the present article, they clearly indicate a genetic connection with that group.

THE BRAIN.

The brain of *Hesperornis* was quite small, and more reptilian in type than in any adult Bird hitherto examined. In figure 7, the skull is represented with the outline of the brain cavity in position. The skull of the Loon is represented in figure 8, also with a cast of the brain in its natural position, and life-size. A comparison of the two places the relative magnitude and proportion of the brain in each in strong contrast. In *Hesperornis*, the olfactory lobes (figure 7, *ol*) were large and elongate, and their nerves passed out of the cranium by separate orifices, one on each side of the interorbital septum. The cerebral hemispheres (figure 7, *c*) were of very moderate size, much smaller, proportionally, than in any existing birds, and strongly representing the corresponding parts in some reptiles. The two lobes were narrow and subovate in outline, and were separated above by an osseous median crest depending from the roof of the brain case. The optic lobes (figure 7, *op*) were large and very prominent, and only slightly covered above by the cerebral hemispheres. Their similarity in size and position to the optic lobes of reptiles is especially noteworthy. The optic nerves were large. The cerebellum (figure 5, *cb*) was quite large, and reptilian in its general features. The flocculi were well developed, and lodged in distinct cavities.

In contrasting the brain cavity of *Hesperornis* with that of *Colymbus*, as shown together in figures 7 and 8, a striking difference is seen in the size,

FIG. 7.

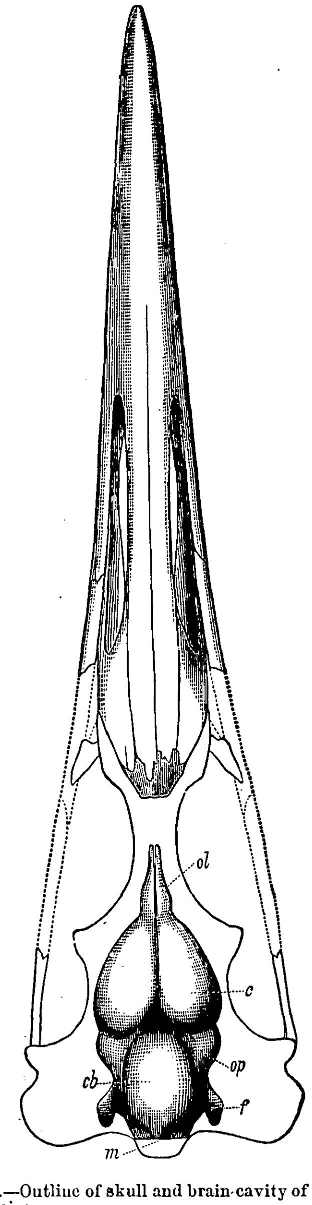

FIG. 8.

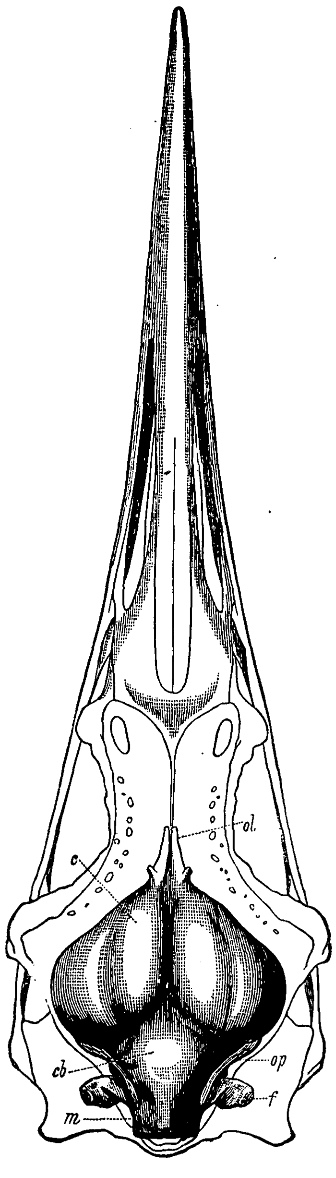

FIG. 7.—Outline of skull and brain-cavity of *Hesperornis regalis*, Marsh; seen from above; three-fifths natural size.
FIG. 8.—Outline of skull and brain-cavity of Loon (*Colymbus torquatus*, Brünnich); same view; natural size.
ol, olfactory lobes; *c*, cerebral hemispheres; *op*, optic lobes; *cb*, cerebellum; *f*, flocculi; *m*, medulla.

the latter being about three times the bulk of the former. The two skulls are represented of the same absolute length, for the purpose of direct comparison. If, moreover, the relative size of the entire skeleton in each case be likewise considered, the brain of *Hesperornis* would have even less than one-third the relative capacity of that of the Loon. As the two birds were evidently similar in shape and habits, the comparison seems to be a fair one. Another marked difference in the brain of the two genera is seen in the relative size of the cerebral hemispheres, as represented in figures 7 and 8. The cerebral lobes of *Colymbus* are very large, and much expanded transversely; and it is in this portion of the brain that the real difference of size is most apparent.

These facts are important, since they tend directly to show that the essential principles of the law of brain growth, established by the writer in extinct mammals, apply also to birds. This law, briefly stated, is as follows:

1. All Tertiary mammals had small brains.
2. There was a gradual increase in size of the brain during this period.
3. This increase was confined mainly to the cerebral hemispheres, or higher portion of the brain.
4. In some groups, the convolutions of the brain have gradually become more complicated.
5. In some, the cerebellum and the olfactory lobes have even diminished in size.
6. There is now evidence that the same general law of brain growth holds good for Birds and Reptiles, from the Jurassic to the present time.

THE VERTEBRÆ.

The pre-sacral vertebræ of *Hesperornis* (figures 10 and 11) resemble, in their more important characters, the corresponding vertebræ of existing Birds. The articular faces of the centra conform strictly to the modern ornithic type, an interesting fact, as we shall see when we compare them with another group (*Odontotormæ*), from the same geological horizon.

The neck of *Hesperornis* was long and slender. Including the atlas and axis, there were seventeen cervical vertebræ; and twenty-three in all between the skull and sacrum. There were fourteen vertebræ in the co-ossified sacral series, and twelve more in the tail (figure 17), making the entire column consist of forty-nine. This is a very large number for this class, and is equaled in but very few recent Birds. None of the vertebræ contained pneumatic openings, although some were lightened by medullary cavities.

THE SCAPULAR ARCH.

The scapular arch of *Hesperornis* (figure 13) presents several very interesting features, and shows a wide divergence from the normal type in existing aquatic Birds. Viewed as a whole, it has but little functional importance, and indicates a degradation of structure before unknown in this group of Birds. It throws much light, however, on the past and present forms of flightless Birds, both the denizens of land and water. Its contrast with the powerful pelvic arch is especially noteworthy.

In its more important characters, the shoulder girdle of this genus shows an approach to that of the *Ratitæ*, or Birds allied to the Ostrich. Some of these characters hint at reptilian affinities, while others are merely adaptive, and connected directly with the lack of wings. The most marked points of resemblance to Struthious Birds, in this part of the skeleton, are the following:

1. The sternum is devoid of a keel.

Fig. 9.

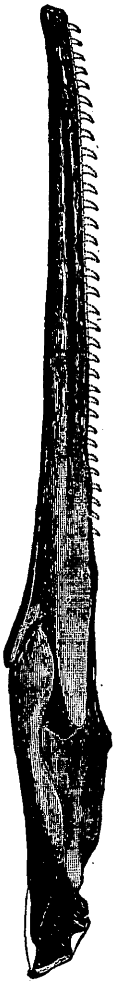

Fig. 11.

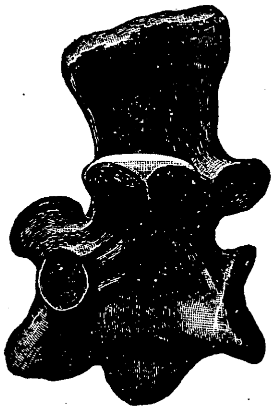

Fig. 10.

Fig. 12.

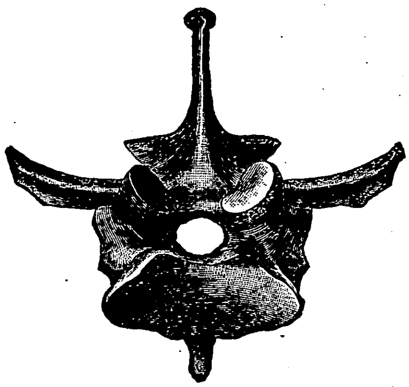

Fig. 9.—Left lower jaw of *Hesperornis regalis*, Marsh; side view, one-half natural size.
Fig. 10.—The same; top view.
Fig. 11.—Twentieth vertebra, dorsal; side view, one-half natural size.
Fig. 12.—The same; front view.

2. The long axis of the adjacent parts of the scapula and coracoid are parallel or identical.

These features are especially characteristic of the *Ratitæ.*

The wings of *Hesperornis* were represented by the humerus alone, and

FIG. 13.

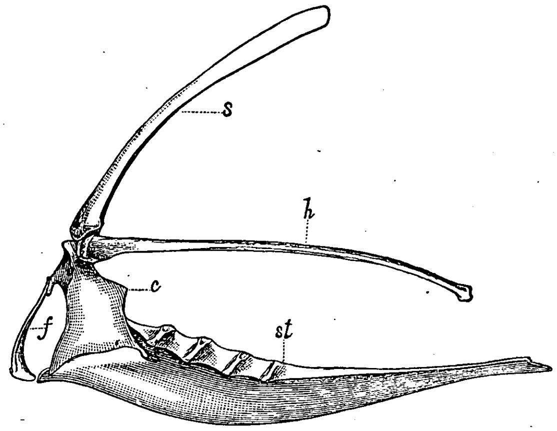

FIG. 13.—Scapular arch of *Hesperornis regalis*, Marsh;—side view; one-half natural size. *s*, scapula; *h*, humerus; *f*, clavicle, or furculum; *c*, coracoid; *st*, sternum.

this was rudimentary. The remaining bones of the anterior extremity had entirely disappeared, or, if minute remnants of them remained as ossicles, they were loosely attached to the extremity of the humerus by cartilage, and thus have left no trace of their union.

The humerus of *Hesperornis* is long and very slender, and somewhat curved downward, especially in the distal half. The head is compressed, and has a convex ovate articulation for insertion into the shallow glenoid cavity. The shaft is somewhat twisted, and of nearly equal width throughout its entire length. When the humerus is in position, the longer transverse axis of the middle of the shaft is horizontal, or at right angles to the same axis of the head. The shaft is nearly solid, having only a very small medullary cavity. There is no distinct radial or ulnar crest, and no trace of articular facets on the distal extremity.

The ribs of *Hesperornis* present no marked features to distinguish them from those of modern Birds. They are composed of dense bone, but some of them contain irregular cavities. The articulated vertebral ribs of *Hesperornis* are nine in number on each side. The first three of these were attached to the last three cervical vertebræ, and had their distal ends free. The remaining six are all well-developed ribs, which were connected by means of the sternal ribs with the sternum.

In *Hesperornis*, there are four sternal ribs, which articulated directly with each costal border of the sternum, and on this are four well-developed processes for the union. Behind these true sternal ribs were two others, which, as in many recent Birds, united together at their lower attenuated extremities, and were thus attached to the preceding sternal rib by cartilage.

THE PELVIC ARCH.

The pelvic arch of *Hesperornis* (figure 14) exhibits many features of interest; and characters more distinctly reptilian than that of any recent Bird. In its general form, the pelvis of *Hesperornis* resembles that of *Podiceps*. It is very long and narrow, as in that genus, and in other diving Birds.

The acetabulum differs from that in all known Birds, in being closed internally by bone, except a foramen that perforates the inner wall, as in the Crocodiles. The ilium, ischium, and pubis, moreover, have their posterior extremities free and distinct. This reptilian character is seen, likewise, in the Emeu, as well as in *Tinamus*, which in other respects also shows affinities with the Ostriches.

FIG. 14.

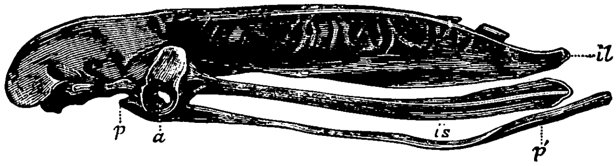

FIG. 15

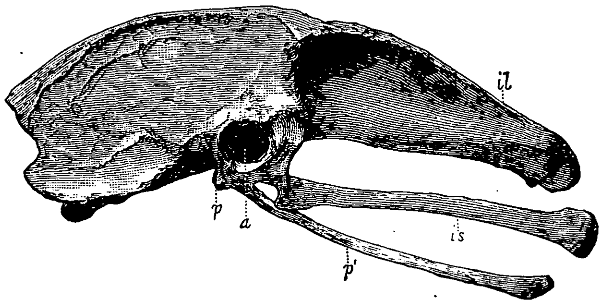

Fig. 16.

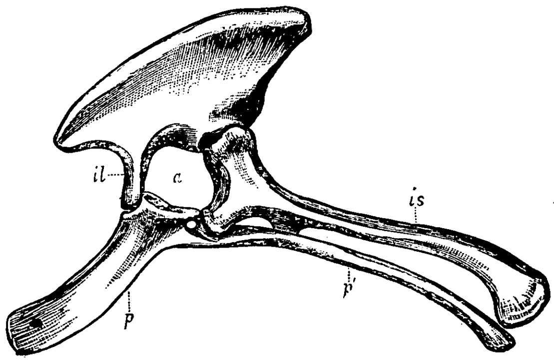

FIG. 14.—Pelvis of *Hesperornis regalis* Marsh; seen from the left, one-fifth natural size.
FIG. 15.—Pelvis of Emeu (*Dromæus Novæ Hollandiæ*, Latham); side view, one-fifth natural size.
FIG. 16.—Pelvic arch of *Camptonotus dispar*, Marsh; side view, one-twelfth natural size.
a. acetabulum; *il*, ilium; *is*, ischium; *p*, pubis; *p'*, post-pubis.

The ilium is extremely long and narrow (figure 14). Its superior outline is gently arcuate, and this border joins the dorsal margin of the other ilium on the median line, thus forming a roof-shaped covering over nearly all the sacrum. The pre-acetabular portion of the ilium is only about one-fourth its entire extent. From the acetabulum forward, the ilia diverge, showing at first, between their upper margins, the neural spines of the vertebræ below, and then, in front, the zygapophyses of the first of the sacral series. The post-acetabular part of the ilium is very elongate, and its lower border somewhat curved downward. The free extremity, behind the last co-ossified vertebra, is thin, and turned slightly upward and outward.

The acetabulum has a well-defined border, which is nearly circular. Above this, there is a large anti-trochanter, or articular surface to which was applied the neck of the femur. The internal face of the acetabulum was not closed merely by fibrous tissue, as in modern Birds, but by bone, which is penetrated by a foramen of moderate size.

The ischium forms part of the acetabulum, and then, contracting rapidly, is continued backward as a long slender bone, which is entirely free at its distal end.

The bone usually called "pubis" in modern birds, which the writer has shown to be probably the post-pubis, forms, in *Hesperornis*, the lower portion of the acetabulum, and then extends backward as a long, slender, rod-like bone, nearly parallel with the ischium. It is somewhat longer than the ischium, and its distal extremity is truncated at right angles with the shaft. This bone is of nearly equal width throughout its entire length, and sends off no processes or projections toward the ischium, or from its own lower margin.

The sacrum in *Hesperornis* is very long and narrow, and the vertebræ which compose it are usually well co-ossified. The number of vertebræ in the true sacrum cannot be accurately determined, but in the ankylosed series there are fourteen.

THE TAIL.

The tail of *Hesperornis* (figure 17) presents some peculiarities of structure not before seen in Birds. It was composed, apparently, of twelve vertebræ, and all of these are preserved, with the exception of that portion of the last which formed the extreme end of the tail. The number

Fig. 17.

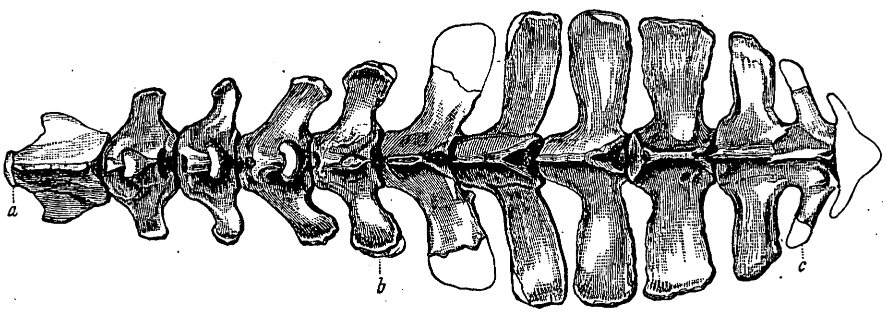

Fig. 17.—Caudal vertebræ of *Hesperornis regalis*, Marsh; seen from above, in position; two-thirds natural size. *a*, anterior convex face of first caudal; *b*, transverse process of fifth caudal; *c*, transverse process of eleventh caudal, or middle vertebra of the pygostyle.

of caudal vertebræ in *Hesperornis* exceeds those in any known recent Bird, with the possible exception of the Great Auk (*Alca impennis*, Linn.), now nearly or quite extinct. The number falls far short, however, of that in the tail of *Archæopteryx*, which also differs essentially in its general structure from the caudal extremity of *Hesperornis*.

The anterior free caudals of the *Hesperornis* are short, with high neural spines and moderate transverse processes. They are opisthocœlian, as in the corresponding vertebræ of *Pavo* and *Geococcyx*. The middle and posterior caudals have very long, and horizontally expanded, transverse processes, which restricted lateral motion, and clearly indicate that the tail was mainly moved vertically, evidently as an aid in diving. The last three or four caudal vertebræ are firmly co-ossified, forming a flat, horizontal, terminal mass, analogous to, but quite unlike, the ploughshare bone of modern Birds.

The last six or seven vertebræ in the tail of *Hesperornis* were so interlocked by the expanded transverse processes that very little lateral motion was possible. The hypapophyses, also, of the last two free caudals would restrict vertical flexure materially, so that the end of the tail would move mainly as a whole. This would give great power, similar to that in the Beaver's tail, or in the flexible blade of an oar.

THE LEGS AND FEET.

The posterior limbs of *Hesperornis* present an admirable example of adaptive structure. The means of locomotion were confined entirely to these extremities, and the life of *Hesperornis* was probably more completely aquatic than that of any known Bird. It may fairly be questioned whether it could even be said to walk on land, although some movement on shore was of course a necessity. Considering the posterior limb as a whole, it will be found a nearly perfect piece of machinery for propulsion through the water. Provision was made for a very powerful backward stroke, followed by a quick recovery, with little loss by resistance, a movement quite analogous to the strong stroke of an oar, feathered on its return.

Among recent Birds, we have in the genus *Podiceps* the nearest approach to the legs and feet of *Hesperornis*, and the osseous structure of these parts is essentially the same throughout in the two genera. The muscular system, also, of this member must have been very similar in both. In many respects, however, the bones of the posterior limbs of *Hesperornis* present evidences of a more primitive structure than is seen in any recent diving Birds.

The femur of *Hesperornis* is remarkably short and stout, more so than in any known Bird, recent or fossil. In its general features it resembles the femur of *Podiceps*, but the shaft is much stouter, and is flattened in an antero-posterior direction. The shaft of the femur is somewhat curved, with the convexity forward, and is marked on the posterior, inner, and outer surfaces by strong prominences for the attachment of muscles. The shaft contains no pneumatic foramina, but there is a large medullary cavity.

The tibia of *Hesperornis* is very long and powerful, and much the largest bone in the skeleton. In its general features, it most resembles the tibia in the genus *Podiceps*. There is no osseous bridge in front, over the canal through which passes the tendon of the *tibialis anticus* muscle. The absence of this osseous bridge is noteworthy also in *Podiceps*, as it is apparently present in all other known aquatic Birds. The groove between the posterior projections of the two condyles is broad and flat, but narrows rapidly above.

The patella in *Hesperornis* is a large bone, and entirely distinct from the tibia. In its general proportions it resembles the patella in *Podiceps*. It differs materially, however, in being perforated by a large foramen for the tendon of the *ambiens* muscle, agreeing in this respect with the patella of the Gannet (*Sula bassana*, Briss.).

The fibula of *Hesperornis* agrees essentially with that of *Podiceps* in its general characters. It is about three-fourths of the length of the tibia, and was united to the fibular ridge of that bone only by cartilage.

In the tarso-metatarsal bone of *Hesperornis* we have the extreme modification of a form characteristic of modern diving birds. There were four digits in the foot, the fifth digit being entirely absent, as in all known Birds, recent and fossil. In the adult *Hesperornis*, the second, third, and fourth metatarsals are thoroughly co-ossified into a stout, transversely compressed bone of moderate length, but in most specimens traces of the sutures remain. The fourth metatarsal element so greatly exceeds the other two in size that it forms by far the greatest part of the entire tarso-metatarsal bone.

The plane of motion for the whole limb, which above was coincident with the axes of the femur and tibia, was continued below through this element of the tarso-metatarsal, and through the fourth or outer digit, which it supported. In this structure of *Hesperornis*, so admirably adapted for swimming, we have an example of the same kind of specialized modification that has prepared the foot of the Ostrich, among recent Birds, and the Horse among Mammals, for extreme speed on the land.

The feet of *Hesperornis* resembled more closely those of the genus *Podiceps* than of any other known Birds. The number of digits is the same, the number of phalanges in each digit identical, but the proportions of the latter are different, and quite peculiar. In *Podiceps*, and the other Grebes, the outer toe is indeed the longest, but the middle one almost equals it in length and size, while the second is but slightly smaller. In *Hesperornis*, however, the fourth, or outer, toe is the dominant one, being three or four times as powerful as the adjoining middle one, or, indeed, as the other three combined. Again, the phalanges in *Podiceps* are very elongate and slender, and the terminal ones spatulate, while in *Hesperornis* the phalanges are short and thick, with the terminal ones more or less pointed. The phalanges in *Hesperornis* are, in fact, shorter than in most swimming Birds, and in their individual proportions remind one of the toe bones of the Penguins.

THE RESTORATION OF HESPERORNIS.

The foregoing description of the bones of *Hesperornis*, together with the illustrations given, will make clear to anatomists the more important points in the osseous structure of this ancient bird, in many respects

FIG. 18.

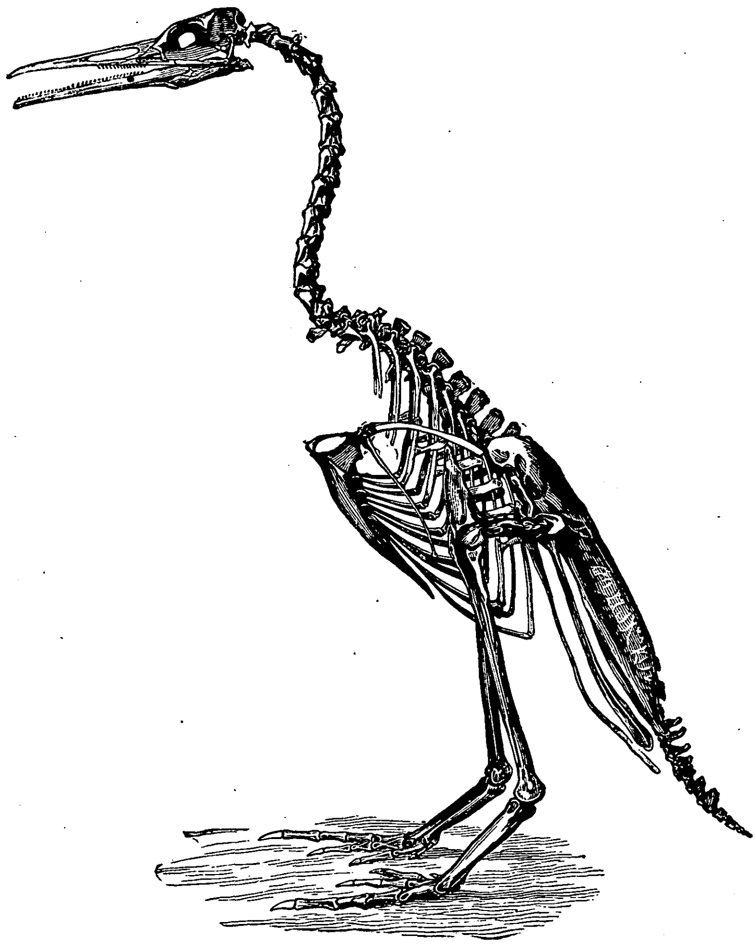

FIG. 18.—Restoration of *Hesperornis regalis*, Marsh. One-eighth natural size.

the most interesting member of the class yet discovered. With the exception of one or two terminal toe-bones, and the extreme point of the tail, every part of the skeleton is preserved in one or more specimens, and this ample material has been used in the restoration represented in figure 18. Not a few of the bones were nearly in their natural position, when discovered, and the remainder have been placed in their appropriate places in the skeleton, after much careful comparison of the fossils with the allied living forms. It is therefore confidently believed that the field of conjecture has been reduced to a minimum in the skeleton as restored.

The restoration of *Hesperornis regalis*, in figure 18, represents the skeleton one-eighth natural size, and in a position which the Bird doubtless sometimes assumed when on land, although it is probably more erect than was habitual. On the water, the body was of course more nearly horizontal, the neck more bent, and the legs usually much farther behind.

The magnitude of *Hesperornis regalis* may be judged from the fact that the skeleton, if extended, would measure over five feet ($1.6^{M.}$) from the point of the bill to the end of the toes. *Hesperornis crassipes* was somewhat larger, and *Hesperornis gracilis*, so far as known, was apparently smaller, and of more delicate proportions. When on land, in the position represented in figure 18, *Hesperornis regalis* would be rather more than three feet in height.

Hesperornis was a typical aquatic Bird, and in habit was doubtless very similar to the Loon, although, flight being impossible, its life was probably passed entirely upon the water, except when visiting the shore for the purpose of breeding. The nearest land at that time was the succession of low islands which marked the position of the present Rocky Mountains. In the shallow tropical sea, extending from this land 500 miles or more to the eastward, and to unknown limits north and south, there was the greatest abundance and variety of fishes, and these doubtless constituted the main food of the present species. *Hesperornis*, as we have seen, was an admirable diver, while the long neck with its capabilities of rapid flexure, and the long slender jaws armed with sharp recurved teeth formed together a perfect instrument for the capture and retention of the most agile fish. As the lower jaws were united in front only by cartilage, as in Serpents, and had on each side a joint which admitted of some motion, the power of swallowing was doubtless equal to almost any emergency.

ORIGIN OF PECULIAR FEATURES.

Having thus shown what the skeleton of *Hesperornis* is, and what its mode of life must have been, it remains to consider the more important question of how the peculiar combination of general and specialized characters manifested in its structure originated. The two most striking features of *Hesperornis* are the teeth and the limbs, and an inquiry in regard to them first suggests itself.

The teeth of *Hesperornis* may be regarded as a character inherited from a reptilian ancestry. Their strong resemblance to the teeth of Reptiles, in form, structure, and succession, is evidence of this, and their method of implantation in a common alveolar groove (Holcodont), conforms strictly to what we have in one well-known group of Reptiles, exemplified by *Ichthyosaurus*. This method of insertion in the jaw is a primitive dental character, quite different from what we should naturally expect as an accompaniment of the modern style of vertebræ, and is a much lower grade than the implantation of the teeth in distinct sockets (Thecodont), a feature characteristic, as we shall see, of another group of Odontornithes, of which *Ichthyornis* is the type. These teeth indicate unmistakably that *Hesperornis* was carnivorous in habit, and doubtless was descended from a long line of rapacious ancestors.

In considering the limbs of *Hesperornis*, two explanations of their peculiar modifications naturally suggest themselves. The rudimentary wings, viewed in the light of modern science, clearly indicate that *Hesperornis* was in this respect a degraded type. The Struthious characters which we have noticed in various parts of the skeleton might be regarded, not as evidence of close relationship, but rather as general reptilian characters, common to the two groups through inheritance from a remote reptilian ancestry. According to this view, the wings may have been gradually lost by disuse, after the aquatic life was assumed. In proportion as the wings diminished, the legs and feet increased in size, for their work increased. This change would be strictly in accordance with the law of compensation, and the well-known economy of nature.

We may suppose, moreover, the ancestors of *Hesperornis* to have been at one time on an equality with the Loon, and later with the Penguin, in respect to means of flight and swimming. As the wings slowly diminished in size, first came the loss of flight, while the wings retained, doubtless for a long time, their power of propulsion through the water. As this, too, became gradually restricted, the legs and feet gained proportionally. The power derived from them, aided indirectly by the tail, in time so predominated that the wings became entirely aborted, a remnant of the humerus alone remaining.

During the life-history as thus indicated, *Hesperornis* would exemplify in the waters of the Cretaceous period the evolution that has recently taken place in ocean navigation, in the gradual change of the side-wheel steamer into the modern propeller.

REPTILIAN ANCESTRY.

Another explanation seems on the whole more reasonable, and more in accordance with the known facts. The Struthious characters seen in *Hesperornis* should probably be regarded as evidence of real affinity, and in this case *Hesperornis* would be essentially a carnivorous, swimming Ostrich. The diminutive wings and very large posterior extremities would then have been acquired on land, by the same means that have given similar characters to the *Ratitæ*, and subsequently have been adapted to an aquatic life. Against this view the carnivorous character of *Hesperornis* would be no valid objection. The long neck and peculiar jaws and teeth would be equally effective in seizing prey on the land, and many of the herbivorous cotemporaries would doubtless have been easy victims. This would be precisely analogous to what we have among the corresponding groups in the Dinosaurs.

There is to-day no evidence that any of the Struthious Birds, or their ancestors, ever possessed the power of flight, although this is generally assumed. The case is even stronger with *Hesperornis*, as this genus stands much nearer the ancestral type, both in structure and in time. The absence from the sternum of any trace of a keel is alone strong proof against flight; the peculiar Dinosauroid union of the scapula and coracoid, unlike that of any volant Bird or Reptile, confirms this; and other testimony bearing in the same direction is not wanting.

All Carinate Birds, moreover, so far as known, indicate by their embryology that they have passed through the Struthious, or lower stage; and some of them, *Tinamus*, for instance, still retain one or more of its distinctive characters. There are, indeed, various flightless Birds, recently extinct, which do not belong to the Ostrich group, but are truly Carinate in all their essential features. The Dodo (*Didus*), Solitaire (*Pezophaps*), *Cnemiornis*, and *Notornis* are well-known examples; but these all show in their shoulder-girdle unmistakable traces of the lost power of flight. The characters necessary to volant movements, once attained, would appear never to be completely lost, and this alone seems to furnish a crucial test. When such suggestive indications are wanting in the skeleton, we may fairly challenge any assumption of previous flight.

Although *Hesperornis* may thus, like its reptilian ancestry, have always been incapable of flight, the anterior limbs may have long continued limited aids to locomotion. Whether used actively in the air, like the wings of the Ostrich, or of young swimming Birds, or passively, like the sail-set pinions of the Swan, or later as imperfect paddles, the wings of *Hesperornis* were certainly not well fitted for diving, and hence they gradually became useless, and virtually disappeared. We may imagine, among the reasons for the gradual loss of wings, the fact that they were too weak to be of much service under water, while from their position they added greatly to the resistance, especially during rapid diving. To diminish this resistance, they would naturally be applied closely to the side, and from such disuse, would gradually suffer atrophy.

LOCOMOTION.

In this great swimming Bird, as thus modified, we have presented to us an interesting problem in animal mechanics. The wings may be regarded as wanting, since the remnant of the humerus was attached closely to the side, as in *Apteryx*, if not entirely concealed beneath the skin, like a scapula. The locomotion was therefore entirely performed by means of the posterior limbs, a specialization here seen for the first time in aquatic birds, recent or fossil. Those who have observed a Penguin or a Loon swimming beneath the water know what a vigorous use such Birds then make of their wings, however useless these members may appear to be on land. Not only do the wings, in such a case, assist in the forward movement through the water, but they are of much service in steering. A Penguin, when in swift subaqueous flight, can turn around, by the aid of its wings, while moving twice its length. *Hesperornis* had no such aid, but the legs and feet were far superior, for swimming and diving, to those of the Penguins, not merely in power, but in the more perfect adaptive mechanism. This was doubtless the main reason why the posterior limbs of *Hesperornis* became so predominant.

The tail of *Hesperornis* was clearly of great service in its aquatic life. In the number of vertebræ and length, it exceeds nearly all known Birds, and it is unique in its widely expanded transverse processes, and in its depressed, horizontal, plow-share bone. This broad horizontal tail reminds one of that of the Beaver, and was undoubtedly of great assistance in steering and in diving. Whether it was, like the Beaver's tail, destitute of feathers, or like the tail of *Plotus* was furnished with long stiff *rectrices*, so as to act as a rudder, cannot at present be determined with certainty, although the latter view seems more probable. That *Hesperornis* was provided with feathers of some kind, we can hardly doubt.

The surrounding circumstances were evidently very favorable to *Hesperornis* for a long period. There was apparently during this time an absence of the enemies in the air above, and an abundance of food in the water. *Hesperornis* was more than a match for the gigantic toothless Pterodactyles, which hovered over the waters here in such great numbers, and the other inhabitants of the air all appear to have been small. The ocean in which *Hesperornis* swam teemed with fishes of many kinds, and thus a great variety of food was at hand, and obtained with little effort. In this aquatic paradise *Hesperornis* flourished, disturbed only by the serpentine Mosasaur, which, even without tradition, we may imagine, caused its banishment, if not its destruction.

AFFINITIES.

In the preceding description, the writer has compared *Hesperornis* with the *Ratitæ*, or Ostrich group, and also with the diving Birds as exemplified by *Colymbus* and *Podiceps*, and the more noteworthy points of resemblance or difference have been stated. It will hardly be profitable to extend the comparison to other groups of modern Birds, as the similarity in points of structure is mainly of a general nature.

The genus *Archæopteryx*, from the Jurassic of Europe, the only Bird, with the exception of *Laopteryx*, at present known more ancient than *Hesperornis*, presents some marked points of difference, for example its elongated tail; as well as some peculiar resemblances, which will be discussed in the concluding part of this article.

The genera *Ichthyornis* and *Apatornis*, which are from the same geological formation as *Hesperornis*, and are described below, differ widely from that genus in having biconcave vertebræ, as well as in other most important characters.

Hesperornis really stands alone among all known birds, and the special characters which thus separate it will be stated in the table of classification at the end of the present article.

DESCRIPTION OF ICHTHYORNIS.

The Birds included in the second order of *Odontornithes*, so far as now known, were all of small size, and possessed powerful wings, and very small legs and feet. They differed widely therefore in form and habit from those described above, and, as we shall see, exhibited various significant characters, which distinguish them more strongly from the *Odontolcæ* than any existing Birds are separated from each other. Some of these characters, as, for instance, their biconcave vertebræ, separate them widely from all Birds recent and extinct, and point back unmistakably to a very lowly ancestry, even below the Reptiles.

The remains of this group preserved are more or less pneumatic, and this fact, in connection with their small size, is perhaps the main reason why so few have been discovered. As might naturally be expected, the hollow bones of flying Birds, being filled with air, enable the carcass to float upon the water much longer than it otherwise would, and it is thus liable to be destroyed by fishes or other animals. Hence, the chances of the entombment of a complete skeleton are greatly diminished. Such delicate bones, moreover, even after their entombment, require a favorable combination of circumstances for their preservation in good condition. Fortunately, the bottom of the Cretaceous ocean, in which the remains of these Birds were embedded, left nothing to be desired in this respect, since in its fine calcareous sediments the most delicate vascular impressions on the bones were often preserved.

A most careful search in these deposits, as they are now exposed on the plains east of the Rocky Mountains, conducted by the writer in person, with the aid of other members of the various expeditions already mentioned, has resulted in bringing to light various remains representing no less than seventy-seven different individuals of this group of the *Odontornithes*. These remains are all in the Yale College Museum, and form the material on which the following descriptions are based. An investigation of these fossils shows that they are included in two well marked genera, *Ichthyornis* and *Apatornis*, the former represented by several species, and the latter by only one. These were all small Birds, scarcely larger than a Pigeon. In their powerful wings and small legs and feet they remind one of the Terns, and, according to present evidence, they were aquatic Birds of similar life and habits.

THE SKULL.

In *Ichthyornis dispar*, the type of the genus *Ichthyornis* and of the order *Odontotormæ*, the skull was very large in proportion to the rest of the skeleton. This disproportion is shown in the restoration, figure 27. The cranial portion of the skull is quite short, but the facial part is

FIG. 19.

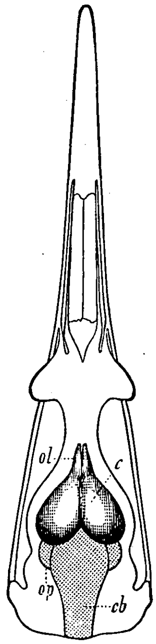

FIG. 20.

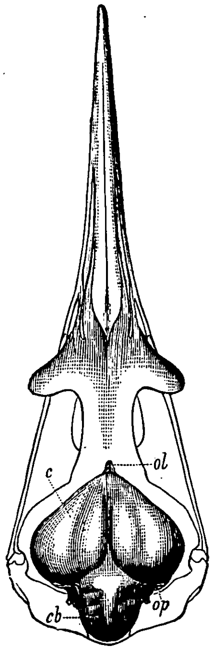

FIG. 19.—Outline of the skull and brain-cavity of *Ichthyornis victor*, Marsh; seen from above; five-sixths natural size.

FIG. 20.—Outline of the skull and brain-cavity of *Sterna cantiaca*, Gmelin; same view; natural size. *ol*, olfactory lobes; *c*, cerebral hemispheres; *op*, optic lobes; *cb*, cerebellum.

much produced. The occipital condyle is very small and directed backward. Above the condyle, the occipital portion of the skull was nearly vertical. The lateral margin of this surface is bounded by a sharp ridge which separates it from the temporal fossa, and this ridge, united with its fellow above, was continued forward on the median line, as a sagittal crest, between the temporal fossæ. The latter were large and deep, and were separated from the orbit by a moderate post-orbital process. The orbits were very large, and near together. The quadrate is well preserved in one species, and its articular head has only a single facet, as in *Hesperornis* and the *Ratitæ*.

The skull of *Ichthyornis* has deep glandular depressions along the roof of the orbits similar to those on the cranium of *Hesperornis* and some recent water Birds. The premaxillary bones are separate throughout their posterior half, but were doubtless firmly united in front. The anterior part has not been recovered, but the lower jaws would seem to indicate that, in some respects, it resembled the beak of *Hesperornis*.

THE BRAIN.

The brain of *Ichthyornis* was remarkably small, and in its main features strongly reptilian. In form and proportions it resembled the brain of *Hesperornis* more nearly than that of any other known Bird. The figure given (19) represents an outline of the skull of *Ichthyornis*, with a cast of the brain-cavity in position. A comparison of this figure with that of the skull and brain of *Hesperornis* (figure 7) will show the main points of resemblance. The most noticeable reptilian features in the two brain casts are the elongated form and prominent optic lobes.

The olfactory lobes of *Ichthyornis* (figure 19, *ol*) were large and prominent. They were separated in front by the inter-orbital septum, and their crura made their exit, apparently, through separate foramina.

The cerebral hemispheres were of moderate size, and proportionally less elongated than in *Hesperornis*. Their form and proportions, in *Ichthyornis*, are well shown in the figure, which represents a cast taken directly from a cranium with this portion well preserved.

The optic lobes (figure 19, *op*) are very large, and the brain at this part was nearly as wide as across the hemispheres. The cerebellum (*cb*) was large and elongate.

The general form and dimensions only of the posterior part of the brain of *Ichthyornis* are shown in the figure, and hence are indicated by a uniform shading. The outline given was obtained from a comparison and measurements of two different specimens.

Figure 20 represents the skull and cast of the brain-cavity of a Tern, and the figure of *Ichthyornis* beside it is made of the same absolute length, for comparison. The Tern was chosen for this purpose, because in size and structure of its skeleton it has considerable resemblance to *Ichthyornis*. The mode of life, also, of the two Birds was probably similar.

In comparing the brain-cavity of *Ichthyornis* with that of *Sterna*, as shown in figure 20, the strong contrast in size is at once apparent, while the most marked difference is seen in the cerebral hemispheres. If the latter alone be compared, the hemispheres of *Ichthyornis* are less than one-fourth the size of those of *Sterna*. If, however, the bulk of the entire brain of each be compared, that of *Ichthyornis* would be less than one-third the size of that of the Tern. This would hold true after allowing a considerable reduction for any uncertainty in regard to the exact proportions of the posterior part of the brain-case of *Ichthyornis*.

The result of this comparison between *Ichthyornis* and the Tern agrees very closely with that obtained in contrasting the size of the brain-cavities of *Hesperornis* and *Colymbus* as given above, and hence is of special interest, as in no other instances have the brain cavities of Mesozoic Birds been investigated.

THE TEETH.

In the type specimen of *Ichthyornis dispar*, both lower jaws are preserved. The two rami of the jaws of *Ichthyornis* are entirely separate, having been united in front only by cartilage. They are large and massive, nearly straight, and much compressed transversely, especially in the posterior portion. The upper margin of the dentary bone

Fig. 21.

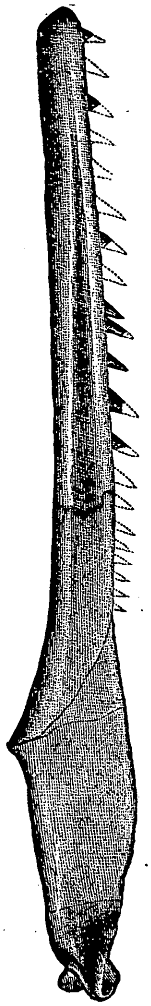

Fig. 22.

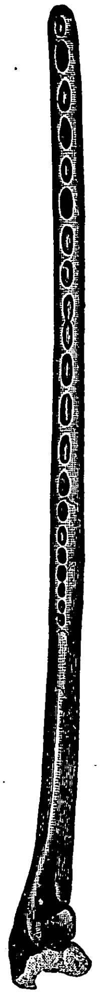

Fig. 23.

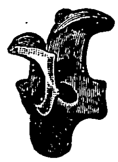

Fig. 24.

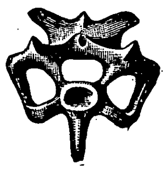

Fig. 21.—Left lower jaw of *Ichthyornis dispar*, Marsh; side view, twice natural size.
Fig. 22.—The same; top view.
Fig. 23.—Cervical vertebra of *Ichthyornis dispar*, Marsh; side view, twice natural size.
Fig. 24.—The same; front view.

is nearly straight. The anterior extremity is rounded, and without any distinct symphysial surface. The right ramus is shown (reversed) in figures 21 and 22. The sutures in the jaw are nearly all obsolete, with the exception of that between the splenial and angular bones. This suture is especially open on the inner surface of the jaw, and, in life, doubtless admitted of some motion. There is no mandibular foramen, and, just behind the articular face for the quadrate, the extremity is abruptly truncated.

The dentigerous portion of the lower jaw is so similar to that of some of the smaller Mosasauroid Reptiles, that, without other portions of the skeleton, the two could hardly be distinguished.

The teeth of *Ichthyornis* were planted in distinct sockets, thus differing widely from those of *Hesperornis*. They are all sharp and pointed, more or less compressed, and strongly recurved. The crowns are coated with enamel, and the two fore and aft cutting edges are sharp and smooth, without serrations.

The maxillary teeth appear to have been larger than those opposing them. Their alveolar cavities are crowded together, and yet distinctly separated from each other by a thin septum of bone. They are oval in outline, and quite shallow, owing to the small vertical extent of the maxillary. Whether the premaxillary bones contained teeth is uncertain, but they were probably edentulous, as in *Hesperornis*.

The dental cavities in the lower jaw are elliptical in outline, and vary in size according to position. They are in general deeper, and separated more widely from each other than those in the maxillaries. In the lower jaw of *Ichthyornis* there are twenty-one distinct sockets. The anterior one is very near the extremity, and contains a tooth of moderate size. The largest teeth of the lower jaw are just back of the middle dentary bone. From this region to the posterior end of the dentary the teeth diminish gradually in size. The whole surface of each tooth exposed above the jaw is covered with smooth enamel.

In the lower teeth of *Ichthyornis*, the pulp-cavity passes well up into the base of the crown. The fang is compressed, and directed downwar \ and forward. It is firmly set in a deep socket, which it nearly or quite fills. The dental succession took place vertically, as in Crocodiles and Dinosaurs; not laterally, as in *Hesperornis* and the Mosasaurs, a fact of no little significance. The young teeth are much inclined when they first appear above the jaw, after the old teeth have been expelled.

THE VERTEBRÆ.

The presacral vertebræ of *Ichthyornis* present characters more remarkable than those of any other known Birds. Both articular faces of the centra are concave (figures 23 and 24). This peculiar feature is fully discussed below. None of the vertebræ of *Ichthyornis*, in front of the sacrum, are ankylosed together, and a number of them contain cavities in the sides, which are apparently pneumatic. Among existing Birds, the Terns appear to bear in their vertebræ the nearest general resemblance to *Ichthyornis*.

THE SCAPULAR ARCH.

The scapular arch of *Ichthyornis*, and its near ally, *Apatornis*, conforms strictly to the type seen in living carinate Birds. This part of the skeleton gives no hint of the peculiar reptilian features in other portions of the structure, and has none of the Struthious characters noticed in *Hesperornis*. There is apparently no part of the entire shoulder girdle of *Ichthyornis*, or the allied genus, that might not have been used by some existing Birds with strong powers of flight.

The sternum in the type species of *Ichthyornis* is deeply keeled, affording ample room for muscular attachment. The manubrium is broad,

FIG. 25.

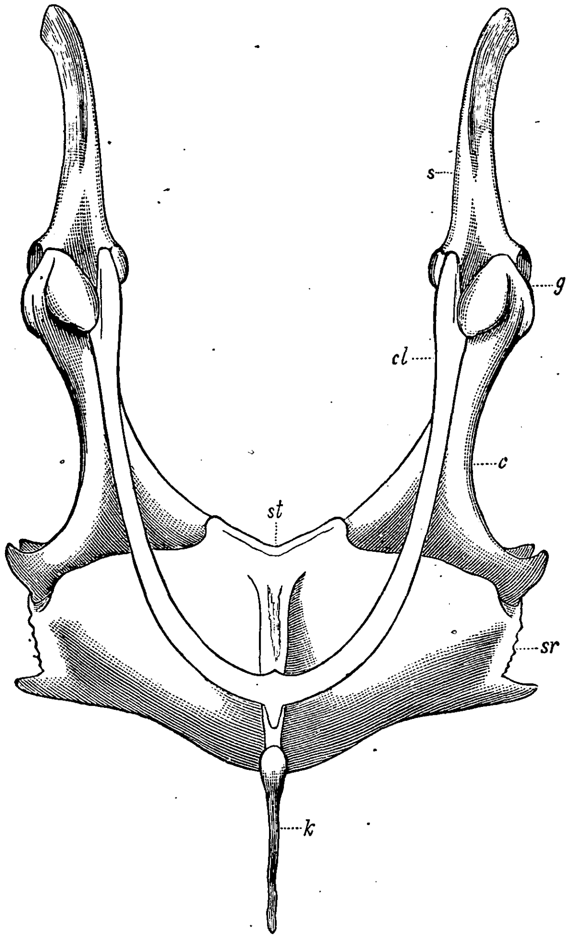

FIG. 25.—Scapular arch of *Ichthyornis victor*, Marsh; twice natural size. *s*, scapula; *c*, coracoid; *cl*, clavicle; *st*, sternum; *k*, keel of sternum; *sr*, costal border; *g*, glenoid fossa.

and somewhat unsymmetrical. The coracoid grooves are elongated, and overlap widely across the median line, as in *Ardea*, and some Birds of prey. As usually occurs in living Birds with this peculiarity, the inner end of the left coracoid was above that of the right.

In the genus *Apatornis*, the sternum was keeled as in *Ichthyornis*, although the precise depth of the keel cannot be determined. The manubrium was narrower than in *Ichthyornis*, symmetrical, and ended in a blunt point. The coracoid grooves scarcely more than meet on the median line, and the left is but little depressed below the right, the asymmetry being only about as great as in a Cormorant (*Graculus dilophus*, Gray).

THE WINGS.

The wings in the two genera of *Odontotormæ* clearly indicate very strong powers of flight, thus differing as widely as possible from the corresponding parts in *Hesperornis*. In *Ichthyornis* nearly all the bones of the wings are well preserved, and these are all remarkably like those of some carinate Birds living to-day. These remains give but slight indications of the reptilian features seen in the portions of the skeleton already described.

The humerus of *Ichthyornis* is strong and well developed, thus widely differing from that of *Hesperornis*. The most striking feature of the bone is the enormous radial crest, surpassing in comparative size that of any living bird. This crest is, moreover, remarkable for its position, which is in a plane nearly parallel with the long axis of the head of the humerus, instead of considerably inclined to this axis, is in most birds. This fact is clearly shown by a number of well-preserved examples, including the type specimen of *Ichthyornis dispar*. In these two points, the humerus of *Ichthyornis* strongly resembles the corresponding bone in the Pterodactyles.

The radius, like the other bones of the wings in *Ichthyornis*, is strong and robust. The ulna in *Ichthyornis* is a strong, moderately curved bone, somewhat trihedral proximally, but becoming more nearly cylindrical toward the distal end, where it is also less curved than in the proximal half. The surface for articulation with the humerus is placed more obliquely to the shaft of the bone than in *Sterna*, and occupies a greater proportion of the proximal end than in that genus, agreeing better in both these respects with the ulna of *Ardea*. The shaft of the bone is hollow, with thin walls, and presents faint but unmistakable evidence of the attachment of about a dozen secondary quill-feathers.

The united metacarpal elements of *Ichthyornis* form a short and decidedly robust bone, somewhat resembling that of *Sterna*, but presenting more points of resemblance to the genus *Graculus*. The united metacarpals in the genus *Apatornis* are much more slender than in *Ichthyornis*, but the bone is still of moderately robust proportions, when compared with the same part in modern Birds of flight.

THE PELVIC ARCH.

The pelvic arch in the two known genera of *Odontotormæ* exhibits some interesting reptilian characters, one of which is seen also in *Hesperornis*. This portion of the skeleton is small in comparison with the pectoral arch, corresponding to the difference in size between the wings and the feet.

The sacrum is well preserved in the type specimen of *Ichthyornis dispar*, Marsh, and appears to be composed of ten united vertebræ. The centra of these vertebræ are thoroughly co-ossified, and in the anterior part of the sacrum they are also considerably reduced in diameter. The anterior articular face is slightly concave. The neural spines are moderately developed in the anterior part, and are united with ossified tendons, which diverge posteriorly and form a flattened upper surface in the median part of the sacrum. The middle part of the sacrum is much crushed below in the present specimen. The more posterior centra are of moderate size, and the articular face of the last is depressed, and distinctly concave.

Fig. 26.

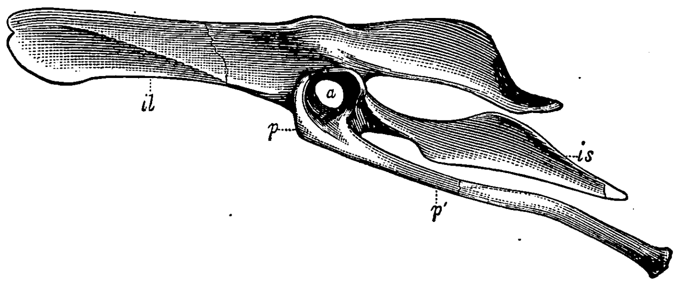

FIG. 26.—Pelvis of *Apatornis celer*, Marsh; lateral view, seen from the right, one and one half times natural size; *il*, ilium; *is*, ischium; *p*, pubis; *p'*, post-pubis; *a*, acetabular foramen.

The pelvic bones in *Ichthyornis* are strongly co-ossified with each other. The ilium is obtusely rounded in front, and its antero-superior border is separated a short distance from its fellow. The pre-acetabular part of the ilium is concave externally, and considerably longer than the posterior portion. The ischium is expanded medially, and extends further back than the ilium. It is not united with the ilium posteriorly, thus agreeing with the corresponding part in *Hesperornis*. The pubis has no distinct anterior process, but the post-pubic element is elongated, and its distal portion free.

The pelvic bones of *Apatornis* (figure 26) are very similar in form and proportions to those of *Ichthyornis*. The pre-acetabular part of the ilium is much more extensive than the posterior portion. The acetabulum is perforate, but the foramen (*a*) is of moderate size. The ischium does not coalesce with the posterior part of the ilium, and its distal end was free, as in *Ichthyornis* and *Hesperornis*, and a few modern reptilian Birds. The post-pubic element of the pelvis is longer than in *Ichthyornis*, and also much longer than the ischium.

The tail in *Ichthyornis* is notable mainly for being of the modern ornithic type, thus widely differing from that of both *Archæopteryx* and *Hesperornis*, the only other two Mesozoic Birds in which this organ is preserved. The tail in the genus *Ichthyornis* was comparatively short, and the terminal vertebræ were co-ossified.

A series of seven caudal vertebræ are preserved in one specimen of *Ichthyornis victor*. They pertain to the median and distal part of the tail, although not including the extreme end, a portion of the *pygostyle*, or the part formed by the united centra of the terminal vertebræ, being lost.

THE LEGS AND FEET.

The legs and feet in the two genera of *Odontotormæ* are comparatively small, and present no peculiar features. The remains preserved agree most nearly with the corresponding parts in modern carinate Birds.

The femur in *Ichthyornis* is a short and comparatively small bone. The shaft is slender, and nearly smooth, being destitute of the rugosites seen on the femur of *Hesperornis*. Both the articular faces present the ordinary avian type of articulation, and the shaft of the bone is hollow, with thin walls. The ratio of the fibular face to that for the tibia is about the same as in the Tern, and the general proportions of the bone, as to length, diameter of shaft, and size of articular faces, are nearly the same as in that bird. The femur of *Ichthyornis*, however, is more than half the length of the humerus.

The tibia of *Ichthyornis* is a slender bone of moderate length. The cnemial process is but little developed, and only slightly elevated above the articular face of the bone. The shaft was hollow, with rather thin walls, and was gently curved inward toward its distal end rather more strongly than in the Tern.

The tarso-metatarsal bone of the *Ichthyornis* appears to be composed of the same number of elements, united in the same degree as in living Birds, a condition similar to that prevailing in the wings. The resulting tarso-metatarsal bone may be compared with the same bone in the Tern, which it considerably resembles, although rather more robust in proportion to its length.

RESTORATION OF ICHTHYORNIS.

The preceding description of the remains of *Ichthyornis*, in connection with the illustrations given, will make known some of the more important characters which separate these remarkable Mesozoic Birds from all others, recent or extinct. The material on which the present investigation of this genus is made consists of portions of more than seventy different individuals.

The restoration of *Ichthyornis* (figure 27) is one-half size, and is based on portions of several skeletons. The other species of the genus *Ichthyornis* did not differ widely from this in size. The bones represented in outline are taken in part from other specimens of the same species, but mostly from the skeleton of the Royal Tern (*Sterna regia*, Gambel), which, after a careful comparison, seemed well adapted for completing, approximately, the restoration here presented. The position chosen is one which seemed on the whole to best accord with the remains at present known.

In considering the skeleton of *Ichthyornis*, the anatomist is at once confronted with a strange combination of characters. The wing-bones are conclusive proof that *Ichthyornis* was a highly specialized Bird, with great powers of flight. The individual bones correspond closely with those of Birds living to-day. The legs and feet, also, are much like those of some modern Birds. With these portions alone before him, the comparative anatomist would unhesitatingly refer the remains to the class of Birds, and would naturally conclude that they belonged to the modern type. If, however, the skull should then be found with the wings and feet, very strong evidence would be required to convince him

FIG. 27.

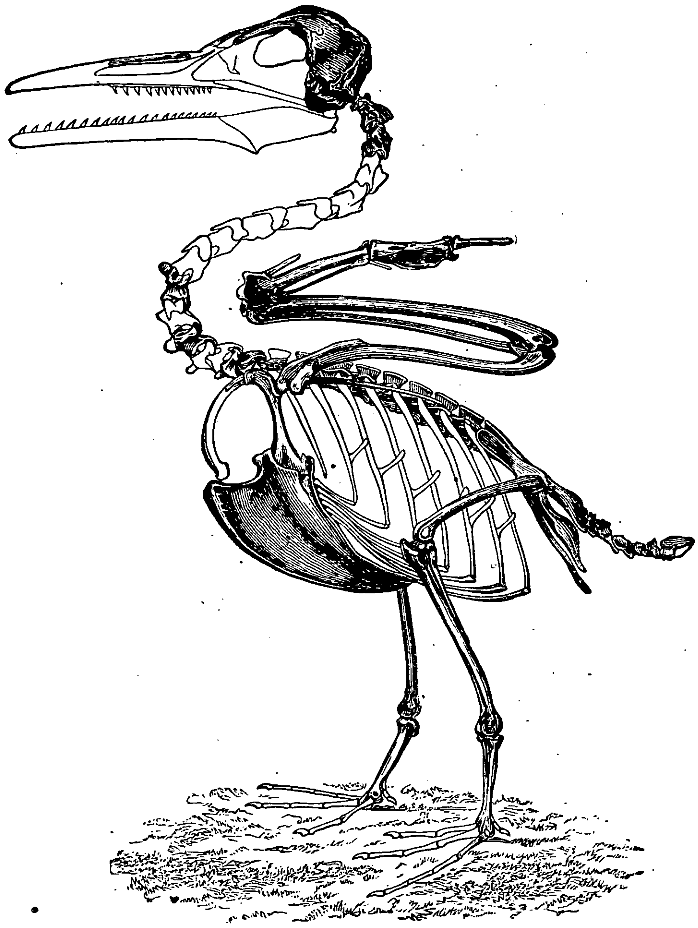

FIG. 27.—Restoration of *Ichthyornis victor*, Marsh. One-half natural size.

that they were parts of one and the same Bird. The jaws and teeth present reptilian characters wholly unknown in modern Birds, while the base of the skull and the small brain point strongly in the same direction. The biconcave vertebræ lead *Ichthyornis* still farther away from all knows Birds, recent and extinct, and, if found alone with the jaws and teeth, would force any anatomist to the conclusion that he had before him the remains of a Reptile.

The skeleton of *Ichthyornis*, as we know it to-day, can be interpreted only, in the light of modern science, by supposing that certain parts have become highly specialized in the direction of recent Birds, while others have been derived, with but little change, from a reptilian, or even a more lowly, ancestry. In the wings, the most characteristic modern feature is the co-ossification of the metacarpal bones, a character universal among existing Birds. In reptiles, however, and in the only known European Jurassic Bird, *Archæopteryx*, these bones are separate. The sternum of *Ichthyornis* is very similar to that of modern carinate Birds. In the feet of *Ichthyornis*, also, the compound tarso-metatarsal is another modern feature, especially characteristic of recent Birds.

If, now, we consider the skull of *Ichthyornis*, we find the avian and the reptilian characters strangely blended. The teeth are evidently a strong reptilian feature, and, before the discovery of *Ichthyornis*, were entirely unknown in the class of Birds. Their method of implantation in distinct sockets is a specialized character in reptiles, and was not shared even by *Hesperornis*, the contemporary of *Ichthyornis*. The diminutive elongated brain, also, points back to the Reptiles. Other features of the skull, for example the single-headed quadrate, are shared only by the most reptilian of Birds. The union of the lower jaws in front, by ligament only, is characteristic of many Reptiles, and is seen in *Hesperornis*, but is unknown in recent Birds. The form of the skull, and the obliteration of most of the cranial sutures are points of resemblance to many modern Birds.

The locomotive organs of *Ichthyornis* are so similar to those of typical Birds that they present no such interesting mechanical problems as were suggested by the skeleton *Hesperornis*. In the vertebræ, however, we find a primitive form retained, and also have the key to the origin of one remarkable character in recent Birds, which has hitherto remained unexplained.

ORIGIN OF VERTEBRAL FORMS.

While all existing Birds, and all of the extinct forms so far as known, including *Hesperornis*, have the peculiar saddle-shaped vertebræ, those of *Ichthyornis*, and its near ally *Apatornis*, are biconcave. This form is seen in a few recent and in many extinct Reptiles, and in the Amphibians; but it is especially characteristic of Fishes, from which class it was undoubtedly inherited by the superior groups. This character alone indicates unmistakably a great antiquity for the class of Birds.

The saddle-shaped vertebræ are certainly one of the most marked features in the skeleton of modern Birds. This form is so peculiar and so constant that it has been considered by many anatomists as the best distinctive character for the class. In no other group of animals known do we find the true saddle-shaped articulation of the centra seen in the vertebræ of Birds.

Not only do the presacral vertebræ of all existing Birds exhibit this structure, but the many extinct species now known from the whole series of Tertiary deposits have the same articulation. If we knew only these fossil forms, in addition to the existing species of Birds, the origin of this peculiar vertebral articulation would perhaps remain a mystery. Most fortunately, however, one of the vertebræ of *Ichthyornis* throws much light on this point, and virtually explains the difficulty.

We have seen that *Hesperornis* has the same kind of vertebræ as modern Birds, while those of *Ichthyornis* are biconcave. The marked contrast between the shape of the vertebral articulation in these two genera is seen in the figures below, which show a characteristic cervical vertebra in each form. In the vertebra of *Ichthyornis* shown in figures 28 and 29 it will be seen that the articulation of the centrum is cup-shaped; while, in the corresponding vertebra of *Hesperornis*, the ends of the centrum are saddle-shaped, as in ordinary Birds. Thus the distinction between the two types in this part of the skeleton is as wide as between *Ichthyornis* and any living bird.

FIG. 28.

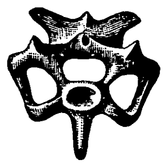

FIG. 29.

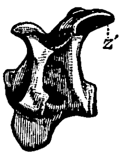

FIG. 30.

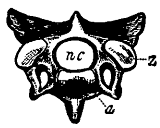

FIG. 31.

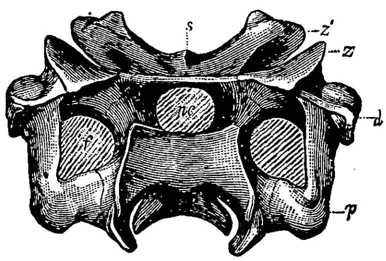

FIG. 32.

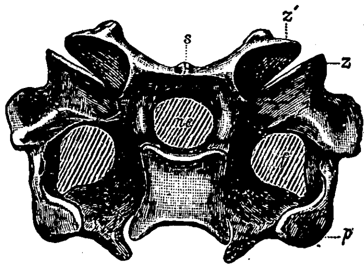

FIG. 28.—Twelfth cervical vertebra of *Ichthyornis dispar*, Marsh; front view; twice natural size.
FIG. 29.—The same vertebra; seen from the left side.
FIG. 30.—Third cervical vertebra of *Ichthyornis victor*, Marsh; front view; twice natural size.
FIG. 31.—Thirteenth cervical vertebra of *Hesperornis regalis*, Marsh; front view; natural size.
FIG. 32.—The same vertebra; posterior view.

a, anterior articulation; *d*, diapophysis; *p*, parapophysis; *f*, lateral foramen; *nc*, neural canal; *s*, neural spine; *z*, pre-zygapophysis; *z'*, post-zygapophysis.

To the evolutionist, who believes that Birds are all closely connected genetically, this difference in structure, at first sight, offers a most serious difficulty; since hitherto we have had no hint of a transformation from the one form to the other.

In the third cervical vertebra of *Ichthyornis*, however, we catch nature in the act, as it were, of forming a new type, by modifying one form of vertebra into another. Following this clew, the connection between these widely divergent types of structure soon becomes apparent; and the development of the modern style of avian vertebra from the fish-like, biconcave form finds a ready solution. In the anterior articulation of this vertebra of *Ichthyornis* (figure 30) the surface looks downward and forward, being inclined at an angle of nearly 60° with the axis of the centrum. In vertical section, it is moderately convex, while transversely it is strongly concave; thus presenting a near approach to the saddle-like articulation. None of the other known vertebræ of *Ichthyornis* possess this character.

This highly specialized feature occurs at the first bend of the neck, and greatly facilitates motion in a vertical plane. If, now, we consider for a moment that the dominant motion in the neck of a modern Bird is in a vertical plane, we see at once that anything that tends to facilitate this motion would be an advantage, and that the motion itself would tend directly to produce this modification. With biconcave vertebræ, the flexure in any direction is dependent on the elasticity of the fibrous tissue that connects them, as the edges of the cups do not slide over each other. An increasing movement in the neck of *Ichthyornis* in a vertical plane would tend to deflect the upper and lower margins of the circular cup, and to produce a vertical constriction, and at the same time to leave the lateral margins projecting; and this is precisely what we have in the third vertebra of this genus.

This modification of the vertebræ would naturally appear first where the neck had most motion, viz, in the anterior cervicals, and gradually would be extended down the neck; and on to the sacrum, if the same flexure were continued.

Behind the axis, or where the vertical motion prevails, we find in modern Birds no exception to the saddle articulation of the vertebræ in the whole cervical series.

In the dorsal vertebræ, this cause would be less efficient, since the ribs and neural spines tend to restrict vertical motion, and hence to arrest this modification. This region, then, as might be expected, offers strong confirmatory evidence of the correctness of the above explanation; for here occur, among existing Birds, the only true exceptions known in the presacral series to the characteristic saddle-shaped articulation. In *Strigops* and a few other land Birds; in the Penguins, the Terns, and some other aquatic Birds, one or more vertebræ in the dorsal region are without the saddle-shaped articulation, and are either opisthocœlian or imperfectly biconcave. In such instances we can usually, if not always, detect evidence of an arrest of vertical flexure. This may lock together the posterior dorsals by their neural spines, as in *Strigops*, leaving the power of lateral flexure; or several vertebræ may be co-ossified, as in *Accipiter*, and some *Raptores*, in which a stiff back is a positive advantage.

In the co-ossified sacral series of many Birds one or more of the anterior vertebræ have the saddle-shaped articulation. This, however, is no valid objection to the above explanation, since these vertebræ are really dorsals, and have gradually coalesced with the true sacral vertebræ.

In the caudal vertebræ of recent Birds we have, in a measure, the original biconcave structure preserved, for here the motion in every direction was much restricted. The caudal vertebræ of these Birds, even in the most aberrant forms, are essentially the same, and in the fossil species the articulations at least appear to follow the general rule. In *Pavo* and *Geococcyx* the caudal vertebræ exhibit a tendency to a procœlian union. Some other forms also show unimportant modifications of the normal type of caudal articulation, but nothing to suggest a real objection to the explanation now proposed of the origin of the saddle-shaped vertebræ, characteristic of Birds.

In bringing together the above facts, and others suggested by them, the classification and development of the various forms of vertebræ appear to be somewhat as follows:

(1.) *Biconcave vertebræ* (Fishes and Amphibians); the primitive type; a weak articulation, admitting free but limited motion. From this form have been directly derived the other varieties, namely:

(2.) *Plane vertebræ* (Mammals); affording a stronger joint, with motion still restricted.

(3.) *Cup-and-ball vertebræ* (Reptiles); a strong and flexible joint, well fitted for general motion, and evidently produced by it. The vertebræ are procœlian when lateral motion is dominant (Serpents); opisthocœlian with varied motion (Dinosaur cervicals).

(4.) *Saddle vertebræ* (Birds); the highest type; a very strong and free articulation, especially adapted to motion in a vertical plane, and mainly due originally to its predominance.

HABITS OF ICHTHYORNIS.

In considering the mode of life and habits of *Ichthyornis*, many important suggestions may be derived from its structure, as well as from the localities where the remains are found. The sharp-cutting teeth of *Ichthyornis* prove, beyond a doubt, that it was carnivorous; its great powers of flight, long jaws, and its recurved teeth suggest, moreover, that it captured its prey alive. Its food was probably fishes, as their remains are found in great abundance mingled with those of *Ichthyornis*. These fossils occur in the bed of the old Cretaceous ocean in which *Hesperornis* swam. Both of these Birds were clearly aquatic in habit, as shown by various points in their structure, already described, and the conditions under which their remains were deposited. In many respects *Ichthyornis* probably resembled the modern Terns in its mode of life. The powerful wings and small feet suggest similar habits in flight and rest. That *Ichthyornis* was provided with feathers is proved beyond question by the tubercles for the attachment of quills on the forearm.

Beside *Ichthyornis* and its allies, the only other denizens of the air at present known to have then inhabited the same region were the toothless Pterodactyles. *Ichthyornis* doubtless competed with these huge dragons for the fishes in the tropical ocean, about which they lived.

CONCLUSION.

Having now described the more important characters in the structure, so far as known, of the two groups of Cretaceous *Odontornithes*, or Birds with teeth, it remains to consider what relation these birds bear to each other, and to allied members of the class; and, also, to inquire if the facts presented throw any light on the profounder question as to the origin of Birds.

In comparing *Hesperornis* and *Ichthyornis*, as the types of their respective orders, the *Odontolcæ* and *Odontotormæ*, the contrast in their principal characters is as striking as it is unexpected. *Hesperornis* had teeth implanted in a continuous groove, a low, generalized character; with, however, the strongly differentiated saddle-shaped vertebræ. *Ichthyornis*, on the other hand, had the primitive biconcave vertebræ, and yet the highly specialized feature of teeth in distinct sockets. Better examples than these could hardly be found to illustrate one fact brought out by modern science, that an animal may obtain great development in one set of characters, and at the same time retain other low features of the ancestral type. This is a fundamental principle of evolution.

The more superficial characters of the absence of wings and the strong swimming legs and feet of *Hesperornis* are in striking contrast, also, with the powerful wings and diminutive legs and feet of *Ichthyornis*. These and other characters already mentioned separate the two Birds so widely that a more detailed comparison seems here unnecessary.

COMPARISON WITH ARCHÆOPTERYX.

It would be highly desirable to carefully compare both *Ichthyornis* and *Hesperornis* with *Archæopteryx*, the still older Mesozoic Bird. This unfortunately cannot be done at present, as the two skeletons of *Archæopteryx*, now known, have not yet been fully described, nor even prepared for examination by removal of the matrix. That *Archæopteryx* belongs to the *Odontornithes*, the writer fully satisfied himself by a personal examination of the well-known specimen in the British Museum. This examination was made in 1878, several years after the writer had become familiar with the American forms of toothed Birds. The teeth seen on the same slab with this specimen of *Archæopteryx*, and referred to it by Evans, although imperfectly preserved, agree so closely with the teeth of *Hesperornis* that the writer identified them at once as those of Birds, and not of Fishes.

During his investigation of *Archæopteryx* last year,* the writer

*See *Jurassic Birds and their Allies;* a paper read before the British Association for the Advancement of Science, at York, September 2, 1881. American Journal of Science, vol. xxii, pp. 337–340, November, 1881.

examined with some care the three known specimens, and observed several characters of importance not previously determined, the more noteworthy of which are as follows:

1. The presence of true teeth, in position, in the skull.
2. Vertebræ biconcave.
3. A well-ossified, broad sternum.
4. Three digits only in the manus, all with claws.
5. Pelvic bones separate.
6. The distal end of fibula in front of tibia.
7. Metatarsals separate, or imperfectly united.

FIG. 33.

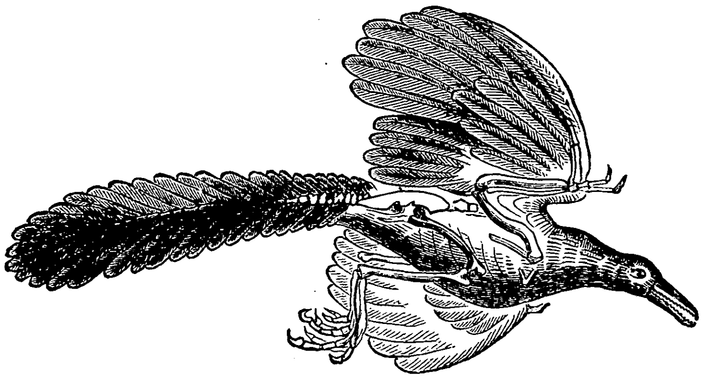

FIG. 33.—*Archæopteryx macrura*, Owen (restored).

These characters, taken in connection with the free metacarpals and long tail, previously described, show clearly that we have in *Archæopteryx* a most remarkable form, which, if a Bird, is certainly the most reptilian of Birds.

If now we examine these characters in detail, their importance will be apparent.

The teeth actually in position in the skull appear to be in the premaxillary. The form of the teeth, both crown and root, is very similar to the teeth of *Hesperornis*. The fact that some teeth are scattered about near the jaw would suggest that they were implanted in a groove. No teeth are known from the lower jaw, but they were probably present.

The presacral vertebræ are all, or nearly all, biconcave, resembling those of *Ichthyornis* in general form, but without the large lateral foramina. There appear to be twenty-one presacral vertebræ, and the same, or nearly the same, number of caudals. The sacral vertebræ are fewer in number than in any known Bird, those united together not exceeding five, and probably less.

The scapular arch strongly resembles that of modern Birds. The articulation of the scapula and coracoid, and the latter with the sternum is characteristic; and the furculum is distinctly avian. The sternum is a single broad plate, well ossified. It probably supported a keel, but this is not exposed in the known specimens.

In the wing itself, the main interest centers in the manus and its free metacarpals. In form and position these three bones are just what may be seen in some young birds of to-day. This is an important point, as it has been claimed that the hand of *Archæopteryx* is not at all avian, but reptilian. The bones of the Reptile are indeed there, but they have already received the stamp of the Bird.

One of the most interesting points determined during the writer's investigation of *Archæopteryx* was the separate condition of the pelvic bones. In all other known adult Birds, recent and extinct, the three pelvic elements, ilium, ischium, and pubis, are firmly ankylosed. In young Birds, these bones are separate, and in all known Dinosaurian Reptiles they are also distinct, as shown in figure 16.

In Birds, the fibula is usually incomplete below, but it may be co-ossified with the side of the tibia. In the typical Dinosaurs, *Iguanodon*, for example, the fibula, at its distal end, stands in front of the tibia, and this is exactly its position in *Archæopteryx*, an interesting point not before seen in Birds.

The metatarsal bones of *Archæopteryx* show, on the outer face at least, deep grooves between the three elements, which imply that the latter are distinct, or unite late together. The free metacarpal and separate pelvic bones would also suggest distinct metatarsals, although they naturally would be placed closely together, so as to appear connate.

Among other points of interest in *Archæopteryx* may be mentioned the brain-cast, which shows that the brain, although comparatively small, was like that of a Bird, and not that of a Dinosaurian Reptile. It resembles in form the brain-cast of *Laopteryx*. The brain of both these Birds appears to have been of a somewhat higher grade than that of *Hesperornis*, but this may have been due to the fact that the latter was an aquatic form, while the Jurassic species were land Birds.

The other Mesozoic Birds now known from the deposits of this country, and the few discovered in Europe, may, some or all of them, have had teeth, but their remains are too fragmentary to determine this point, or even their near affinities.

It is an interesting fact that the Cretaceous Birds at present known, some twenty species or more, were all apparently aquatic forms, which of course are most likely to be preserved in marine deposits, while the Jurassic *Archæopteryx* was a land Bird.

The Birds found in more recent formations all belong apparently to modern types, and hence present few points for profitable comparison with the *Odontornithes*. The existing Birds with reptilian characters are nearly all confined to the *Ratitæ*, or Ostrich tribe. These are evidently the remnants of a very numerous group, once widely extended over different parts of the earth; and it is to the fossil forms of these Birds that we must look eventually for the intermediate types between them and the less specialized Mesozoic Birds.

CLASSIFICATION.

For the present at least it seems advisable to regard the *Odontornithes* as a subclass, and to separate them into three orders, according to the characters given below. These orders are all well marked, but evidently are not of equal rank. *Archæopteryx* is clearly separated much more widely from both *Ichthyornis* and *Hesperornis* than are those two genera from each other. The free metacarpals and metatarsals of *Archæopteryx* are significant characters. Gegenbaur and Morse have shown, however, that young Birds of existing species have these bones separate, and this is true for all Birds up to a certain age. Hence this character is of less importance than the presence of true teeth, since in no recent Birds, young or old, have these been found. The length of tail is perhaps a character of more value, but even this is a variable feature in modern Birds. The separate pelvic bones are known only in *Archæopteryx*.

Subclass ODONTORNITHES (or AVES DENTATÆ), Marsh.

Order ODONTOLCÆ, Marsh.	ODONTOTORMÆ, Marsh.	SAURURÆ, Haeckel.
Genus *Hesperornis*, Marsh.	*Ichthyornis*, Marsh.	*Archæopteryx*, von Meyer.
Teeth in grooves.	Teeth in sockets.	Teeth in ——— ?
Lower jaws separate.	Lower jaws separate.	Lower jaws ——— ?
Vertebræ saddle-shaped.	Vertebræ biconcave.	Vertebræ biconcave.
Wings rudimentary.	Wings large.	Wings small.
Metacarpals wanting.	Metacarpals ankylosed.	Metacarpals separate.
Sternum without keel.	Sternum with keel.	Sternum with keel?
Metatarsals ankylosed.	Metatarsals ankylosed.	Metatarsals separate.
Pelvic bones ankylosed.	Pelvic bones ankylosed.	Pelvic bones separate.
Tail short.	Tail short.	Tail longer than body.

That the three oldest known Birds should differ so widely from each other points unmistakably to a great antiquity for the class. *Archæopteryx*, *Hesperornis*, and *Ichthyornis* are all true Birds; but the reptilian characters they possess are convergent toward a more generalized type. No Triassic Birds are known, and hence we have no light on this stage of the development of the class. They will doubtless be found, however, and, if we may judge from Jurassic Mammals and Reptiles, the next classes above and below Birds, the avian forms of that period would still be Birds, although with even stronger reptilian features. For the primal forms of the Bird-type, we must evidently look to the Palæozoic; and in the rich land fauna of our American Permian we may yet hope to find the remains of both Birds and Mammals.

ORIGIN OF BIRDS.

The genera *Archæopteryx*, *Hesperornis*, and *Ichthyornis*, each possessed certain generalized characters not shared by the others. These characters were undoubtedly united in some earlier form, and this fact gives us a hint as to what the more primitive Birds must have been, and suggests the prominent features of the ancestral type.

In the generalized form to which we must look back for the ancestral type of the class of Birds, we should therefore expect to find the following characters:

(1.) Teeth in grooves.
(2.) Vertebræ biconcave.
(3.) Metacarpal and carpal bones free.
(4.) Sternum without a keel.
(5.) Sacrum composed of two vertebræ.
(6.) Bones of the pelvis separate.
(7.) Tail longer than the body.
(8.) Metatarsal and tarsal bones free.
(9.) Four or more toes, directed forward.
(10.) Feathers rudimentary or imperfect.

These various characters may indeed have been combined in an animal that was more Reptile than Bird; but such a form would be on the road toward the Birds, rather than on the ancestral line of either Dinosaurs or Pterodactyles, as feathers were not a character of these groups. With this exception, all of the characters named belong to the generalized Sauropsid, from which both Birds and the known Dinosaurs may well have descended. An essential character in this ancestral type would be a free quadrate bone, since this is a universal feature in Birds, and only partially retained in the Dinosaurs now known.

The Birds would appear to have branched off by a single stem, which gradually lost its reptilian characters as it assumed the ornithic type, and in the existing *Ratitæ* we have the survivors of this direct line. The lineal descendants of this primal stock doubtless early attained feathers and warm blood, but, as already shown, never acquired the power of flight. The volant birds doubtless separated early from the main avian stem, probably in the Triassic, since, in the formation above, we have *Archæopteryx*, with imperfect powers of flight.

POWER OF FLIGHT.

This power of flight probably originated among the small arboreal forms of reptilian birds. How this may have commenced, we have an indication in the flight of *Galeopithecus*, the Flying Squirrels (*Pteromys*), the Flying Lizard (*Draco*), and in the Flying Tree-frog (*Rhacophorus*). In the early arboreal Birds, which jumped from branch to branch, even rudimentary feathers on the fore limbs would be an advantage, as they would tend to lengthen a downward leap, or break the force of a fall. As the feathers increased, the body would become warmer, and the blood more active. With still more feathers, would come increased power of flight, as we see in young Birds of to-day. A greater activity would result in a more perfect circulation. A true Bird would doubtless require warm blood, but would not necessarily be hot-blooded, like the Birds now living.

The short wings and clumsy tail of *Archæopteryx* were quite sufficient for short flights from tree to tree, and, if the body were partially naked, as some have supposed, we have in this Jurassic form an interesting stage in the development of Birds before full plumage was attained.

Whether *Archæopteryx* and *Laopteryx* were on the true Carinate line cannot at present be determined, and this is also true of *Ichthyornis;* but the biconcave vertebræ of the latter evidently suggest that this form was an early offshoot. It is probable that *Hesperornis* came off from the main Struthious stem, and has left no descendants.

These four ancient Birds, so widely different from each other, and from all modern Birds, prove beyond question the marvelous diversity of the avian type in Mesozoic time; and also give promise of a rich reward to the explorer who successfully works out the life-history of allied forms, recorded in ages more remote.

THE COPPER-BEARING ROCKS

OF

LAKE SUPERIOR.

BY

ROLAND DUER IRVING.

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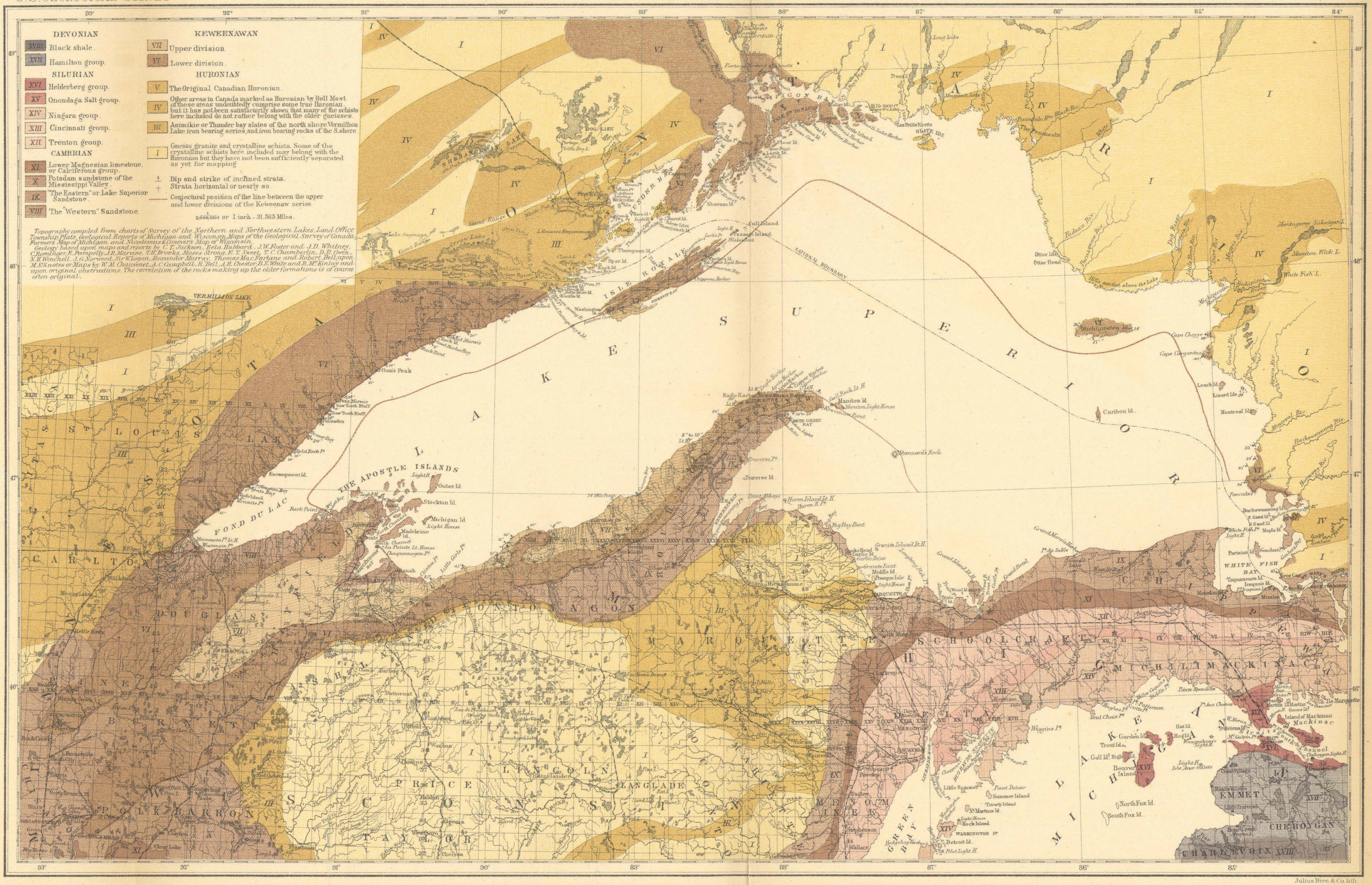

GEOLOGICAL MAP OF THE LAKE SUPERIOR BASIN.

THE COPPER-BEARING ROCKS OF LAKE SUPERIOR.

BY R. D. IRVING.

CHAPTER I.

INTRODUCTORY.

The memoir from which the following pages are abstracted forms Vol. V of the monographic series of reports of the Survey. It aims at a general exposition of the nature, structure, and extent of the series of rocks in which occurs the well-known native copper of Lake Superior.

This is a work which has never been attempted before; nor could it have been accomplished sooner. A number of geologists have written on different portions of the Lake Superior basin during the past fifty years, but until very recently any attempt to compile a general account of the copper-bearing rocks would have met with some insuperable obstacles. Not to speak of the difficulties to be encountered in trying to reconcile the conflicting statements of different authors, any one making the attempt would have met the two serious obstacles of nearly complete ignorance as to the nature of the crystalline rocks which form so large a part of the series, and complete ignorance as to distribution and structural relations of the formations of the western end of the Lake Superior basin, both on the Minnesota and the Wisconsin side. The first of these obstacles was in part removed by the microscopic studies of Professor Pumpelly, whose conclusions as to the nature of the Keweenaw Point rocks were published in 1878.[1] The second was also in part removed by the investigations of the Wisconsin Geological Survey, whose results as to that portion of Wisconsin which borders on Lake Superior were first published in 1880.[2] There still remained unknown, however, a wide extent of the series in Minnesota—a most important omission, since in this region only is it possible to connect the rocks of the south and north shores. The rocks of the southern range of Keweenaw Point were also still but very vaguely known, and the structure of the Porcupine Mountains had never yet been made out.

[1] "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior." Proc. Am. Acad., 1878, XIII, 253-309.

[2] R. D. Irving, R. Pumpelly, E. T. Sweet, T. C. Chamberlin, and M. Strong, in the Geology of Wisconsin, Vol. III.

It thus became necessary for any one attempting to present anything like a general account of the series to cover these gaps, and extend the microscopic investigations begun by Professor Pumpelly, so far as possible, over the whole extent of the series. It was also necessary that he should familiarize himself as much as possible with those districts, which had already been more or less thoroughly worked up, by studying the descriptions of others on the ground.

This work I undertook to accomplish during the months between July, 1880, and March, 1882, under the combined auspices of the United States Census Office, and the United States Geological Survey, the field work being of necessity confined to the season of 1880. The memoir of which this is an abstract is the result of this work.

In the following pages those chapters of the original memoir containing the more general matter are in several instances reproduced almost entire, but other chapters, and especially those containing local descriptions, can only be very briefly quoted from, or barely alluded to.

In this chapter in the original memoir I have attempted to show briefly the condition of our knowledge of the copper-bearing rocks—which have also been somewhat variously known as the Cupriferous, Keweenian, Keweenawian, Keweenawan, or Nipigon rocks—previously to my own work; to give a rapid *resumé* of the different views which have been and are held as to the relations and origin of these rocks; to give as complete a list as possible of all publications with regard to them; to show the extent of my own observations; and to explain just how far I am indebted to previous publications, and to other observers, and how far to my own independent investigations, for the facts incorporated in the memir. These are all points whose consideration may be conveniently omitted from an abstract, to make room for matter of more general interest.

CHAPTER II.

EXTENT AND GENERAL NATURE OF THE KEWEENAW SERIES.

The series of rocks under consideration is almost entirely restricted to the Lake Superior basin, whose limits it passes only at the southwest, where there is an extension for a short distance into the valley of the Upper Mississippi. The bottom of the lake itself is for most of its extent composed of these rocks, as are also the immediate shores for a great part of the lake's circumference. In much of its course around the lake basin this group does not reach many miles inland, in some places occupying only projecting headlands, the older rocks forming the intervening shores. Towards the west end of the lake, however, in the stretch across the State of Wisconsin, there is a very wide surface spread, the area in Wisconsin alone being about five thousand square miles.

To convey a more definite idea of their distribution in the circuit about Lake Superior it may be said that, besides underlying the greater part of the lake, the Keweenawan rocks form the larger part of Keweenaw Point, probably also underlying the horizontal sandstone of the remainder; constitute the Michigan shore from Keweenaw Point to the Montreal River, extending back into the country 8 to 20 miles; in all probability underlie the sandstone country still farther away from the lake, since they appear again in a few places on its southern edge, which would carry them inland from the Michigan shore as much as 30 to 35 miles; underlie all of northern Wisconsin north of a line from the Montreal River at a point 15 miles from Lake Superior to Numakagon Lake, and thence to Saint Croix Falls, on the west boundary of the State; stretch in Minnesota over two-thirds of the triangular area included between the State boundary, the Saint Croix River, and the Saint Paul and Duluth Railway; constitute the entire Minnesota shore of the lake, from Duluth to Grand Portage Bay, running back into the interior about midway in the coast as much as 30 miles; make up the outer ones of the Lucille group of islands off Pigeon Point, and the whole of Isle Royale; form the entire peninsula between Black and Nipigon bays, with all outlying islands, and also the whole group of islands, large and small, south of Nipigon Bay; spread over a very wide area in the valleys of Black-Sturgeon and Nipigon rivers, north of Lake Superior; after a long interval, during which older rocks only appear on the coast, come up again in Michipicoten Island, which they entirely compose; appear again on the east coast of the lake at Cape

Choyye, Cape Gargantua, Pointe aux Mines, Mamainse, Batchewanung Bay, and Gros Cap, at nearly all of which places they form mere edgings between the lake and the older rocks, the only exception being at Mamainse, where a great thickness is exposed; and, finally, constitute the isolated reef between Keweenaw Point and Marquette, known as Stanard's Rock. Between Gros Cap and Stanard's Rock the rocks of this series do not appear; but there can be little doubt that they are continuous underneath the lake, and underneath the newer horizontal beds of the eastern part of the upper peninsula of Michigan.

The total area of the lake, exclusive of all the larger islands, but inclusive of all bays, is about 30,880 square miles. Deducting from the last figure 2,500 square miles for lake area underlaid by older rocks in the extreme northeast, in Thunder, Black and Nipigon bays, and again between Keweenaw Bay and Marquette, we obtain 28,380 square miles as the approximate total extent of the group under the waters of Lake Superior.

To obtain the whole geographical extent we must add to the last figure as follows: For Michigan, in the area between Point Keweenaw and the Montreal River (the "Main Trap Range," and Porcupine Mountain region), 1,744 square miles; for the area of horizontal sandstone south of the main range of Michigan, and west of the head of Keweenaw Bay, which area is undoubtedly underlaid by rocks of this group, 1,400 square miles; for Wisconsin, including the area in the immediate vicinity of Lake Superior, and again on the Saint Croix River, where the Keweenawan rocks are covered with horizonal sandstone, about 5,000 square miles; for Minnesota south of the Saint Louis, including portions buried beneath horizontal sandstone, 1,000 square miles; for Minnesota north of Lake Superior, about 3,200 square miles; for Isle Royale, 210 square miles; for Isle Saint Ignace and adjoining islands, 180 square miles; for Michipicoten Island 75 square miles; and for small areas along the east shore between Cape Gargantua and the Sault, 90 square miles. These rocks are also undoubtedly buried beneath the horizontal formations of the south shore of the lake west of the Sault, but not to any very great extent. So that we may be safe in placing the entire geographical extent of the series at 41,000 square miles for the immediate basin of Lake Superior. This is exclusive of an extension northward of some of the lower beds into the basin of Lake Nipigon through the valleys of Black-Sturgeon and Nipigon rivers. The thickness of this extension, judging from Bell's description,[1] is inconsiderable, the rocks being often nearly horizontal. In the valleys of Black-Sturgeon and Nipigon rivers they appear to form strips between older rocks on either side, but in the Nipigon lake basin to have a wider extent; Bell's map makes the total area in this basin as much as 5,000 square miles.

Throughout all of this wide extent, though local peculiarities are to be noted, the general characteristics of the group are wonderfully con-

[1] Reports of Geological Survey of Canada; 1866–'69; 1872–'73.

stant. The predominant rocks belong to the basic crystalline class. They are, as a rule, in distinct, but for the most part heavy layers, their bedded structure being due, as I believe, to their having been spread out as successive molten flows. These basic rocks belong wholly to the augite-plagioclase family, hornblende occurring only very rarely, and then always as an alteration-product Pumpelly has heretofore recognized the three types of diabase, melaphyr and gabbro as characterizing the Keweenaw point district; and after a study in the field of the entire north shore, and the examination of large numbers of specimens from all portions of the Lake Superior basin, I am able, though having discovered a number of interesting new varieties, to add only two kinds deserving of distinct names, viz: diabase-porphyrite and anorthite-rock; and these are, after all, so closely allied to the others as to be hardly more than varieties. Indeed, the three kinds first named grade into each other in the field, and are themselves merely phases of an ancient class of rocks for which science has as yet established no common name, but which are the old equivalents of the post-Cretaceous basalts.

The diabase is a plagioclase-augite rock, with or without olivine, and unindividualized base; the melaphyr carries more or less of this base with olivine, and is, throughout the Lake Superior region, everywhere characterized by the presence of relatively large areas of augite, including numbers of minute plagoiclases; while the gabbro has part or all of the augitic ingredient as diallage, is orthoclase-bearing or not, and is either olivine-bearing or not. The diabase-porphyrite is an olivine-free diabase, with a strong porphyritic development, and a more or less thoroughly unindividualized base; and the anorthite rock is merely a coarse gabbro in which all ingredients but the feldspar are wanting. The nomenclature adopted for these rocks is Rosenbusch's. There are numbers of peculiar phases of the three kinds named, due to amygdaloidal and compact conditions, relative abundance of the several ingredients, coarseness of grain, the presence of unusual constituents, and especially to internal molecular rearrangements. But the same types constantly recur in the circuit of the lake, and there are only one or two subordinate varieties which have not been seen again and again, and at points widely removed from each other. Some arrangement of the kinds as to horizon is also to be observed. One of the most interesting results of my work is the finding of gradation phases not only between all the kinds named, but from the most basic kinds, with less than 46 per cent. of silica, to the most acid of the acid varieties subsequently mentioned.

Interstratified with these basic crystalline rocks, at many different horizons, but generally greatly more abundant above, are detrital beds, chiefly reddish conglomerate and sandstone. The conglomerates are for the most part made up of pebbles of one or more of three kinds of acid rocks, viz: (1) a red to brown or purple felsite, nearly or quite without either quartz or orthoclase as porphyritic ingredients; (2) a true quartziferous porphyry, usually brick-red in color; (3) a non-quartziferous porphyry with bright-red, striated, feldspar crystals; and (4) fine-grained to coarse-grained granitic porphyry and augite-syenite, of which the several phases verge towards quartziferous porphyry or quartzless porphyry on the one hand, and granite or an orthoclase-bearing gabbro on the other. The first two kinds are commonly without structural lines, but occasionally show faint and wavy bandings. One or two of these kinds will be found to predominate greatly among the pebbles at any one place, the same conglomerate belt showing at different points along its course great differences in this respect.

Pebbles of the basic rocks also occur in the porphyry conglomerates, but they are relatively very rare. Pebbles of altogether different rocks are occasionally seen, as, for instance, on the peninsula of Mamainse on the east coast, where granitic and gneissic pebbles are abundant. The matrix of these conglomerates appears to be of the same material as the pebbles themselves, and in the coarser kinds can easily be seen to be so. It is frequently permeated by calcite, which at times has completely replaced the matrix, yielding a striking combination of red and brown pebbles, with a background of pure-white, cleavable calcite.

An altogether different conglomerate from those just described, and one of much more restricted distribution, has a red, shaly matrix, often finely laminated, in which the pebbles are wholly of the common diabase and diabase-amygdaloid. Of these conglomerates there seem to be again two kinds—one in which the pebbles are distinctly waterworn, and another in which there are no such distinct evidences of water action, and in which the vesicular exteriors of the balls suggest their origin as volcanic scoriæ that have become buried in the accumulating detritus. The first of these varieties has been noted on the north, or Minnesota, shore only; the other has been observed on both the south and north shores, and is often hard to distinguish from a kind in which the red, shaly material is most confusedly mingled with the vesicular amygdaloidal diabase, which at times seems to grade into the detrital matrix, and again to be separated from it in more or less distinctly defined balls—an appearance suggesting the deposition of detrital material upon and within the extremely scoriaceous upper portion of a lava flow.

Sandstones make up much the greater portion of the detrital members of the series, reddish sandstones prevailing. These run from earthy and shaly to coarsely granular, but are always aluminous from the presence of a more or less decomposed feldspathic constituent. They vary from brick-red to quite dark-red in color, and are made up in large measure of the detritus of the same acid rocks that have supplied the pebbles of the conglomerates, as was first shown by Pumpelly. In the darker kinds more or less basaltic detritus is contained. Quartz is never an exclusive, and not often a very prominent, ingredient in any of the sandstones belonging to this group. Many of the sandstones are highly charged with secondary calcite. Those kinds of sandstones which are dark-gray to nearly black in color are made up of basic detritus, usually mingled with more or less of the common porphyry detritus, and cemented by secondary calcite. These sandstones often contain only a few grains of quartz, having then not over 50 per cent. of silica. They grade into finer varieties, which at times pass into an earthy black shale or slate. These gray sandstones and accompanying black shales, with a thickness of several hundred feet, have been recognized in a single belt running from the neighborhood of the Gratiot River, on Keweenaw Point, to Bad River, in Wisconsin, a total distance of 150 miles.

The source of the materials of which the porphyry conglomerates and red sandstones are made up has been a matter of speculation to all writers on Lake Superior geology. Foster and Whitney supposed them to come from the friction of the ascending igneous rocks against the rocks penetrated,[1] but they ignored the totally different natures of the porphyry of the pebbles and of the diabase forming the greater part of the series. Besides, it has long been plain that the pebbles of these conglomerates are simply water-worn fragments of some massive acid rocks, which could never have been far removed from where the pebbles now are. It has been supposed by some that the original massive rocks were to be looked for in the older so-called Huronian, although whereever this Huronian is exposed in the Lake Superior country such acid rocks are noticeably wanting.

I find the source of the pebbles in the massive acid rocks of the series itself, and recognize now, for the first time, that these original acid rocks are a prominent feature of the Keweenaw Series, which they characterize throughout its entire extent, although always greatly subordinated in quantity to the basic kinds.[2] I find it even possible to trace some of the pebbles of the conglomerate to their immediate sources. It is well

[1] *Op. cit.*, p. 99.

[2] Foster and Whitney (Report on the Lake Superior Land District, Vol. I, pp. 65 and 70) speak of "quartzose porphyry" and "jasper" as occurring at Mount Houghton on Keweenaw Point, and in the Porcupine Mountains, but they do not seem to have appreciated the true nature of these rocks, which, moreover, they regarded as merely alterations of the red sandstones by the heat of the intrusive rocks. Macfarlane distinctly recognizes the existence of true quartzose porphyry, "trachyte," and "phonolite," on Michipicoten Island (Report of the Geological Survey of Canada for 1866, pp. 137–143), but he does not appear to have realized the importance of his observation.

Hunt has recently spoken of a true quartzose poryphyry as occurring on a small island near Saint Ignace Island, on the north shore, but he appears to regard this as Huronian, though it is undoubtedly merely one of the numerous instances of the occurrence of this rock within the Keweenaw Series. In my work in the Bad River country of northern Wisconsin, in the years from 1873 to 1877, I had recognized true granites cutting gabbro at the base of the Keweenaw Series, and also noted and mapped two or more belts of apparently massive quartzose porphyry and felsite; but these latter were so poorly exposed—the deceptively massive appearance of some of the conglomerates being well known to me—that I only provisionally announced the existence of massive acid rocks in my published results. (Vol. III, Geology of Wisconsin, pp. 11 and 193–198.)

known that the same belt of conglomerate will vary in its predominant pebbles in different portions of its longitudinal extent, while several conglomerates in one section will often show the same characteristic pebbles; facts which are to be explained by the difference in the original rocks at different points along the trend of the formation, and the derivation of the pebbles of the several conglomerates of one section from a common source. Thus the Portage Lake conglomerates all carry a great predominance of non-quartziferous porphyry pebbles, while further northeast a granite-porphyry or augite-syenite becomes very abundant, and still further, in the region of the Calumet mines, a true quartz-porphyry prevails. In the latter case the source was a quartz-porphyry mass to the southeast, of which small exposures are still to be seen. In the Eagle River conglomerate again a common pebble is composed of quartzless porphyry, much like the rock exposed at the old Suffolk mining location, a few miles to the south.

These original acid rocks embrace all of the kinds included as pebbles in the conglomerates, viz: true quartzose porphyries, with large doubly-terminated quartzes and orthoclases as porphyritic ingredients; a non-quartziferous porphyry; compact felsites; granitic porphyry and augite-syenite, and true granite. Most of these rocks are of some sort of reddish hue, running from a pale pink to a bright brick-red, whence, in a large measure, the red colors of the conglomerates and sandstones derived from them.

In recapitulation, then, it is to be said that the Keweenaw Series consists of eruptive flows and bedded detrital rocks interstratified with one another, the eruptive rocks occurring also, subordinately, in the form of dikes.

These eruptive rocks include basic, intermediate, and acid kinds, as is commonly the case with volcanic regions of more modern activity; but there is no such chronological relation between these three kinds as is so often found to be the rule in Tertiary and post-Tertiary volcanic regions.

An extraordinary thing is the complete absence of anything like volcanic-ash from the series. This is another point of difference between it and the rocks of regions of more recent volcanic activity, and one which goes far to support the view that the eruptive rocks of this region have come through open fissures, and not after the manner of the volcanic flows of the present day.

The detrital rocks are all made up of water-derived fragments, worn for the most part from the acid rocks of the series itself. Such viscous materials as these acid rocks must have been when molten would naturally solidify into bulky, more or less erect, masses of relatively small lateral extent. Arranged as they were around the rim of a basin whose middle portion was constantly depressing, each one of these masses was able to contribute to the making of a number of layers of sandstone and conglomerate.

OLIVINE-GABBROS

Julius Bien & Co. lith.

CHAPTER III.

LITHOLOGY OF THE KEWEENAW SERIES.

The natural grouping of all of the rocks of the Keweenaw Series, into the three classes of basic eruptive, acid eruptive, and detrital rocks, has already been indicated. In the original memoir this chapter includes detailed accounts of each prominent variety, along with the tabulated results of microscopic observations.

BASIC ERUPTIVE ROCKS OF THE KEWEENAW SERIES.

I. *Coarse-grained:*

1. Gabbro and diabase; olivine-gabbro and olivine-diabase; all free from orthoclase.
2. Orthoclase-bearing gabbro.
3. Hornblende-gabbro.
4. Anorthite-rock.

II. *Fine-grained:*

5. Diabase of the "ordinary type."
6. Olivinitic fine-grained diabase, and melaphyr.
7. Ashbed-diabase and diabase-porphyrite.
8. Amygdaloids (vesicular diabase and melaphyr).

Pumpelly first showed, in 1878, the true nature of the prevalent basic rocks of the copper region of Michigan.[1] Subsequently (1880) the same geologist extended his researches to a suite of rocks collected in northern Wisconsin by the Wisconsin State Geological Survey.[2] The investigation thus begun by Pumpelly I have extended for this memoir over nearly the whole extent of the Keweenaw Series. So far as the amygdaloids are concerned, and the peculiar metasomatic changes to which the amygdaloids and many fine-grained diabases are prone, I have accomplished little beyond extending the area to which his conclusions are applicable. The chief additions that I have been able to make are with regard to the non-amygdaloidal and less altered kinds.

The classification given above of the basic original rocks of the Keweenaw Series is based not only on microscopic differences and resemblances, but also upon the characters and relations of the several kinds as seen in the mass, and on their prominence and persistence in the field. For

[1] Proc. Am. Acad. Arts and Sciences, Vol. VIII, pp. 253–309.

[2] Geology of Wisconsin, Vol. III, pp. 27–49.

instance, the first group given is made to include olivine-diabase,[1] orthoclase-free gabbro, and olivine-gabbro; because all of these in the hand specimens bear the closest resemblance to each other, and in the field are seen to constitute parts of the same continuous mass or bed, forming together one of the most prominent types. The distinction between diallage and augite is a valueless one, since not only are both often found in the same section, but every gradation is found in the rocks of this class from augite to diallage.

It will be seen at once that all of the kinds named are very closely related. Except one extreme phase, the anorthite-rock, they are all plagioclase-augite rocks—the diallage being but a phase of ordinary augite—and all carry magnetic or titanic iron, while olivine is a common ingredient. The differences consist only in variations in coarseness of grain, relative amounts of the several ingredients, presence or absence of olivine, presence or absence of unresolvable base, presence or absence of orthoclase, variations produced by metasomatic changes and variations in texture from granular to vesicular (amygdaloids). All of the kinds, though distinct enough in the field, are in fact, lithologically considered, but phases of one kind of rock, for which usage has not established any common name. They are the ancient equivalents of the Tertiary and Recent basalts.

Orthoclase-free diabase, olivine-diabase, gabbro and olivine-gabbro.—The rocks included here have a prevailing very dark-gray, often black, shade; more rarely they are light-gray, when the plagioclastic ingredient becomes greatly predominant, as is apt to be the case in the coarsest kinds. Not uncommonly a resinous hue is produced by the presence of a brownish film of ferric oxide over the shining black augite. The texture is a highly crystalline one, causing a very rough-surfaced fracture. The several primary ingredients, except olivine, can nearly always be recognized with a lens, in the coarser kinds with the naked eye. The specific gravity ranges from 2.8 to 3.1.

The olivine, which is a common but not constant ingredient of these rocks, is, when present, always the oldest of the chief constituents.

[1] The terms "diabase," "melaphyr," "gabbro," &c., are here applied in accordance with the usage of H. Rosenbusch (Microscopische Physiographie der Massigen Gesteine, Stuttgart, 1877, pp. 317-458), who has classed the pre-Tertiary plagioclase-augite rocks as indicated in the following scheme:

I. GRANULAR:
- *a.* Plagioclase-augite=*diabase.*
- *b.* Plagioclase-augite-olivine=*olivine-diabase.*

II. PORPHYRITIC, containing more or less of an insoluble base.
- *a.* Plagioclase-augite=*diabase-porphyrite.*
- *b.* Plagioclase-augite-chrysolite=*melaphyr.*

III. GLASSY: Known only as subordinate vitreous modifications of diabase-porphyrite not deserving a special name.

IV. GRANULAR PLAGIOCLASE-DIALLAGE ROCKS.
- *a.* Plagioclase-diallage=*gabbro.*
- *b.* Plagioclase-diallage olivine=*olivine-gabbro.*

Occasionally, in the fresher rocks, it may be detected in the hand specimen with the lens, while in a few instances it has been observed of a size so large as to attract the unaided eye. As seen under the microscope, the olivine occurs nearly always in irregularly outlined, rounded particles, which run from a fraction of a millimeter to two or three millimeters in length. Only very rarely does it present crystalline outlines. Commonly it is in large measure still fresh, but only very rarely is so completely so as to be without some traversing rifts, edged with a greenish-brown or brownish-yellow alteration-product. In not a few cases this brown alteration has affected the whole area. In other cases, again, the iron oxide, instead of being deposited about and within the olivine, has been leached out, and then the mineral is more or less completely represented by a greenish material supposed to be serpentine. This greenish alteration has at times been accompanied by the production of a secondary magnetite.

Next to the olivine in order of age is the plagioclase. Its crystals are usually in elongated forms, from less than one-sixteenth of an inch to two or three inches in length. The outlines of these crystals are commonly linear, or at least partly so, but in some thin sections the mutual interruptions accompanying crystallization are seen to have produced rounded contours. In composition the plagioclase appears to be always near the basic end of the feldspar series, the optical measurements indicating anorthite, or a labradorite verging on anorthite in basicity. The plagioclastic ingredient of these rocks is commonly quite fresh, and always much fresher than the olivine or augite. When alteration occurs, it is usually but a slight cloudiness. The alteration of plagioclase to prehnite, noted by Pumpelly as so common in the fine-grained diabases of Keweenaw Point, is unknown in these more coarsely-grained rocks.

The iron oxide constituent of these rocks appears commonly to stand between the plagioclase and the augitic ingredient in point of time of crystallization, but it is not evident that this has always been the case. In composition this constituent appears to be a slightly titaniferous magnetite. In size, its particles run from a mere dust, as seen with a high power, to areas one-fourth of an inch across. It occurs, as a rule, in very irregularly outlined forms, much more rarely in elongated parallel rods, in which no distinct crystalline outlines can be made out.

The augitic constituent, which varies from augite to highly-fibrous diallage, is invariably of later formation than the olivine and plagioclase, and usually is later than the magnetite also. It includes often the olivine grains, and always has its outlines determined by those of the previously-formed plagioclase. As seen with the naked eye, it is, on a fresh surface, of a lustrous black color. On a weathered surface, however, it presents at times a brilliant brassy, metallic luster. It is often the coarsest ingredient present, its particles at times reaching a width of one or two inches, even when the rest of the rock is not unusually coarse. Very often one crystal will present in the thin section a number of wholly detached areas, which are proved to be parts of one individual by their common cleavage-directions and common optical behavior. In some cases, when the augitic constituent is diallage, and reaches the extraordinarily large sizes above noted, it will include a large number of plagioclase crystals. The body of the rock in these cases is no coarser than usual, nor does the hand specimen present any peculiar appearance until it is held in a certain position, when brilliantly flashing, brassy surfaces are seen, each from half an inch to two inches across, where before seemed to be only the usual promiscuously mingled fine particles. In the thin section the augitic ingredient presents a wine-colored or violet section, varying considerably in depth of tint. It often shows the characteristic prismatic cleavage, but more commonly is traversed by irregular cracks, or is affected in very varying degree by the diallage-cleavage, parallel to the clinodiagonal. It is often quite fresh, but often also has undergone alteration, generally to some sort of soft, green, chloritic substance, which is not unfrequently more or less brown-stained from the peroxidation of the iron of the original augite. More rarely the iron oxide thus produced has taken the form of magnetite. The change of augite to uralite, so characteristic of the orthoclase-gabbros of the Keweenaw Series, is only very rarely seen in rocks of this class, and then with an inconsiderable development.

In only two or three sections out of the forty studied of this class of rocks was any apatite found, and then only in rare and minute crystals.

The rocks of this class present in the field very massive exposures, occurring in very heavy beds, which are often affected by a marked columnar structure, and are never furnished with an upper amygdaloidal or vesicular portion. As typical and easily accessible localities may be mentioned the cliffs of the Minnesota shore, between Sucker and Knife River bays, and the shore of Nipigon Bay, near the mouth of Nipigon River, Ontario, Canada.

Orthoclase-bearing gabbro.—The rocks of this class are less common than those last described, but are nevertheless often met with. They are distinguished from the ordinary gabbros and coarse-grained diabases by the presence of more or less orthoclase-feldspar, and of a plagioclase near oligoclase; by the abundance of coarse-grained apatite, often large enough to be readily seen with a lens or with the naked eye; by the invariable absence of olivine; by the comparatively greater tendency to decomposition of the feldspars, the results of which are a clouding and reddening of the constituents and the introduction of a greater or less amount of secondary quartz; by the greater richness of the magnetite in titanic acid; and by the common presence of a uralitic alteration of the augitic ingredient. So constant is the association in the Keweenaw basic rocks of orthoclase, oligoclase, coarse apatite, secondary quartz and uralitic alteration of augite or diallage, that only in rare cases is one of these found without most of the others.

ORTHOCLASE-GABBRO

Julius Bien & Co. lith.

In coarseness of grain these rocks have about the same range as those of the class last described. The specific gravity is lower—2.7 to 2.8. In the mass the orthoclase gabbros do not present any features different from those of the orthoclase-free kinds, like which they occur chiefly in heavy flows without amygdaloids. They may also occur as intersecting masses, but this needs proof. As typical instances of orthoclase-bearing gabbros may be mentioned the coarse syenite-like rock of the Bohemian Mountain, on the north shore of Lac La Belle, Keweenaw Point, and the coarse, gray rock of the Saint Louis River bluffs at Duluth, Minnesota.

Hornblende-gabbro.—Along a belt of country some 14 to 20 miles in length, running westward from Bad River, Wisconsin, through parts of townships 44 and 45, ranges 3, 4, 5, and 6 west, at a horizon not far above the Huronian Slates, exposures of a peculiar hornblende-gabbro have been noticed. This rock differs from the uralitic gabbros previously described of groups I and II in containing, instead of the fibrous, greenish, comparatively weakly dichroic uralite, a deep-brown, intensely absorptive so-called basaltic hornblende. Some of these rocks have been described briefly by Pumpelly in the third volume of the Geology of Wisconsin,[1] under the name of "augite-diorite." He regarded the hornblende as primary, and the rocks as intermediate between diabase and diorite, whence the name. In the same volume I suggested that the hornblende was secondary, and that the rocks were merely altered gabbros.[2] This opinion I find sustained by a re-examination of Pumpelly's sections, and a study of a number of new sections from other outcrops. The rocks described in the table in the original memoir have been selected to illustrate the different phases of this hornblende-bearing rock. The first one is a rock in which the basaltic hornblende is in small quantity only. The next three contain more hornblende, and are peculiar microscopically, being mottled black, white and pinkish. They also carry a good deal of original quartz. The last two are black rocks in which the hornblende makes up most of the section. Abundance of coarse apatite, presence of a low-angled plagioclase, of orthoclase, and of original quartz seem to be prevailing characteristics.

Anorthite-rock.—At several points on the north or Minnesota shore of Lake Superior, between the mouth of Split Rock River and the great Palisades, and again in the high point near the mouth of Temperane River, known as Carlton's Peak, are to be seen exposures of a very coarse, light-gray to colorless or white rock, occasionally with a faint greenish tinge. This is seen in the thin section to be composed exclusively or nearly so of anorthite feldspar. Often there is no other mineral present except in exceedingly minute inclusions, and these are very sparse. In one section a few grains of altered olivine were noticed within the

[1] P. 36. [2] P. 170.

anorthite, and in two or three a little augite between the feldspar grains. The feldspar appears in every case to be anorthite. In no section did it show the peculiar arrangement of needle-like inclusions met with in European gabbros and so commonly found in the coarse gabbros of Lake Superior, to which these anorthite rocks are very nearly related.

Olivine-free diabase of the "ordinary type."—The diabases here included, which Professor Pumpelly first described as of the "ordinary type," because of their prevalence in the typical region of Keweenaw Point, make up relatively thin flows, which are almost invariably furnished with vesicular or amygdaloidal upper portions. These vesicular portions have always undergone great internal changes, both in connection with the deposition of minerals in the vesicles and in the formation of pseud-amygdules, or minerals replacing primary constituents in such a way as to present macroscopically very much the appearance of the true vesicular fillings. The latter change, with others, has usually affected also the lower non-vesicular portions of the beds in a greater or less degree. So general are the alterations that an account of these rocks has to be taken up more with the internal changes that they have undergone than with the nature and arrangement of the original constituents. In the original memoir I have quoted at length in this connection from Professor Pumpelly's exhaustive studies of these changes. For the most part my own studies of these fine-grained rocks have merely served to extend the geographical range to which Pumpelly's conclusions are applicable.

Externally the different varieties of these diabases "are dark in shade, varying from almost black in unaltered specimens to dark-green or dark-brown, or varying minutely-subdivided mixtures of these colors, according to the relative proportions of chlorite and ferric oxide among the decomposition products. They vary in texture from medium fine-grain to crypto-crystalline, and the fracture from uneven and hackly to conchoidal."[1]

The pseud-amygdaloidal alteration of these rocks is especially characteristic of the middle portions of the beds. The common pseud-amygdules are chlorite, quartz, prehnite and calcite. They vary in size from one-fourth of an inch or more in diameter down to microscopic particles. In the former case the rock is coarsely blotched with the pseud-amygdules, while in the latter case the only effect on the external appearance is some variation of the general shade.

Under the microscope, when not too profoundly altered, the diabase "is seen to have for primary constituents plagioclase, augite, and an opaque black mineral, which may be either magnetite or a titaniferous iron ore.[2] The plagioclase appears from optical measurements to belong near oligoclase in the feldspar series. It appears in tabular polysyn-

[1] R. Pumpelly, in Geology of Wisconsin, Vol. III, p. 31.
[2] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 32

thetic crystals, whose long, narrow sections are scattered confusedly through the section, while the spaces between the crystals are occupied by augite, the augite in each space generally giving the integral polarization which indicates a single individual. In ordinary light, the augite is distinguishable from the plagioclase by its very faint, delicate, violet-gray color, and by its anastomosing cracks. The sharpness with which it fills the interstices between the feldspar crystals shows that it crystallized after them. The magnetite occurs in small grains, rarely with an appearance of crystal outlines."

Almost always, however, the rock has undergone changes to a greater or less degree. The commonly resulting alteration-products are, as Pumpelly has shown, from the augite a green and greenish-brown chloritic substance, often with red-stained cracks; and from the feldspar a true chlorite, antecedent to which has been in many cases a change to prehnite.

These rocks receive their typical development in the mining region of Keweenaw Point, but similar rocks are known throughout the entire extent of the series.

Olivinitic fine-grained diabase, including Pumpelly's melaphyr.—To these rocks, which grade through coarser and coarser kinds into the coarse-grained olivinitic gabbros already described, Pumpelly has given the name of melaphyr, because of the presence in those examined by him from Keweenaw Point of a small amount of altered residuary magma. Precisely the same rocks are, however, found without a residuary base, which is at best but a very unimportant ingredient, so that I have preferred to call them here all by the above general title.

These rocks form a class very strongly marked by external characteristics both in the fresh and altered states. They have commonly undergone great alteration, the amount of change lessening rapidly as the rock becomes coarser. "The Greenstone" of Keweenaw Point, which Pumpelly has selected as a type of the fresh state of the rock, is one of the coarser phases. The following is quoted from Pumpelly's description of these rocks as developed on the South Shore.[1] It applies equally well to the fine-grained olivinitic kinds of the North Shore, where "luster-mottled," fine-grained rocks are very abundant:

In its fresh state it is dark-green or greenish-black, finely crystalline, very compact, hard and brittle, and breaks with an uneven to semi-conchoidal fracture. * * * It is an important characteristic of this rock that its freshly-fractured surface is mainly occupied by spots $\frac{1}{16}$ to $\frac{3}{4}$ of an inch in diameter, each of which reflects the light with a satin-like sheen. * * * Aside from this sheen there is nothing either in difference of color or texture visible to the naked eye to betray the presence of these spots, which might be called luster-mottlings. To the naked eye the phenomenon suggests at once interrupted cleavage of large individuals of one of the constituents as the cause, but under a strong hand-glass these reflecting surfaces show the same granular texture and character as the rest of the rock; and it is only when examined under the microscope, with an objective of low power and in polarized light, that the appearance to

[1] Geology of Wisconsin, Vol III, p. 33.

the unaided eye is corroborated. We here find the cause in the fact that each spot is the cross-fracture or cleavage of a crystal of pyroxene, which, in crystallizing, has inclosed hundreds of feldspar crystals. The weathered surface is a rusty gray, scarcely one-fifth of an inch thick; but it is covered with knobs, which are due to the more rapid destruction of the materials between the pyroxene individuals. Examining these sections under the microscope, we find the constituents to be plagioclase, pyroxene, olivine, and the alteration product of the latter, as well as magnetite, and an unindividualized substance, both fresh and altered, occupying interstices. In thin sections the plagioclase is seen to exist in very sharply-defined, and fresh, thin, tabular crystals, .001 to .002 inch thick, and .01 inch and less long. It contains scattering interpositions of an opaque black substance, and minute brown particles, which may be, or have been, glass. The crystals of plagioclase have predetermined the contours of all the other constituents, except the olivine, which crystallized first. The predominating feldspar is near anorthite. * * * The augite is very fresh and transparent, almost colorless in the thin section, but with a tendency to purple-gray. An imperfect cleavage is indicated by somewhat irregular, parallel fractures. It fills the interstices between the closely-packed individuals of feldspar in such a manner that a single pyroxene crystal incloses many hundreds of these, while its crystalline integrity is shown by the uniform color in polarized light, and by the arrangement of the cleavage cracks throughout the area of the augite individual. It is a remarkable fact that, while these large individuals of pyroxene contain thousands of feldspar crystals, they inclose only very few of olivine or of magnetite. These minerals, together with the unindividualized substances, are crowded into the interstices between the pyroxenes. In this intermediate space, which surrounds the pyroxene individuals with a continuous network, we find, also, a few small pyroxenes, just as isolated grains of olivine occur in the pyroxene areas. A careful examination of this occurrence will, I think, convince the observer that, at the time the pyroxene crystallized, both the olivine and feldspar crystals, and apparently the magnetite, were already individualized; for where we find any of these in contact with the augite, we find that the latter has adapted itself to the already defined contours of the others. While the augite inclosed the feldspar crystals with ease, it crowded the other constituents almost wholly into the surrounding spaces, a process which was facilitated by the presence of the then fluid unindividualized substance. The magnetite is in irregular-shaped bodies, which mold themselves sharply around the contours of the feldspar and olivine. The olivine is abundant in grains and roughly-outlined crystals, but as a rule, however fresh the melaphyr may otherwise be, the olivine is partly or wholly altered.

As with the olivine-free "ordinary type" diabases, so also with the olivinitic kinds, much altered forms are more common than the fresher ones. The space is not available here for the description of these altered forms.

As typical occurrences of these rocks, may be mentioned "The Greenstone" of Keweenaw Point; the rock of the north shore of Bête Grise Bay, Keweenaw Point, S. W. ¼, Sec. 27, T. 58, R. 28 W.; and that of the south point of Agate Bay, on the Minnesota coast. These fine-grained olivinitic rocks are among the most common of the Keweenawan eruptives.

Ashbed-diabase and *diabase-porphyrite*.—The olivine-free fine-grained diabases of the "ordinary type" pass into still finer-grained kinds, in which there is a black or brown color, and a more or less perfectly developed conchoidal fracture. The finest of these rocks are completely aphanitic, and all kinds tend to a porphyritic development, carrying

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DIABASE PORPHYRITES AND ASHBED-DIABASE

Julius Bien & Co. lith.

as porphyritic ingredients oligoclase and orthoclase, and more rarely labradorite and augite. The augite is always a subordinate ingredient and appears at times to be almost wholly absent, at least as an individualized substance. These rocks play a very prominent rôle in the copper series, and are always very strongly characterized in the field.

Some of the more distinctly crystalline of these rocks Pumpelly has described under the name of "ashbed"-diabase, the name being given from the fact that such a diabase forms the base of the flow whose upper vesicular portion is the well-known and so-called "ashbed" of Keweenaw Point.

As to the external characteristics of this class of rocks, Pumpelly gives a light or dark gray or black color, a very compact texture, and a conchoidal fracture; and as the accompanying microscopic characters the subordinate position of the augite, and more especially its occurrence in rounded grains, whose contours are not determined by the feldspars.[1]

My own study has shown me that the typical ashbed-diabases of Pumpelly are but phases of a large class of rocks; that between these type kinds and the fine-grained olivine-free diabase of the "ordinary type" there are various gradation-forms in which the rounded grains of augite are mingled with more and more of the augite whose contours are determined by the feldspars; and also that, in the other direction, there are gradation-forms into aphanitic kinds in which there is much nonpolarizing unindividualized material. In extreme cases, as in a rock from Michipicoten, figured on Plate IX of the original memoir, the unindividualized base makes up the greater part of the rock. The presence of unindividualized base and the absence of recognizable olivine places these rocks among the diabase-porphyrites, according to Rosenbusch's nomenclature. But the ashbed-diabases are so plainly linked with these, both through intermediate kinds and through similarity of occurrence in the field, that all are considered here together. They all indicate rapidity of solidification, not only by the presence of unindividualized matter, but also by the mode of occurrence of the augite.

The ground-mass of these rocks externally varies from light-gray to dark-gray in color, in more distinctly crystalline kinds, and is from light-gray to jet-black,—in one phase deep-reddish brown—in the less crystalline kinds. With the former kinds the fracture is subconchoidal; with the latter very highly conchoidal and even glass-like, as in the case of some black semi-vitreous rocks that have a large development on Michipicoten Island.

The microscopic characters of these rocks, which are of the greatest interest, are fully described in the memoir, but the space is not available for the insertion here of these descriptions.

These diabase-porphyrites frequently assume an amygdaloidal character in the upper portions of the flows, where they are commonly ex-

[1] Geology of Wisconsin, Vol. III, p. 32.

traordinarily vesicular, very often with the vesicles elongated in a common direction. Frequently these extraordinarily vesicular amygdaloids have mingled with them, and even filling the vesicles, a red, shaly matter.

The rocks here included vary considerably in silica content, ranging from 48 to 60 per cent. It is possible that some of the more basic blackish kinds may represent the half-glassy forms of the olivinitic diabases, but this has not been proved by analysis or recognition of olivine as an ingredient. On the other hand, there is evidently in some kinds, especially some of the redder varieties nearly free from augite, a greater amount than usual of orthoclase material, and with this often is a little secondary quartz. These kinds make up much of the so-called quartzless porphyries, and are plainly the half-glassy form of the orthoclase-gabbros. These kinds have about 55 to 60 per cent. of silica, and stand between the acid and basic half-glassy rocks, just as the orthoclase gabbros do between the basic and acid granular rocks.

As typical occurrences of the diabase-porphyrites, may be mentioned the porphyry of Duluth; that of the south shore of Michipicoten Island; and that of the north shore of Lake Superior, one mile below the mouth of Silver Creek, N. E. ¼, Sec. 22, T. 53, R. 10 W., Minn.

Amygdaloids.—The flows of the finer-grained rocks are all commonly provided with upper vesicular portions, by the subsequent filling of whose vesicles, and the various degrees of alteration of whose matrices, have been produced the manifold types of amygdaloid known in the Lake Superior region.[1] The coarse rocks are not furnished with amygdaloids, save when tending to a distinctly finer grain than usual.

Externally, the matrix of an amygdaloid is commonly quite different from that of the rest of the bed. This difference consists principally in greater denseness of grain from solidification when much of the matter was not developed into distinct minerals. The difference is least, then, in the case of those beds whose lower portions are composed of some phase of the diabase-porphyrite in which there is also a greater or less proportion of unindividualized matter. In some of these beds, especially when the rock is of the dense brownish kind with highly conchoidal fracture above described, there is no perceptible difference between the matrices of the vesicular and non-vesicular portions of the bed; but more usually there is a great difference in this respect between the lower and the vesicular portions of a flow. The internal changes to which such an open vesicular substance, composed largely of a molecularly unstable material like glass, must always be liable, have greatly increased the difference, and have given rise, by the variation in the decomposi-

[1] Pumpelly has spoken of the olivinitic fine-grained kinds—his melaphyrs—as less commonly provided with amygdaloids than are the olivine-free diabases of the "ordinary type," but in my observations this is only true when the melaphyrs have a distinct tendency to become coarse-grained, as in "The Greenstone" of Keweenaw Point. When they are fine-grained they appear to have amygdaloids quite as frequently as the olivine-free kinds.

tion products, to a great variety of amygdaloids, which it would seem at first sight hard to place together.

Under the microscope the matrix of the unaltered or relatively little altered amygdaloid shows nearly always much non-polarizing matter, commonly deeply stained with red ferrite. In this are developed needles of plagioclase to a greater or less extent, and often these needles seem to be but microliths arrested in the process of aggregation into crystals.[1] Augite particles occur, but are usually relatively sparse, and frequently fail entirely. Very often there is a fluidal structure brought out in the arrangement of the plagioclase microliths and other particles, and in many cases this flowage texture is found to coincide with the longer axes of the elongated vesicles. The vesicles themselves, filled or empty as the case may be, are always sharply outlined in the thin section, and there is immediately about them a crowding of the plagioclases and ferrite particles as if by pressure in the cavity. Moreover, the individualized minerals, as Pumpelly has shown,[2] are often more minute in the vicinity of the vesicles than away from them. Porphyritic feldspars, macroscopically visible, are frequently developed in the matrix of the amygdaloids—so far as my observation has gone, they are at least as often present as not—and in this respect we have yet another affinity between the amygdaloids and the non-vesicular diabase-porphyrites.

Macroscopically the vesicles are seen to be commonly filled with secondary minerals, one or more of "calcite, chlorite, epidote, quartz, prehnite, laumontite, copper, orthoclase, or their products of alteration."[3] Often, however, I have observed the vesicles empty, either from the removal of the amygdules, or from their always having remained empty. The walls of these empty cavities are commonly found to be smooth and dense, apparently from the pressure of the confined vapor.

ACID ERUPTIVE ROCKS OF THE KEWEENAW SERIES.

1. Quartzless porphyry.
2. Quartziferous porphyry and felsite
3. Augite-syenite and granitell, or granitic porphyry.
4. Granite.

As indicated in a previous chapter, I have been able to show that the several kinds of felsite and acid porphyries which make the pebbles of the conglomerates and the material of most of the sandstones of the Keweenaw Series exist in the same series in the massive condition; and that, while subordinated to the basic rocks in total amount, they yet form a very important element in the make-up of the series in which

[1] R. Pumpelly, "Metasomatic Development," p. 282.
[2] *Ibid.*, p. 283.
[3] Geology of Wisconsin, Vol. III, p. 31.

they are found, throughout its entire circuit about the Lake Superior basin.

Quartzless porphyry.—There are several phases of porphyritic rocks in the Lake Superior region, occurring both as pebbles in the conglomerates of the Keweenaw Series, and as flows in the same series, which would formerly have been classed together as quartzless porphyries, that name applying to felsitic rocks in which quartz is present neither in the base nor as a porphyritic ingredient.[1] These several phases have in common an aphanitic dark-brown base, frequent abundance of porphyritic feldspars (although kinds occur in which the feldspars disappear) and freedom from visible porphyritic quartz. They are also distinctly softer than the true acid quartziferous porphyries. A study of the thin sections, however, aided by silica determinations, has shown that in such a grouping we should really be placing together kinds which are but the half-crystalline or crypto-crystalline phase of the less basic diabases, others which verge on the true acid felsites in acidity (70 per cent. silica or over), and kinds again which are intermediate between these. There exist in the Lake Superior region, in fact, porphyritic rocks which range from the true basic kinds, with less than 50 per cent. of silica, to the very acid felsites and quartziferous porphyries with over 70 per cent., thus forming a continuous series. It becomes then necessary to adopt some rather arbitrary divisions between the different phases. The kinds with from 50 to 60 per cent. of silica have already been considered under the head of ashbed-diabase and diabase-porphyrite, while those reaching 70 per cent. are classed below with the true felsites. There yet remain kinds intermediate between these, both as to silica content (60 to 70 per cent.), and as to their microscopic characters. These are the kinds which are here considered under the head of quartzless porphyry. They are in fact the semi-crystalline phases which correspond to the completely crystalline augite-syenites mentioned below.

Macroscopically, these rocks show an aphanitic matrix of a dark reddish-brown or brown color, and more or less strongly developed conchoidal fracture. The porphyritic feldspars, habitually of a red color, and including both orthoclase and oligoclase, vary considerably in size and abundance, but are usually minute.

The principal points with regard to these rocks, developed by microscopic study, are the following: a matrix made up chiefly of a reddish-stained, usually more or less isotropic material; the abundance of minute ferrite particles and needles; the presence of a banding due to flowage in the molten condition; the frequent presence of a saturation of secondary quartz; and the presence, among the porphyritic ingredients, not only of feldspars, but also of augites affected by a peculiar ferritic decay.

[1] Conf. R. Pumpelly, in Geological Survey of Michigan, Vol. I, Part II, p. 16.

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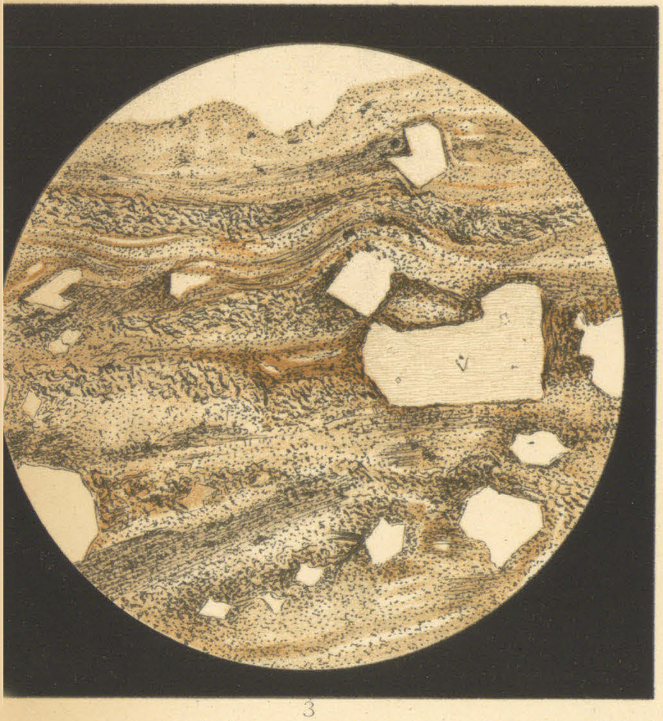

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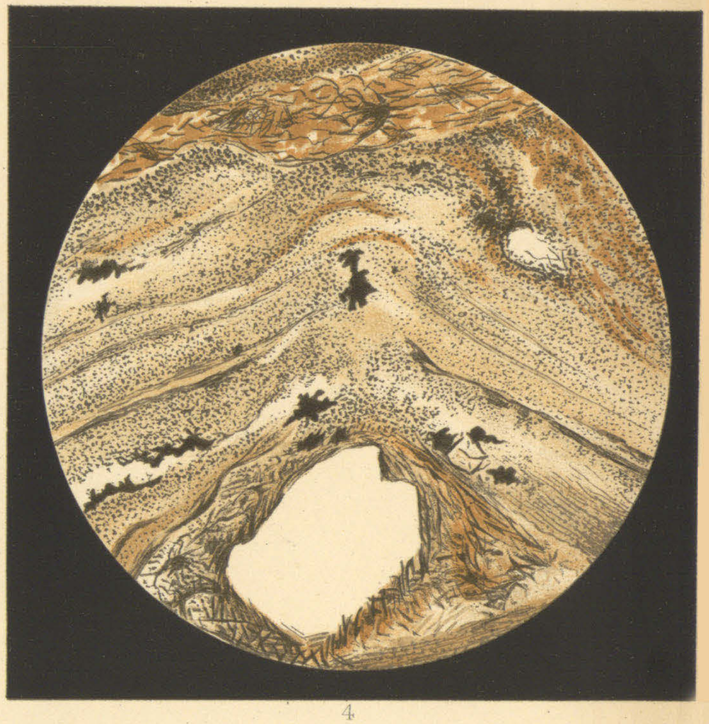

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QUARTZ-PORPHYRIES

Julius Bien & Co. lith.

As instances of the occurrence of these rocks may be mentioned the Stannard's Rock Reef, and the rock largely exposed near the workings of the old Suffolk mine, Praysville, Keweenaw Point.

Felsite and quartziferous porphyry.—Rocks belonging under this head play a very important rôle in the Keweenaw Series, not merely as pebbles and bowlders in the conglomerates, but also as extensive and widely spread original masses.

These rocks belong to a class which is, as is well known, the most difficult of all the rock groups to study satisfactorily with the microscope, and as to the nature of whose aphanitic matrix, even since the application of the microscope in its study, widely different views have been held. In the descriptions of felsitic rocks in this memoir, the views and nomenclature of H. Rosenbusch have been adhered to.

The matrix of the Lake Superior felsitic porphyries, as seen macroscopically, presents nearly always some quite marked shade of red. Frequently there is a fine banding of waving or contorted lines, or rows of spots of a lighter material upon a darker background. As very prominent instances of this peculiarity, which is plainly a flowage result, may be mentioned the rock of the base of the great flow seen at the Palisades on the Minnesota coast, and that of the cliffs on the same coast in the S. W. ¼ of Sec. 28, T. 56, R. 7 W. In the latter case, a lighter pinkish background is thickly strewn by serpentine bands and S-like forms, sometimes several inches in width, of a darker material. The matrix of these rocks is always aphanitic, has often a pronounced conchoidal fracture, and is very frequently much decayed by alteration, in which case fragments come out of the ledge in very characteristic and peculiar sharp-edged, angular, and even tabular, forms. The silica content of this matrix is high, standing between 72 and 77 per cent.

The porphyritic ingredients of these rocks, recognizable macroscopically, are regularly outlined, usually reddish feldspars, including both triclinic and monoclinic kinds, and ranging from very minute sizes to crystals half an inch in length, and glassy, rough-surfaced, black quartzes. Both of these porphyritic ingredients vary greatly in amount in different specimens, at times sinking entirely out of sight, when the rock becomes a felsite, and again nearly equalling the matrix in combined quantity.

The results of a microscopic study of the thin sections of these rocks from all parts of the Lake Superior basin are given at length in the original memoir. It is possible here merely to enumerate some of the principal points. These are: a red-stained matrix, more or less largely isotropic, composed chiefly of "micro-felsitic" and "crypto-crystalline" matter, only very rarely containing recognizable orthoclase and quartz particles, and probably containing often small quantities of glass; a flowage structure indicated by a blotching and banding with a lighter colored, or colorless, often more distinctly crystalline material; the abundance of brown ferrites; the absence of spherulitic structure; the frequent presence of saturating secondary quartz; the peculiar corrosion, evidently by their fluid matrix, of the regularly outlined feldspars; the similar corrosion by the matrix of the always regularly dihexahedral quartzes; the presence of dihexahedral glass inclusions in the quartzes; and the peculiar ferritic decay of the rare porphyritic augites.

Among the very numerous places in the Lake Superior basin where these rocks occur as original masses, may only be mentioned here Mount Houghton, on Keweenaw Point, the central area of the Porcupine Mountains, the mouth of Tyler's Fork of Bad River, Ashland County, Wisconsin, the Great Palisades of the Minnesota coast, Bead Island at the mouth of Nipigon Straits, the islands of the south shore of Michipicoten Island, and the northeast coast of the same island.

Augite-syenite and granitell, or granitic porphyry.—Occurring abundantly as pebbles and bowlders in the Keweenawan conglomerates, in great irregular mountain masses in the lower part of the series, and again in plainly intersecting masses and even in thin seams in the coarse gabbros lying near the base of the series, are found flesh-red to brick-red rocks, which present a plainly and often quite coarsely crystalline structure, and general granitic appearance. Red feldspars, unstriated alone, or both striated and unstriated together, appear always to make up the bulk of these rocks, and quite commonly are the only macroscopically recognizable ingredients. Quartz, however, is often visible, especially in the more coarsely-grained and more strongly granite-like kinds. In some forms, blackish and greenish-black points dot the rock rather sparsely, while occasionally a greenish substance is coarse enough to be recognizable as softened hornblende or augite. With diminishing coarseness of grain there comes to be present in these rocks more or less of a matrix whose crystalline structure is not macroscopically recognizable, when there appears to be a passage towards the uncrystalline felsites. On the other hand, a passage towards the orthoclase-gabbros is presented by kinds containing more than usual of the softened greenish augitic mineral and of striated feldspars.

The principal points determined in the study of these rocks with the microscope are the following: a preponderance of feldspars, including a triclinic kind (chiefly oligoclase or near it), as well as the predominating orthoclase; an almost invariable alteration of the feldspar crystals, as a result of which they have become turbid, charged with red iron oxide, and more or less completely saturated with secondary quartz; a pseudo-spherulitic structure produced by a radial arrangement of secondary quartz and ferrite particles; the presence, in the more distinctly granite-like kinds, of areas of quartz which may be primary; and the presence of augites affected usually by the peculiar red and brown

Summary tabulation of the eruptive rocks of the Keweenaw Series, showing their mutual transitions and relations.

		Coarse granular kinds.		Fine-granular kinds.		Porphyritic kinds, *i. e.*, containing some unindividualized matter.		Half glassy vesicular kinds.
BASIC KINDS. Silica 45 to 52 per cent.	Silica 45 to 48 per cent.	*Olivine-gabbro* (B 1). Olivine. Anorthite. Diallage. Titaniferous magnetite. *Non-orthoclastic, olivine-free gabbro* and *diabase* (in part only) (B 1). Anorthite or labradorite. Diallage or augite. Titaniferous magnetite. *Anorthite rock;* a special phase (B 4).	Grading by increasing fineness of grain and loss of diallagic cleavage in the augite, which remains coarser than the other constituents, into →	*Olivinitic diabase* and *melaphyr* ("luster-mottled" rocks), B 6 (in large part). Anorthite. Olivine. Augite. Titaniferous magnetite. *Pseud-amygdaloids* a special phase.	Grading, by addition of residuary magma, into →	*Melaphyr* or "luster-mottled" rocks of Pumpelly, have at times a little residuary magma, but it never amounts to much. Genuine porphyritic kinds of high basicity are unknown.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	*Amygdaloids.* (Amygdaloids occur, at times, with all the basic and intermediate rocks, but they are not separated by any physical or microscopic characters.) *Fresher forms*... *Groundmass:* Devitrified glass. Feldspar microliths. Ferrite particles. Augite particles (often not seen). *Gas vesicles*, filled with one or more of calcite, chlorite, epidote, quartz, prehnite, laumontite and orthoclase, as secondary minerals. *Porphyritic* ingredients: Plagioclase, orthoclase, augite. *Altered forms*... *Groundmass*, in various stages of alteration and replacement by prehnite, laumontite, epidote, calcite, quartz and copper. *Amygdules.* the prehnite altered to chlorite, epidote, &c.
			Grading by increasing fineness of grain into →	"*Ordinary-type*" *diabase* (in small part only) (B 5). Labradorite. Augite. Magnetite. *Pseud-amygdaloids* a special phase.	Grading by decrease in amount of augite and change of the augite into aggregates of rounded grains, into "*Ashbed*"-*diabase* (B 7) (in small part only) and this, by introduction of unindividualized material and increasing fineness of grain, into →	*Diabase-porphyrite* (in small part only) (B 7). Tabular plagioclases. Round augite particles. Magnetite. Irresolvable base. Porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
		Grading by loss of olivine, decrease in basicity of the plagioclases, and, in some kinds, by addition of orthoclase, into ↓		Grading by loss of olivine and decreasing basicity of plagioclase, into ↓		Grading by decrease in augite and general increase in acidity, into ↓		
	Silica 48 to 52 per cent.	*Non-orthoclastic olivine-free gabbro* and *diabase* (in part only) (B 1). Labradorite. Diallage or augite. Titaniferous magnetite. *Orthoclase-gabbro* (in small part only) (B 2). Labradorite or oligoclase. Orthoclase. Diallage and augite. Titaniferous magnetite. Apatite, uralite, common accessories. *Uralitic gabbro* (B 2). } Special phases. *Hornblende gabbro* (B 3). }	Grading by increasing fineness of grain into →	"*Ordinary-type*" *diabase* (the larger part) (B 5). Labradorite or oligoclase. Augite. Titaniferous magnetite. *Pseud-amygdaloids* a special phase.	Grading, as above, into "*Ashbed*"-*diabase* (in part) (B 7), and this as above, into →	*Diabase-porphyrite* (the larger part) (B 7). Tabular oligoclases. Round augite particles. Magnetite. Irresolvable base. Large porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
		Grading by decreasing basicity of plagioclase, increase of orthoclase, and introduction of secondary quartz, into ↓		Grading by decreasing basicity of feldspars into ↓		Grading by increasing acidity of the feldspars, decrease in the amount of augite, and introduction of much ferritic matter, into ↓		
INTERMEDIATE KINDS.	Silica 52 to 60 per cent.	*Orthoclase-gabbro* (the larger part) (B 2). Oligoclase. Orthoclase. Diallage. Augite. Titaniferous magnetite. Apatite, uralite and secondary quartz, very common accessories. *Uralitic orthoclase gabbro* (B 2). } Special phases. *Hornblende gabbro* (B 3). }	Gradation forms not known, into →	"*Ordinary-type*" *diabase* (in small part only) (B 5). Oligoclase. Orthoclase possibly in a few kinds (?). Augite. Titaniferous magnetite. (These rocks have never been found to contain over 53 or 54 per cent. silica—rarely so much, save when silicified by quartz infiltration.) *Pseud-amygdaloids* a special phase.	Grading through increasing fineness of grain, loss of crystalline outlines to the augite, and introduction of irresolvable base, into →	*Diabase-porphyrite* (in part, especially the reddish-brown and jet-black kinds with highly conchoidal fracture) (B 7). Tabular plagioclases. Round augite particles. Magnetite. Irresolvable base, often in very large proportion. Much ferritic material in the base. Porphyritic plagioclases and augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
		Grading by decrease of augitic constituent, and increase of orthoclase and of quartz, into ↓		Gradation phases not known, into ↓		Grading by still further increase in acidity, introduction of orthoclase among the feldspars, and loss of augite in the base, into ↓		
ACID KINDS. Silica 60 to 78 per cent.	Silica 60 to 70 per cent.	*Augite-syenite* (in part) (A 3). Oligoclase. Orthoclase. Augite (very subordinate). Ferrite and abundant quartz characteristic accessories.	Grading by increasing fineness of grain, into →	Fine-grained *augite-syenite* (A 3). Orthoclase. Oligoclase. Augite. Ferrite. Secondary quartz.	Grading by introduction of felsitic matter, and increasing fineness of grain, into →	*Quartzless porphyries* (A 1). Groundmass: Micro-felsitic matter. Crypto-crystalline matter. Ferrite. Tabular feldspars. Secondary quartz. Porphyritic ingredients: Oligoclase and orthoclase. Augite with ferritic decay.		Vesicular kinds not known among the acid rocks.
		Grading by decrease of oligoclase and great increase of quartz, into ↓		Grading by increasing amount of quartz, into ↓		Grading, by increasing acidity, loss of tabular feldspars in the matrix, and introduction of porphyritic quartz, into ↓		
	Silica 70 to 78 per cent.	*Augite-granite* (A 4) and *granitell* or *granitic porphyry* (A 3) (in part). Orthoclase. Oligoclase (not always present). Quartz. Augite (always more or less thoroughly altered to ferrite or hornblende and very sparse).	Grading by increasing fineness of grain, into →	Fine-grained *granitell* or *granitic porphyry* (A 3) (in part). Orthoclase. Oligoclase. Quartz. Augite (very sparse, altered to ferrite, chlorite, or uralite). Ferrite. Secondary quartz.	Grading by increasing fineness of grain, and introduction of felsitic matter, into →	*Quartziferous porphyry* and *felsite.* Groundmass: Glass (very little). Crypto-crystalline matter. Micro-felsitic matter. Micro-crystalline matter (subordinate). Ferrite. Secondary quartz. Porphyritic ingredients: Quartz (corroded dihexahedral pyramids). Orthoclase and oligoclase. Augite (rare).		

ferritic alteration already mentioned as characterizing the augites of the felsitic porphyries.

As typical instances of the occurrence of these rocks may be mentioned the intersecting masses of Mount Bohemia, Keweenaw Point; the prevailing pebbles of the "Albany and Boston" conglomerate near Portage Lake; the irregular masses and thin veins intersecting the coarse orthoclase-gabbro of Duluth, Minn.; and the great granite-like mass forming the south point of Beaver Bay on the Minnesota coast.

Granite.—In the Bad River country of Wisconsin, red rocks, closely allied to those described under the last head, intersect coarse gabbro. In this region, however, they are peculiar in containing both mica and hornblende in relatively large amounts as compared with the amount of augite in the rocks which I have called augite-syenite. They are thus true granites. Although plainly merely a phase of the wide-spread rocks last described, these granites deserve especial mention, since nothing just like them has been elsewhere observed in the entire extent of the Keweenaw Series.

SUMMARY VIEW OF THE ORIGINAL ROCKS OF THE KEWEENAW SERIES.

Between the several kinds of original rocks above described there are no sharp lines. There is, in fact, a continuous series of kinds from the most basic to the most acid. From the necessity of following some accepted nomenclature, it has been unavoidable to use names which cover very different ranges of acidity. In the following table an attempt is made to classify these various rocks with reference to silica content as well as to texture and mineralogical composition, and thus to bring out more plainly than has been done in the preceding pages the relations of the different kinds to one another. The references B1, A1, &c., are to the classifications of basic and acid rocks given respectively on pages 102 and 111.

DETRITAL ROCKS.

The fragmental rocks of the Keweenaw Series include, as already shown, both sandstones and conglomerates. A general statement as to the nature of these rocks having already been given on a previous page of this abstract, nothing further in regard to them will be inserted here.

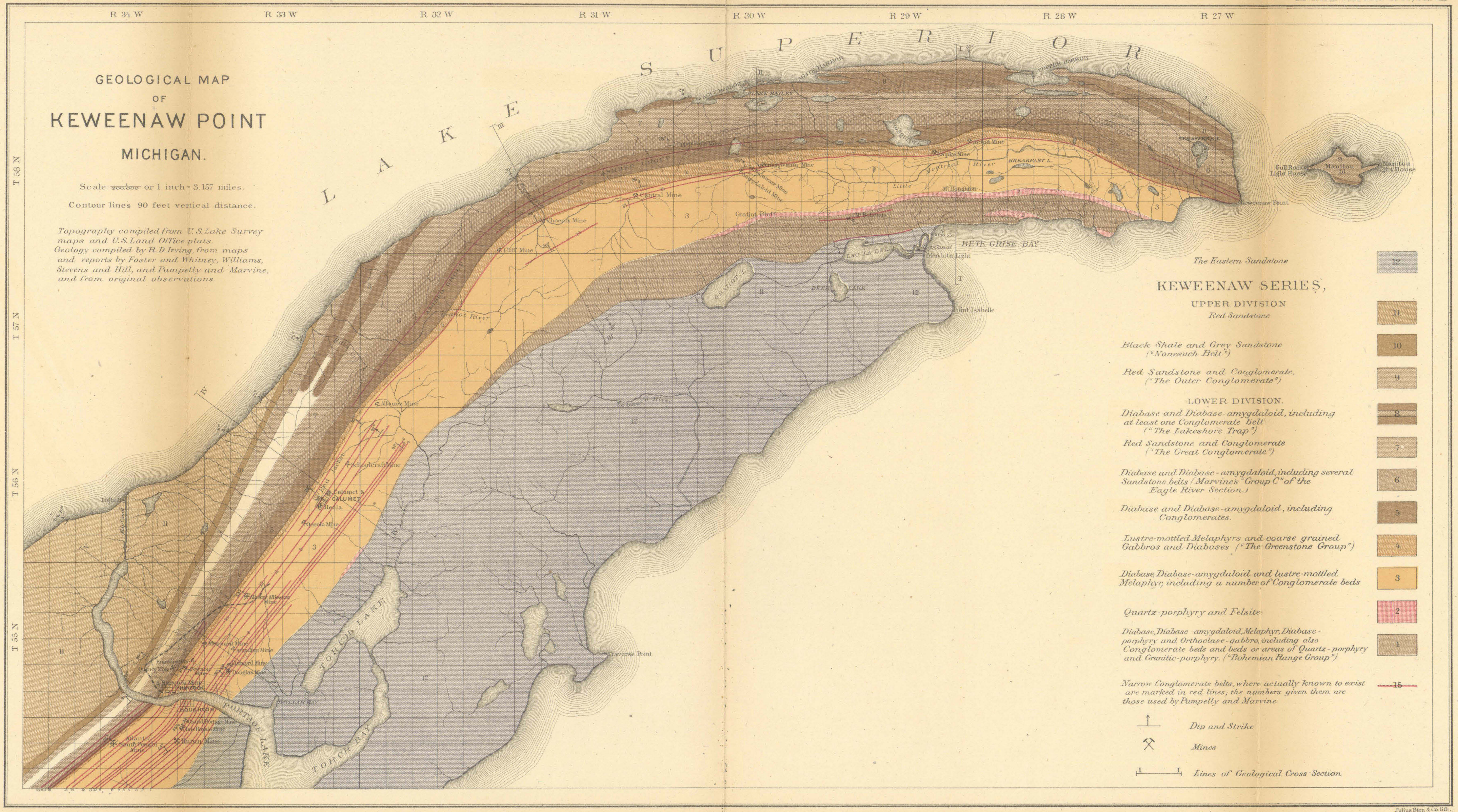
CHAPTER IV.

STRUCTURAL FEATURES OF THE THREE CLASSES OF ROCKS OF THE KEWEENAW SERIES.

The basic crystalline rocks make up the greater part of the thickness of the series. They occur, for the most part, in distinct beds, from a few feet to several hundred feet in thickness, which, while sharply defined from each other, do not commonly possess any subordinate bedding structure, though such a structure is at times to be observed, as noted below.

Often these beds present an easily recognized two-fold division, into an upper, narrower, amygdaloidal portion, and a lower, compact, non-amygdaloidal portion. This subdivision is one characterizing especially the beds composed of the finer-grained diabases, which are, however, much the most abundant of the basic rocks. The coarser-grained diabases and gabbros are never, so far as my observation has extended, furnished with amygdaloids. Of the finer-grained kinds, the olivine-free diabases are perhaps somewhat more commonly supplied with amygdaloids than those carrying olivine, and have the amygdaloids more strongly developed. However, the olivine-bearing kinds are often provided with very highly vesicular amygdaloids, as, for instance, most of the succession of beds seen on the Minnesota coast between Knife River and Split Rock River, and described on a subsequent page under the name of the Agate Bay Group.

The amygdaloidal and compact portions often appear to grade into each other through an intermediate stage in which the amygdules are less plentiful. This intermediate stage, recognized by Pumpelly and Marvine as "amygdaloidal melaphyr," in their descriptions of Keweenaw Point geology, the first-named geologist has since shown to be essentially different from the upper amygdaloid, in that in the latter most of the amygdules fill sharply-defined pre-existing cavities, while in the former they occupy the positions of primary rock constituents. A three-fold division of these beds into a true amygdaloid, a pseud-amygdaloid, and a compact portion is thus often to be recognized. In a number of cases I have myself observed still a fourth division, viz, a true amygdaloid occupying the base of the bed. This has little or no gradation-zone into the overlying compact portion, is thinner than the top amygdaloid, and shows sparser and larger amygdules, which, moreover, occupy cavities whose walls are unusually dense and sharply defined. All of these divisions are often present, but one, or all save one, may fail. When one division only is recognizable, it is commonly the massive portion; but


GEOLOGICAL MAP
OF
KEWEENAW POINT
MICHIGAN.
Scale or 1 inch = 3.157 miles.
Contour lines 90 feet vertical distance.
Topography compiled from U.S. Lake Survey maps and U.S. Land Office plats.
Geology compiled by R.D. Irving from maps and reports by Foster and Whitney, Williams, Stevens and Hill, and Pumpelly and Marvine, and from original observations.
LAKE SUPERIOR
R 34 W
R 33 W
R 32 W
R 31 W
R 30 W
R 29 W
R 28 W
R 27 W
T 58 N
T 57 N
T 56 N
T 55 N
COPPER HARBOR
BETE GRISE BAY
LAC LA BELLE
GRATIOT L.
DEER LAKE
Point Isabelle
Keweenaw Point
Manitou Id.
Gull Rock Light House
Manitou Light House
Mendota Light
Traverse Point
TORCH LAKE
TORCH BAY
PORTAGE LAKE
Tobacco River
Eagle River
Gratiot River
Phoenix Mine
Central Mine
Cliff Mine
Albany Mine
Schoolcraft Mine
Calumet
Hecla
Osceola Mine
Quincy Mine
HOUGHTON
Huron Mine
The Eastern Sandstone 12
KEWEENAW SERIES,
UPPER DIVISION
Red Sandstone 11
Black Shale and Grey Sandstone ("Nonesuch Belt") 10
Red Sandstone and Conglomerate ("The Outer Conglomerate") 9
LOWER DIVISION.
Diabase and Diabase-amygdaloid, including at least one Conglomerate belt ("The Lakeshore Trap") 8
Red Sandstone and Conglomerate ("The Great Conglomerate") 7
Diabase and Diabase-amygdaloid, including several Sandstone belts (Marvine's "Group C" of the Eagle River Section.) 6
Diabase and Diabase-amygdaloid, including Conglomerates. 5
Lustre-mottled Melaphyrs and coarse grained Gabbros and Diabases ("The Greenstone Group") 4
Diabase, Diabase-amygdaloid and lustre-mottled Melaphyr, including a number of Conglomerate beds 3
Quartz-porphyry and Felsite 2
Diabase, Diabase-amygdaloid, Melaphyr, Diabase-porphyry and Orthoclase-gabbro, including also Conglomerate beds and beds or areas of Quartz-porphyry and Granitic-porphyry. ("Bohemian Range Group") 1
Narrow Conglomerate belts, where actually known to exist are marked in red lines; the numbers given them are those used by Pumpelly and Marvine. 15
Dip and Strike
Mines
Lines of Geological Cross-Section
Julius Bien & Co. lith.

in the thinner beds, the pseud-amygdaloid or alteration-zone not unfrequently extends all the way to the base, there being then no massive unaltered portion.

The amygdaloidal portions of these beds present many complicated and much-varied phases, the complexities arising from molecular alterations subsequent to the solidification of the rocks, from admixtures of sediment, or from both of these causes at once. Still, by a study of fresher conditions, it is easy to recognize certain constantly recurring main characteristics, viz: a matrix always different from that of the more compact portion of the bed, in that it is much denser and often less perfectly crystalline, and always much more prone to alteration; and amygdules of one or more of calcite, chlorite, quartz, epidote, prehnite, laumontite, copper, orthoclase, or the alteration-products of these, filling sharply defined and distinctly pre-existing cavities. The amygdules vary very greatly in abundance. Sometimes, as in the upper amygdaloids of the Montreal River, and yet more strikingly in some of the minutely vesicular amygdaloids of the Minnesota shore in the vicinity of Agate Bay, they nearly exclude the matrix, showing that the original rock must have been as vesicular as a sponge. The amygdules at times take on a cylindrical form, with the axis at right angles to the bedding, sometimes extending in this way to a length of several inches. I have noticed such "spike amygdules" in a number of cases in the thin basal amygdaloids. Again, the amygdaloidal cavities will be found elongated laterally in a common direction, this being carried sometimes to such an extent that the amygdules are thinned to mere strings. This is to be finely observed in some amygdaloids on the lake shore at Duluth, as well as at a number of points further to the eastward, and, in general, some traces of this elongation are more often to be made out than not. It suggests a flow of the vesicular matrix while in a viscid condition.

The internal alterations that these amygdaloids have commonly undergone have been described in detail by Pumpelly.[1] The alteration has in some cases been an extreme one, "large parts of the bed have lost their amygdaloidal character, and now consist of quartz, epidote, calcite, prehnite, chlorite, and decomposed amygdaloid associated in the most irregular manner. Such are the beds worked for copper on Keweenaw Point,"[2] and similar beds occur throughout the entire extent of the series.

A kind of amygdaloid, very interesting in its structural relations, is to be seen largely along the Minnesota shore between French and Split Rock rivers, in the "Agate Bay Group" of beds. This is a highly vesicular, true amygdaloid, occurring in two phases which graduate into each other. In the one, a crumbling, light-brownish matrix holds large amygdules of radiating laumontite, to which zeolite the matrix itself has often partly altered. In the other phase a reddish-brown, iron-stained, hard matrix includes thickly-studded, minute amygdules of saponite and laumontite. The point of especial interest with regard to these amyg-

[1] *Op. cit.* [2] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 32.

daloids is their stratiform condition. They lie in layers one inch and upwards in thickness. The layers are quite irregular and non-continuous, but affect the whole mass. This structure is brought out with especial prominence on weathered cliff-sides, the thinner layers falling away in fragments as from a cliff of shaly limestone. Occasionally seams of red sandstone are interleaved, or overlie a thickness of the stratiform amygdaloid into which the sandstone penetrates at times through fissures and irregular openings. This amygdaloid graduates laterally into kinds without stratification. It occurs in thicknesses running from less than a foot up to as much as 15 or 20 feet, but the usual thicknesses lie between 5 and 8 feet. Interbedded with and grading into these amygdaloids are massive layers of fine-grained olivine-diabase or melaphyr, with a quite pronounced vertically columnar structure. A fine show of both is to be seen on the west side of Agate Bay, on the Minnesota shore, where a total thickness measured of 101.5 feet includes seven massive layers running from 2 to 15 feet in thickness, and seven layers of stratiform amygdaloid running from 3 to 20 feet in thickness. A single seam of red, shaly sandstone 2 to 3 feet in thickness is included.

The resemblance of these amygdaloids to beds of sedimentary origin, however striking at the first glance, is nevertheless lost on close inspection; for the vesicular structure is seen to be identical with that of the ordinary amygdaloids, while no trace of a fragmental nature can be detected either with the naked eye or in the thin section with the microscope. The thin section shows a completely interlocked crystalline texture, and a composition precisely the same as the underlying massive rock except as to the alterations and amygdules, and the presence of a considerable amount of unindividualized magma substance. The stratiform condition may be in part due to a succession of thin scoriaceous flows, and in part to a true "fluidal" structure. It appears often to result from an arrangement of amygdules more plentifully on certain planes, subsequent molecular changes bringing out an apparent stratification by following the planes on which the amygdules were thickest. But, however this may be, there can be no question as to the identity of origin of these amygdaloids with all others of the series, although, in Owen's Geological Survey of Wisconsin, Iowa and Minnesota,[1] Norwood has called them "metamorphic shales," in which he has since been followed by N. H. Winchell.[2] The possibility of a sedimentary origin for them is absolutely excluded by the interior crystalline texture, the highly vesicular character, the presence of unindividualized magma,

[1] Pages 345 to 361. In Norwood's descriptions of the Minnesota coast this term constantly recurs, and the coast-line is represented as chiefly formed by "metamorphic shales," which term, having applied it first to the bedded amygdaloids, he spread to nearly all other amygdaloids, as well as to some of the more compact diabases. I could find no rock between Duluth and Grand Portage Bay to which the term "metamorphic shale" would in any sense be applicable.

[2] Reports of the Geological Survey of Minnesota for 1878 and 1879.

the microscopic flowage structure, and the graduation of each bed downward into vertically columnar, non-vesicular, massive olivine-diabase.

The peculiar type of amygdaloid characterizing the so-called "ashbed" of Keweenaw Point is somewhat related to the last described. It appears as a peculiar and irregular mixture of red sand and amygdaloidal material, and bears at first sight some resemblance to those conglomerates already described,[1] in which the pebbles are amygdaloidal. But in the ashbed the apparent pebbles are seen on close observation to be mostly connected, and I am disposed to follow Wadsworth, in considering that it represents a very scoriaceous and open layer, upon and within which more or less sand was subsequently deposited.

In this connection it may be said that materials to which the term "ash," in the sense of volcanic detrital material, could be applied, are almost wholly wanting in the Lake Superior country. It is barely possible hat the basic ingredient of the dark-gray sandstone and black shale of the belt above mentioned as extending from the Gratiot River, on Keweenaw Point, westward to Bad River, in Wisconsin, may be in part of this nature, as also the material of which the somewhat allied gray sandstone at Duluth is composed; but, with these very doubtful exceptions, I have met with nothing in the entire Lake Superior region which could have originated as volcanic ash. I had supposed in the field that some of the crumbly, more or less obscurely stratiform beds of the north shore might be of this nature, their weathered surfaces presenting at first sight the appearance of aggregated angular particles, but all turned out to be completely crystalline rocks, owing their appearance of a fragmental nature to decomposition.

The more massive beds of basic rocks, or the lower massive portions of such beds as possess the crowning amygdaloids, are often without any definite structure. This is the common case in the typical region of Keweenaw Point, where a few beds only show a tendency to a transverse columnar structure. On the Montreal River, however, this structure is well developed in a series of quite thin beds, furnished with very perfect amygdaloids, and standing about vertically. On the Minnesota shore a columnar structure is the rule; and since the beds lie at a very flat angle, cliffs of vertically columnar rock are a prominent feature. Still, the structure never reaches a great perfection.

Allusion has been made above to the elongated vesicles of some of the amygdaloids. Other indications of flowage, sometimes to be seen in connection with the more massive rocks, are a slaggy or ropy texture, and an appearance as if a once solidified crust had broken and the several fragments reunited by further solidification, suggesting the "clinkers" of modern volcanic regions. These appearances, while noted at a number of points, are not common. They are merely additional indications of the once fluid condition in which all of these basic rocks are sufficiently proved to have been by the common division into amyg-

[1] Chapter II.

daloidal (vesicular) and compact portions; by the mineralogical composition—augite, plagioclase, olivine, magnetite; by the completely crystalline condition; by the flowage lines formed by the tabular plagioclase in some of the finer-grained kinds; and by the occurrence in some of the kinds of remnants of the original glass magma. The interstratification of these rocks with wholly unaltered sandstone and shales must preclude at once any thought of a metamorphic origin. As already indicated, I can only regard these beds as true lava flows, owing their interstratification with the accompanying sediments to their having been poured out at surface while the sediment was forming.

A very beautiful additional proof of contemporaneousness is furnished by the peculiar relation of a sandstone to its immediately underlying crystalline rock, the sand penetrating the openings and cracks in the latter. A number of places were noted on the north shore where the overlying sandstone bed has been removed and large surfaces of the underlying diabase, sometimes many hundreds feet long, present the singular appearance of being intersected by veins of sandstone, the seeming veins crossing each other, zigzagging, and branching, like true vein-formed material.

On the Minnesota shore, where single beds can be followed on exposure for long distances, numerous minor bowings and corrugations are seen to affect the layers, which nevertheless preserve a constant lakeward slant at a low angle. Individual layers and sets of layers can be followed for miles, rising into arches, sometimes of short span, and again sinking out of sight to reappear in a short distance. These minor undulations are the only possible[1] foundation Norwood could have had for his profile of the north shore, on which he represents a series of much-folded rocks. This peculiar warped structure I conceive to be in a measure due to the original irregularities of the beds.[2]

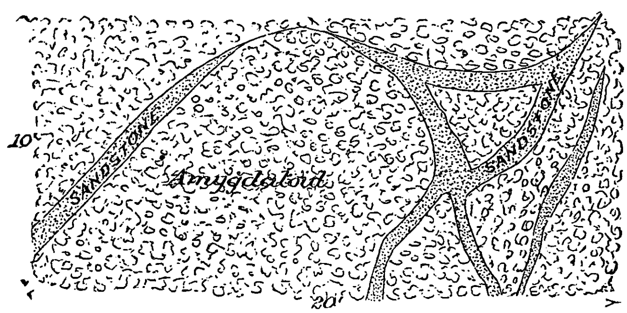


FIG. 34.—Sandstone "Veins"—Minnesota coast. Plan.

Laterally, the beds are of course not of indefinite extent. They must of necessity be far less extensive than sedimentary beds of the same thickness, and these, too, wedge out laterally. With a succession of

[1] Atlas to Owen's Geological Survey of Wisconsin, Iowa, and Minnesota.

[2] See Chapter VII for more specific descriptions of these irregularities, with illustrations.

beds much like each other, it is commonly difficult to prove the continuity or non-continuity of single flows over any great distance. On the Minnesota shore, however, I was able to trace individual layers for 10 to 15 miles with certainty, and with great probability much farther than this. "The Greenstone" of Keweenaw Point, a melaphyr or olivine-diabase flow of considerable thickness, which can, by reason of its peculiar character and marked effect on the topography, be readily traced, runs, beyond question, from near the end of Keweenaw Point westward to the Allouez mine, a distance of nearly thirty miles, and in all probability is represented at Portage Lake, thirty miles farther southwest, by a coarse-grained bed seen near the Atlantic mine. The so-called "ashbed" of Keweenaw Point appears to have been recognized at points thirty miles from each other, but the reference of the rocks of the two places to the same bed is made on stratigraphical and lithological evidence only, no actual continuity having been proved.

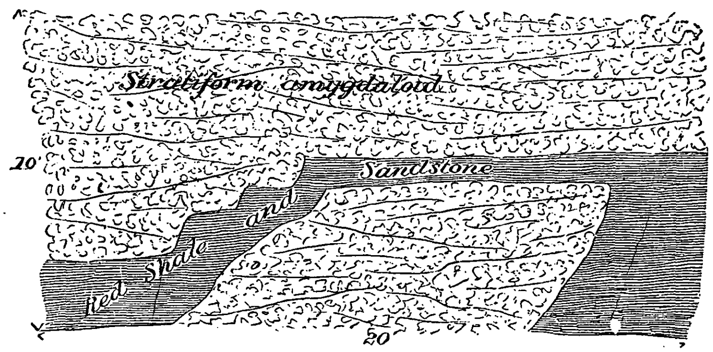


FIG. 35.—Sketch of cliff on Minnesota coast, showing penetration of fissures of amygdaloid by sandstone.

Groups of layers of allied lithological character are recognizable over much longer stretches. The belt of thin amygdaloids and diabases lying above the great conglomerate of Eagle River, Keweenaw Point, with a thickness of some 1,500 feet, must run uninterruptedly from the eastern extremity of Keweenaw Point to the Wisconsin boundary, a distance of 150 miles. Several of the groups into which I have divided the rocks of the Minnesota coast can be recognized for many miles, and there is a strong probability that one or two of them exist on Isle Royale.

The thickness of the individual beds of these basic rocks has been already given as ranging from ten or under to several hundred feet, but for the greater portion of the series the thickness is less than one hundred feet. Towards the base of the series, among the older flows, however, beds occur of great thickness, and present massive exposures in which it is very hard to see any sign of structure. At this horizon in the Bad River region of Wisconsin are huge structureless masses of very coarse-grained gray gabbro, and similar rocks have an immense development at a similar horizon in Minnesota. Fine-

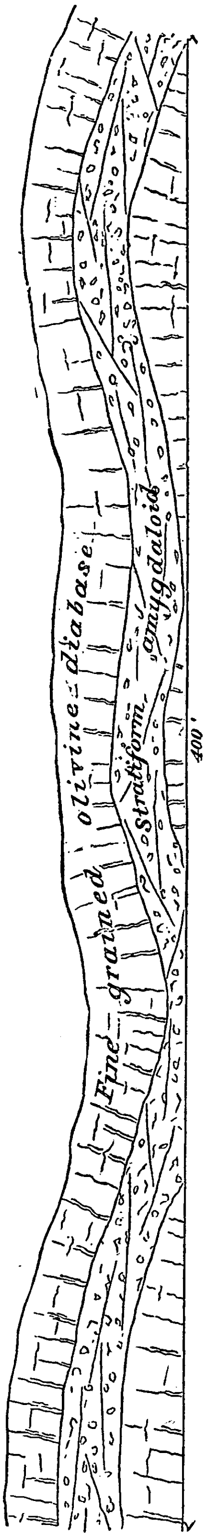
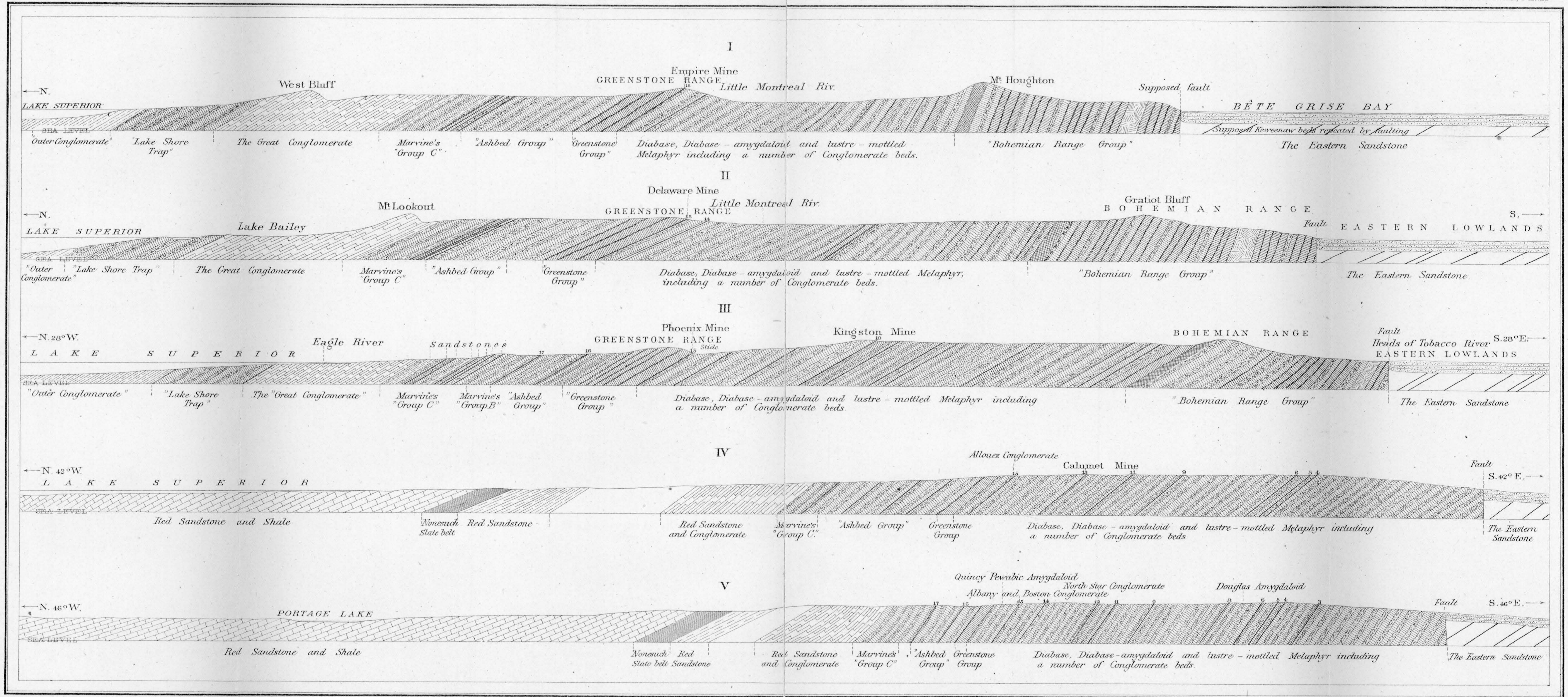


Fig. 36.—Sketch of cliff-side near Agate Bay, Minnesota, illustrating warping of layers. The dip is towards the observer.

grained diabases also occur largely at these low horizons without any such distinct bedding as is characteristic of most of the series; for instance, on the so-called "South Copper Range" of Michigan, between the Montreal and Ontonagon rivers, and in the "Duluth Group" of the Minnesota coast. The apparent lack of bedding in the latter region is perhaps due to the much greater thicknesses of the individual beds, and to their nearly vertical position, but it is possible that the coarse-grained rocks of the Bad River and Duluth regions may owe their want of structure to a different cause, as is subsequently indicated.

The effect of the prevalent bedded basic rocks upon the topography is everywhere very marked, having a common character, varied only by the varying dips and varying thicknesses of the individual layers. Since the dip is almost always lakeward, the common effect is a longer lakeward or front slope, and a steep or precipitous back slope. Where the dip is flat, as all along the Minnesota shore, the front slope coincides with the dip slope, and the shore line of hills ascends at an angle of from five to ten degrees, to drop off suddenly in the rear. The valleys of the streams entering the lake nearly at right angles divide these hills into detached blocks. Such a series of blocks is well seen as one looks towards the west from Grand Marais. From Grand Marais westward to Poplar River the trend of the strata is more easterly than that of the coast, so that in looking in that direction these hill blocks are seen succeeding each other in such a way as to have suggested the very apposite epithet of "Saw-Teeth Mountains." An attempt to represent their appearance is made in the accompanying outline sketch. In the woods of the north shore, away from the lake, the same feature is constantly repeated; ridges are everywhere met with trending with the strike of the formation, sloping gradually to the southeast, and dropping off abruptly to the northwest. This structure has been attributed by N. H. Winchell[1] to faulting, each drop being regarded as the result of a fault. There may be a few such faults, but it is evident enough that the case is just such as is found in every region of flat-dipping, hard rocks, and especially where softer layers are interleaved, as in this case.

[1]Report of the Geological Survey of Minnesota for 1879.



Julius Bien & Co. lith.

GEOLOGICAL SECTIONS OF KEWEENAW POINT,

MICHIGAN.

Scale $\frac{1}{32000}$ or 1 inch = 2666 feet.

On the south shore of the lake the dip is commonly higher, and, although the same structure occurs, the front slope is often flatter than the dip slope. In the eastern part of Keweenaw Point, where the dip flattens, the structure comes out finely in a series of bold ridges. Towards Portage Lake, however, the dip becomes as high as 50° or more, and the several ridges merge into one broad swell. This holds until the Porcupine Mountains are reached, where, though the dip angle is as high as thirty degrees, the structure is most beautifully illustrated in the outer ridge. This ridge rises from the lake shore, somewhat more gradually than the dip,

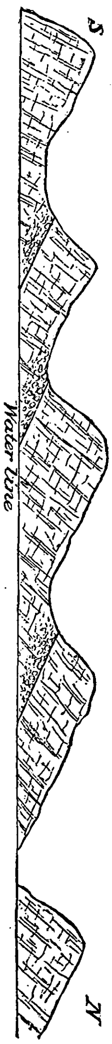


FIG. 38.—Section profile of beds at Eagle Harbor, Keweenaw Point.

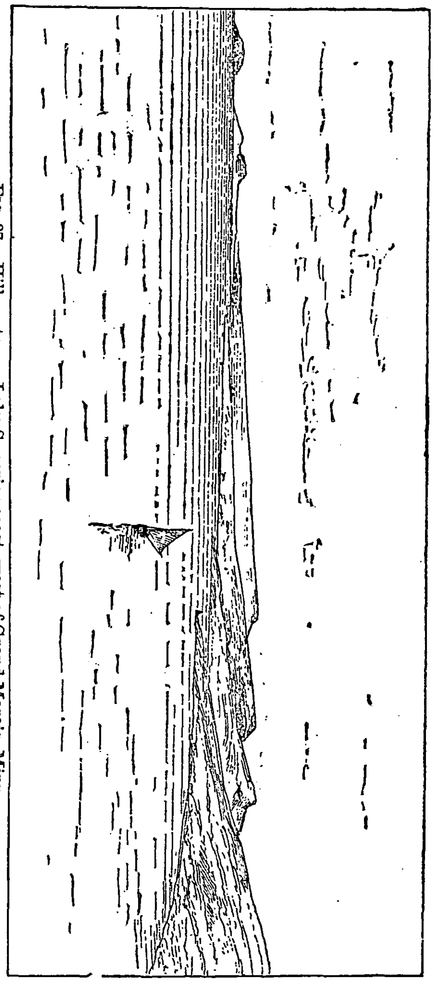


FIG. 37.—Hill contours, Lake Superior coast, west of Grand Marais, Minn.

to a height of over 1,000 feet, and then drops off in a bold escarpment of 400 feet into the valley of Carp Lake. Further west again, as far as Bad River, the dips are high, often reaching 90°, and the harder rocks constitute merely rounded ridges and knobs, with the cliffs facing indifferently in all directions. Beyond Bad River, and all across Wisconsin to the Saint Croix, the dips flatten once more, and the "saw-tooth" shape in the ridges is everywhere well marked.

True cutting masses, or dikes, of the basic rocks occur, though never a prominent feature of the series. They appear to characterize only its lower portions, and have been seen chiefly along the Minnesota shore, and on the east coast in the region of Mamainse. On the south shore they are nearly unknown, though in all probability occurring in the lower portions, where the exposures are commonly not good. Throughout the entire basin they have never been observed more than one-third the way above the base of the series.

As seen on the Minnesota coast,[1] these dikes are always small, commonly under ten feet in width, though seen occasionally wider than this, while a number were noticed under two feet in width. They are usually provided with a well-marked cross-columnar structure, and coarser-grained middle portion, as compared with the sides. They consist, so far as yet examined microscopically, wholly of augite-plagioclase rocks, and are not in any essential point different from the bedded diabases and melaphyrs that constitute the bulk of the series, the differences being only those that would arise from the different situations in which the rocks have cooled, and the different decomposition effects. Indeed, the thin sections of the dike rocks are often indistinguishable from those of the bedded rocks. The dikes of the Minnesota coast trend usually with the strike of the formation, less commonly directly across it. I cannot doubt that these dikes, and others like them, all around the rim of the Lake Superior basin, now unseen only because of unfavorable conditions of exposure, have been the source of the upper flows. The immediately underlying series of slates known to the Canadian geologists as the "Lower Copper-Bearing Group," called by Hunt the "Animikie Group," and regarded in this memoir as unquestionably the equivalent of the iron-bearing or so-called Huronian Series of the south shore, is intersected everywhere by a very much more powerful system of dikes. These are spoken of more especially on a subsequent page, and are merely cited here that I may express my belief that in them, and in the smaller dikes of the Keweenaw Series itself, we see the source of the volcanic strata of the lake basin, all around whose rim I conceive the eruptions to have taken place, rather than from any one vent, as some have supposed,[2] or from within any restricted portion of the basin.

The great structureless masses of coarse gabbro, which, in the Bad River region of Wisconsin, and again in the Duluth region of Minne-

[1] It should be said here that Norwood's descriptions of the Minnesota coast are entirely misleading as to the number and size of the dikes. As already said, small dikes occur somewhat abundantly at low horizons, but the greater number of Norwood's dikes are merely erosion points of the harder and more compact portions of the diabase flows.

[2] See A. R. C. Selwyn in Report of the Geological Survey of Canada for 1877–'78, p. 15, A.

sota, and thence northeastward to the Brulé Lake country, constitute so marked a feature in the geology of those regions, have been above alluded to as possibly owing their lack of structure to the enormous thickness of the outflow. There are some things about them, however, that suggest another origin. The great coarseness of grain; the perfection of the crystallization; the abrupt terminations of the belts; the complete want of structure and the presence of intersecting areas of crystalline granitoid rocks—all suggest the possibility that we have here to do with masses which have solidified at great depths. They certainly cannot, however, be regarded as intrusive; so that, unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come. The acid rocks cutting these coarse gabbros are certainly of this nature.

Of the original acid rocks of the Keweenaw Series true granite has been observed only in the Bad River region of Wisconsin, where it is seen intersecting the coarse gabbro of the base of the series, and also the underlying slates. It is there a coarse, flesh-colored, completely developed granite, cutting the gabbro in irregular masses and in broad bands. In the same region a brick-red granitic porphyry, or granitell, occurs in the same position, as do also thin seams of a rock midway between true granite and granitic porphyry.

Closely similar occurrences, both as to the containing and cutting rocks, obtain at Duluth, save that here we have none of the true granite, a brick-red augite-syenite being the principal intrusive rock. As seen at Duluth, these rocks often verge closely on granite on the one hand, and on the other can be traced through finer kinds into felsite and true quartziferous porphyry. They intersect the gabbro in the most irregular manner, forming great, irregularly-outlined patches in it, often many hundred square feet in area, and again occurring in sharply-defined veins a few feet, or even inches, in thickness. Some three or four miles north and west from the lake shore at Duluth, N. H. Winchell reports the bulk of the hills as composed of a crystalline red rock, similar to that of Duluth.[1]

Mr. W. M. Chauvenet has carried the Duluth gabbro, with its accompanying red rocks, westward for some ten miles, and northward for thirty-five miles to the Cloquet River, where the gabbro appears in large exposures. To the northeast N. H. Winchell reports a similar rock with a similar accompaniment at the headwaters of Poplar River, some twenty miles back from the lake, while Mr. Chauvenet has examined a large area of like character at the headwaters of the Brulé and Cascade rivers, and about Brulé Lake, in townships 62 and 63, ranges 1, 2, and 3 west, where the red granitic rock rises into mountain masses, a prominent instance of which is Eagle Mountain. This lies near the middle of township 63,

[1] The Building Stones of Minnesota, 1880, p. 7; also Annual Report of the Geological Survey of Minnesota for 1879.

range 1 west, and rises, a bald mass of red rock, to a height of 450 feet above the small lake at its western foot, and 1,500 or 1,600 feet above Lake Superior. Similar granitoid rocks occur at higher horizons along the Minnesota coast, and are always in intersecting masses, except when tending towards the quartziferous porphyries in character, when they appear to form flows of a similar nature to those of the latter rock. Intrusive augite-syenites are also met with in the Bohemian Range of Keweenaw Point.

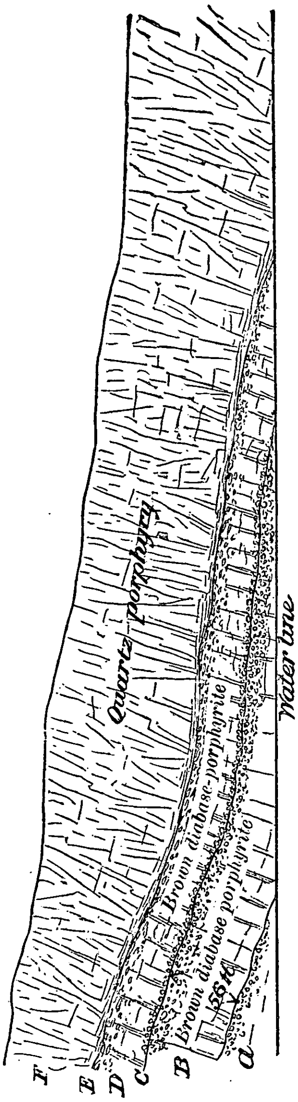


FIG. 39.—Section of South Cliff of the Palisades, Minnesota Coast. A, Amygdaloid. B, Columnar Diabase-Porphyrite. C, Amygdaloid. D, Columnar Diabase-Porphyrite. E, Amygdaloid. F, Quartz-Porphyry.

Quartziferous porphyries, in association with bedded diabases and melaphyrs, are met with at a number of points on the north shore between Duluth and Saint Ignace Island, south of Nipigon Bay.

One of the most instructive occurrences of true quartzose porphyry that I have yet met with throughout the entire lake basin, is at the "Great Palisades," on the Minnesota shore, six miles below the little hamlet of Beaver Bay, Sec. 22, T. 56, R. 7 W. The Palisades, which constitute the most striking feature of North-Shore scenery between Duluth and Pigeon River, rise in a sheer precipice from the water's edge, to a height varying from 150 to 300 feet. The length of the precipice, whose main front looks southeast by east and runs almost exactly with the general trend of the strata in the vicinity, is about three-fourths of a mile. At the north end, at the mouth of Palisade Creek, the cliff turns to the westward, and, facing first north and then west, is nearly as difficult in ascent in the woods as on the lake front. At the south end the shore of the lake runs back with an east and west course, in such a manner as to expose the mass, with the underlying rocks, in cross-section. The same underlying rocks are cut down into by Palisade Creek below the west cliff, so that the Palisade rock is a detached mass of porphyry, three-fourths of a mile long, one-fourth wide, and from 300 to 400 feet thick.[1]

The Palisade porphyry is a hard and dense rock, purplish-red on a fresh fracture, weathering to a light-red and even pink on the face of

[1] For map of these exposures see Fig. 20 of the memoir.

the cliff. The matrix is thickly studded with sharply-outlined, white and partially kaolinized orthoclase crystals, running up to 0.15 inch in length, and somewhat rarer and smaller black quartzes. In many cases the matrix shows a fine banding, due to faint differences in shades of color, lighter-colored laminæ appearing to alternate with darker. Sometimes these apparent laminæ are more definite, and from one to two tenths of an inch in width. More commonly they are exceedingly indefinite, and due to rows of lighter-colored, indefinite spots following one direction. Only rarely will the hand specimen show this lining plainly, but on the exposed and weathered surfaces it stands out prominently. In some places a decomposition akin to kaolinization has followed these lines on weathered surfaces, and then there is a cleavage parallel to them, and the resemblance to a material of sedimentary origin is still more pronounced. The lines preserve only a general parallelism to the bedding of the formation, being subordinately twisted and contorted into all sorts of shapes, so that on a cliff side their inclination will change from a nearly horizontal one to one of twenty or even forty degrees within a few feet. Where the lines are developed, the crystals of quartz and orthoclase are noticed to bear no relation to them at all, cutting across them commonly, and at all angles, the larger orthoclases even extending across two or three of the lines. Very much of the rock is observed to be without any sign of this lining.

Under the microscope, as shown in the previous chapter, the Palisade rock presents the common characters of a quartzose porphyry, and there is no trace of a fragmental nature. The quartzes are all in doubly terminated crystals, and streams of black particles run around them as if pushed aside when the rock was in a viscid condition.[1] The whole rock presents a vertically columnar structure, not developed so completely as in some of the diabases, but still very noticeable. The structure lies at right angles to the dip, which is some ten to twenty degrees east southeast, varying between those figures. On the main cliff, since it trends with the strike, the columns appear at first sight much more nearly vertical.

As already said, both in the Palisade Creek and in the bay at the south end of the Palisades, the underlying rocks are in sight. At the latter place a single cliff-side shows the great porphyry overlying a thickness of a hundred feet of diabase and diabase-amygdaloid. These are disposed in two great flows, 44 and 56 feet thick respectively, while the top of a third is seen rising just above the sand. Each of these diabases has most perfectly developed crowning and basal amygdaloids. We have thus a most unequivocal case of the superposition of true quartziferous porphyry upon the typical diabases and amygdaloids of the series.

The same layer that forms the Palisades—or another one closely like it—appears again in a bold point of bare rock 150 feet high, on the northeast side of Baptism River Bay, a mile and a half below the Palisades.

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[1] See Plate VII.

Here the underlying diabases and amygdaloids are again seen in position. The top of the point slopes off lakeward with the dip (about 8°). The more minute peculiarities of the rock, and its rude columnar structure, at right angles to the dip of the mass, are here just as in the Palisades. The same fine banding also appears in places, but is warped up and down, so as to change from horizontal to vertical within short distances. This rock is traced along the coast for about three-fourths of a mile, when it again disappears *underneath* another series of diabases and amygdaloids, interleaved with which are thin seams of red shale, and one bed of curiously intermingled shale and amygdaloid, precisely resembling the so-called ashbed of Keweenaw Point. Still three-fourths of a mile beyond, to the northeast, these diabases are overlaid by a pebble conglomerate, in which the matrix is red shale, and the pebbles rolled fragments of diabase and amygdaloid.

The occurrence of the porphyry of the Palisades and of Baptism River has thus been given at some length in this connection, because the relations of the basic and acid rocks are here so unmistakably plain, and because upon these relations rest important conclusions. There can be no doubt whatever that we have here, between two sets of perfectly and typically developed diabases and amygdaloids—those on the upper side carrying the customary seams of red shale—a true layer of quartziferous poryhyry, several hundred feet in thickness; while in the previous chapter it has been shown that this porphyry is as truly an eruptive rock as the associated basic kinds, presenting, as it does, all characters of an eruptive porphyry, viz: a base made up of imperfectly individualized or incompletely devitrified material; doubly terminated quartzes with inclusions of the base, and of unmistakable glass; and flowage lines.

Although they approach each other closely at numbers of other points on the north shore, the relations of the porphyry to the diabase flows is not always to be so well made out at first sight as at the Palisades. Often the porphyry exposures occur separated from any exposures of other rocks by long pebble-beaches. Again, they form merely projecting points, or restricted areas, between dark-colored rocks, apparently owing their preservation to a sudden bowing down of the strata, so that they represent subordinate synclinals impressed upon the general lakeward dip. Again, they come into abrupt and vertical contact with dark-colored diabases, and form masses which have been faulted into their present positions. Wherever these less plain occurrences have been closely studied it has become evident that in them, too, we have to do merely with interbedded porphyry masses.

As to the more minute characters of these other porphyries of the north shore, we may say that granitic porphyries are not common, that where they occur, except when almost granitic in texture, they can generally be carried directly into true quartz-porphyries, often showing the fine contorted banding of the Palisade rock; and that a very common feature of the quartz-porphyries and felsites is a close angular jointing, which, on a weathered surface, is often developed to such a degree that it is impossible to obtain a hand specimen of any size, or to get a fresh fracture, a slight blow of the hammer against the cliff bringing down showers of angular fragments. Where the fine banding mentioned is developed, it is commonly possible to trace the rock with contorted band-

FIG. 40.—Surface of felsite on Minnesota coast, showing flowage.

ing into massive and wholly unbanded kinds, with very large porphyritic quartzes and orthoclases. This change is to be seen beautifully at several points on the Canada shore, between Black Bay and Saint Ignace, notably at Bead Island, opposite Lamb Island light-house, at the mouth of Nipigon Straits. At one point on the North Shore, between

Beaver Bay and the Palisades, a pinkish quartzose porphyry was noticed in which the lighter matrix is streaked with a darker porphyry, arranged in all sorts of fantastic and snake-like forms, single figures extending sometimes for several feet, with a width of two or three inches, and running from these dimensions down to mere lines, the whole presenting the appearance of a somewhat irregularly-figured carpet. This peculiar structure I attribute to flowing in a viscid condition. At several places, as, for instance, in the Devil's Track River, near the lake shore, and again on the shore of the Pigeon River, Indian Reservation, the porphyry was noticed with a tendency to come out in thin, flat pieces, or pieces with a corrugated surface, but in this case, as usual, it runs into the compact structureless kind.

Quartziferous porphyries are again largely developed on the South Shore, with the same structural features as noted on the North Shore. Mount Houghton and the Bare Hills of the eastern end of Keweenaw Point are portions of a belt of banded quartziferous porphyry. These were long since mentioned by Foster and Whitney, who describe the rock as hardened sandstone; but I have been able to detect no trace of fragmental origin, the rock, under the microscope, as well as on the large scale, presenting all the characters of an original porphyry. The Mount Houghton porphyry seems to constitute a belt interstratified with the prevailing diabases and standing at a very high angle. It has a con siderable lateral extent, and I am disposed to place with it the quartzose porphyry of the Torch Lake Railroad, south of the Calumet mine, which is evidently the source of the pebbles of the Calumet conglomerate.

In the region between the Ontonagon River, of Michigan, and the Bad River, of Wisconsin, true massive quartziferous porphyries are largely developed. The exposures appear to lie in certain horizons, at least two of which have been recognized, and so to constitute layers in the series, though evidently very much less regular ones than those of the diabase.

In the Porcupine Mountains a quartzose porphyry constitutes the central mass of the mountains, the beds of sandstone, conglomerate, and slate dipping away from it on all sides, save where it connects on the south with the "Main-Trap Range." Here the subordinate features of the porphyries of the north shore are seen constantly repeated, but the mass as a whole is without any trace of stratification. The structure of these mountains is described and illustrated in some detail in Chapter VI of the original memoir.

As already indicated, I conclude with regard to all of these porphyries that they are unquestionably of eruptive origin. That they were formed both after and before the more common basic eruptive rocks is shown by such occurrences as that of the Palisades of the North Shore. These porphyry eruptions were evidently more plentiful in the earlier part of the time of formation of the series. Still, in the Ontonagon region, they occur at quite a high horizon. The structure of the Por cupine Mountains has so much in common with that of the laccolitic mountains of southern Utah, described by G. K. Gilbert, that they might be supposed to owe their elevation to an eruption of the porphyry of their central portions, in which case we should have to believe in an eruption of acid rocks at a time quite subsequent to that of the formation of the latest of the basic flows and of the larger part of the detrital division of the series. But, as shown in the original memoir, these mountains owe their existence in all probability to a fold, the porphyry of the central portions being one of the usual embedded masses laid bare by subsequent denudations.

The detrital members of the series do not present any structural features that are peculiar to them as compared with similar mechanical sediments of other regions. The conglomerate layers reach sometimes an extraordinary thickness, and are often made up so completely of large-sized pebbles that it is necessary to believe in the existence in such places of very powerful currents. Traced laterally these conglomerate belts have often a great extent, but they never remain constant as to coarseness or exact nature of materials. The "Outer Conglomerate," for instance, of Keweenaw Point—that seen from Copper Harbor eastward to the extremity of the point—is undoubtedly the same as the outer sandstone and conglomerate, immediately beneath the black slate of the Porcupine Mountains, and is the same as the great conglomerate of the Montreal, Potato and Bad rivers in Wisconsin. It has thus a continuous lateral extent as a single layer of at least 170 miles, and possibly a much greater extent, but in this long distance it varies from less than 100 to 4,000 feet in thickness, is now pure sandstone, now nearly all conglomerate, now a sandstone with conglomerate bands, and again a coarse bowlder conglomerate. Moreover, as already noticed, the nature of the pebbles presents many variations along the course of the belt, depending upon similar variations in their source of supply.

Of the thinner conglomerates which are intercalated at all horizons in the Keweenaw Point region, one, the so-called Albany and Boston, lying immediately underneath "The Greenstone," has been traced for a distance of as much as 50 miles, but varying along its course from a full conglomerate to a mere red shale seam. From what I have seen, I have little doubt that a number of the thinner conglomerates have even a greater extent than this.

CHAPTER V.

GENERAL STRATIGRAPHY OF THE KEWEENAW SERIES.

The most prominent fact in regard to the stratigraphy of the Keweenaw Series is its separation into two grand divisions: an upper member, apparently wholly made up of detrital material, for the most part red sandstone and shale; and a lower member, made up chiefly of a succession of flows of basic rocks, but including layers of conglomerate and sandstone nearly to the base, and more or less of original acid rocks.

The line of separation between these two groups has to be adopted somewhat arbitrarily, since the sandstone gradually increases in quantity upwards; but placing it at the base of the outer conglomerate of Keweenaw Point—which corresponds to the top of the upper amygdaloid of the Porcupines, and to the base of the great conglomerate of the Montreal, and which is above any known occurrence of eruptive matter[1]—I estimate the upper division to attain a maximum thickness of about 15,000 feet in the middle portion of the Lake Superior basin Towards the eastern and western ends of the basin the thickness must be much less than this.

The sandstones of the upper group are largely concealed beneath the waters of Lake Superior, whose basin has been in some measure carved in them; but they form the outer part of Keweenaw Point, reaching in the neighborhood of Portage Lake a considerable surface width. Westward from Portage Lake they underlie, sloping at a low angle lakeward, the flat land north of the Trap Range, and are well exposed at a number of points along the shore to the Porcupine Mountains. The Porcupine Mountain fold throws them well out into the lake, but further west they form a belt along the edge of the land, and, since they are here standing at high angles, a large thickness is embraced in this narrow belt. On the Montreal the angle reaches ninety degrees, and nearly the whole thickness of the upper group is crossed by the lower reaches of the river. Here the upper division consists of some 12,000 feet of red sandstone and shale, about 500 feet of black shale alternating with hard, gray, nearly quartzless sandstone, both shale and sandstone being composed largely of basic detrital material, and about 1,200 feet of very coarse bowlder conglomerate. The same succession seems to hold all the way to where, on Keweenaw Point, the base of the upper division runs out into the lake, the only difference being that the basal conglomerate at times passes into a sandstone.

Westward from the Montreal River, also, the same succession seems

[1] See accompanying Plates VIII to XIII.

THE EASTERN SANDSTONE — 9

KEWEENAW SERIES.

UPPER DIVISION.

Red Sandstone	8
Dark-grey Sandstone and Black Shale	7
Sandstone with thin bands of Conglomerate	6

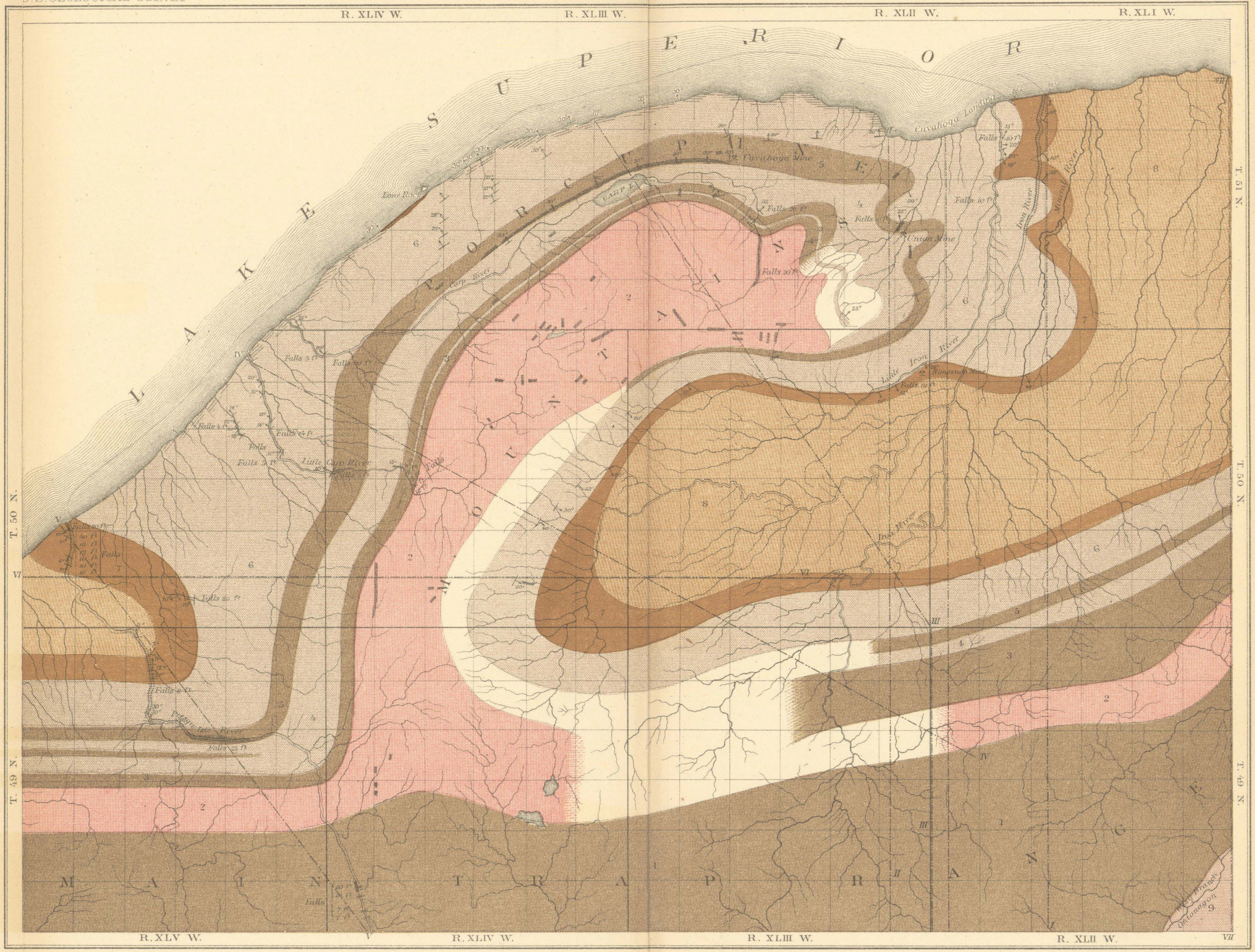
LOWER DIVISION.

Diabase, Diabase-amygdaloid and Melaphyr.	5
Sandstone and Conglomerate	4
Diabase, Diabase-amygdaloid Melaphyr and Diabase-porphyry with one Porphyry-conglomerate	3
Quartz-porphyry, and Felsite	2
Diabase and Diabase-amygdaloid including narrow Conglomerate Belts	1

Scale: $\frac{1}{125000}$ or 1 inch 1.973 miles

Prominent exposures of massive rocks

Exposures of detrital rocks showing dip and strike.



GEOLOGICAL MAP OF THE PORCUPINE MOUNTAINS, MICHIGAN.

to hold, the conglomerates and shale at the base, however, thinning out. The last seen of these northward-dipping sandstones and shales, which have thus been traced all the way from Keweenaw Point, is on the Brunschweiler River, in the western part of Ashland County, Wisconsin. West of this they have not been observed, the country which would be occupied by them being everywhere drift-covered. The underlying diabase, however, appears all across Wisconsin with a flattened dip; while on the Upper Saint Croix there is a large development of sandstones dipping southward, which are evidently the same we have been following, forming the other side of the great synclinal which crosses the whole northern part of Wisconsin. The same southward dipping sandstones are to be seen in the northern part of Ashland County.

The Apostle Islands and the adjoining coast of Wisconsin are underlaid by horizontal sandstones. These are to be regarded as an overlying, unconformable formation belonging with the horizontal sandstones of the east side of Keweenaw Point;[1] but it is to be observed that it is not structurally impossible that these horizontal sandstones should be the same as those I have been considering, since, according to the structure I have worked out for this part of the basin, the upper Keweenawan sandstones should themselves have here a position not appreciably different from horizontality.[2]

The upper sandstones appear to view again on the south side of Isle Royale, with a considerable development. Caribou Island, south of Michipicoten, appears also to be made of them, but they do not show at any other point. Still, they must have a very extensive development underneath the waters of Lake Superior in its eastern as well as in its western portions.

The lower division of the series must, from the nature of the case, present very considerable variations in subordinate stratigraphy and total thickness. For portions of the basin, and even over areas fifty to two hundred miles in length, it is possible to recognize a pretty constant subordinate arrangement; the constancy increasing, of course, in inverse ratio with the size of the district covered. It is not possible, however, to lay down any scheme of subordinate stratigraphy which shall hold for the entire extent of the series. This results not only from the mode of formation of the rocks, but from the great similarity of the beds at different horizons, and through great thicknesses. Nevertheless, it is possible to make a number of generalizations as to the characteristics of broad horizons which will hold throughout most, often all, of the geographical extent of the lower division of the series. These are enumerated in the next paragraph.

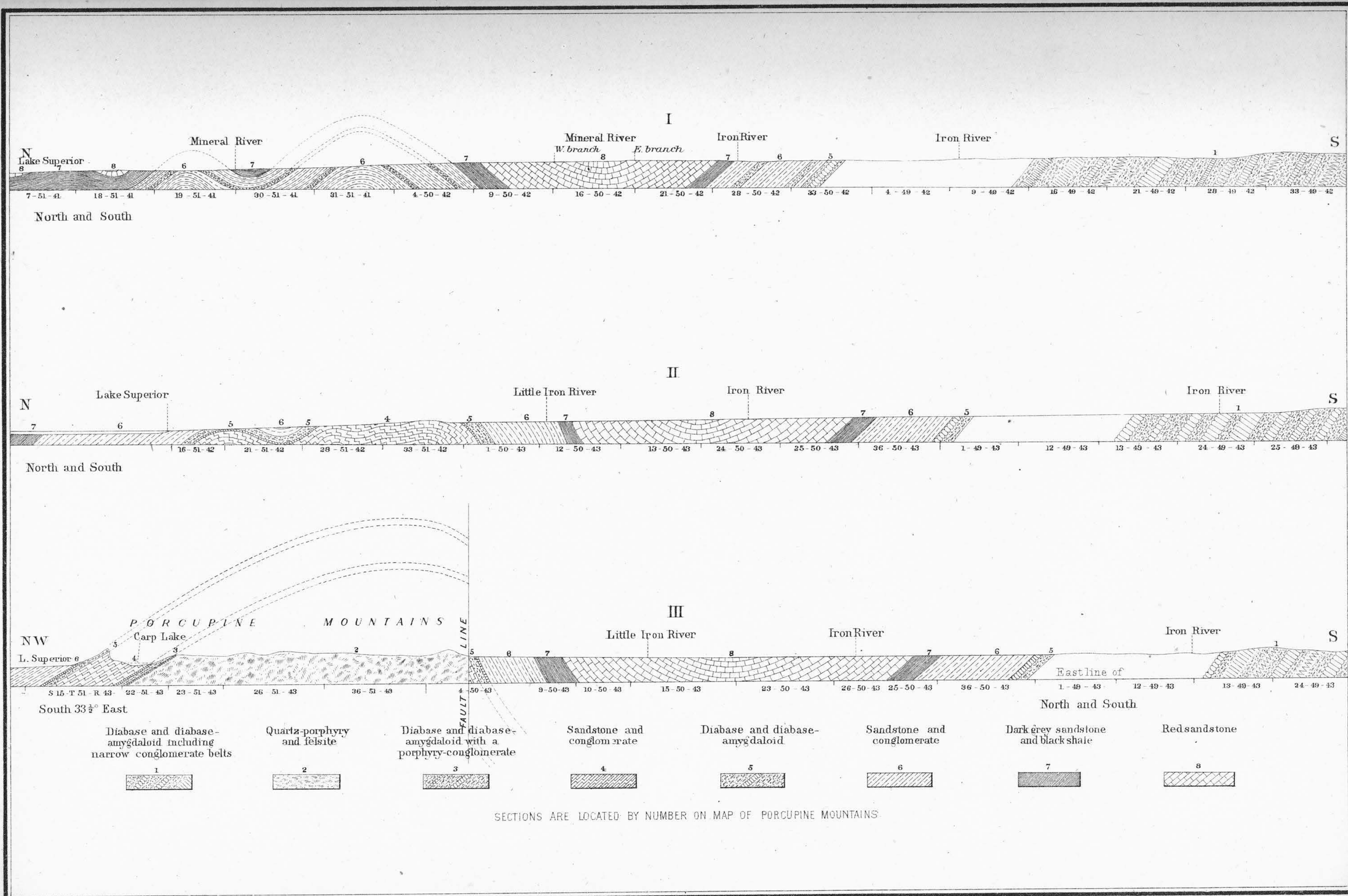
(1) Coarse-grained rocks, including both orthoclase-free and orthoclase-bearing kinds, though occurring now and then well up in the lower division (*e. g.*, some of the beds of the "Greenstone Group" of

[1] Geology of Wisconsin, Vol. III, Part I.

[2] See Plate XVI, and the explanations of Chap. IX.

Keweenaw Point), are very much more common at low horizons; and the very coarsest kinds have been observed only at the base of the series (Bad River gabbros; Duluth gabbros). (2) Very heavy bedding is also much commoner at low horizons; and this statement affects both coarse-grained and fine-grained kinds (*e. g.*, the fine-grained diabases of the "Duluth Group" of the north shore). (3) The amygdaloidal texture is more frequent, and more highly developed at high horizons than at low; the thinner beds generally having the most strongly developed amygdaloidal or vesicular portions. (4) As to the distribution of the different kinds of basic rocks, the fine-grained, olivine-free or "ordinary" diabases affect very decidedly the higher horizons (*e. g.*, Keweenaw Point), though occurring throughout. Olivine-bearing kinds, both the coarse-grained gabbros and fine-grained, luster-mottled kinds, are decidedly more common at low horizons, though as before not restricted to them (*e. g.*, the "Greenstone Group" of Keweenaw Point). The ashbed-diabases and diabase-porphyrites are also very much more common at low horizons (*e. g.* "Lester River Group," "Duluth Group," etc.), and the same is true of the orthoclase-gabbros. (5) Of the acid rocks all kinds affect especially low horizons, rarely reaching above the middle of the lower division. The porphyries of the region between the Ontonagon and Bad rivers on the south shore seem to be an exception to this rule; but in this case their appearance at so high a horizon may be due in some measure to the thinning out of overlying beds. A more distinct exception to the rule is probably to be found in the case of the red felsite of the island off the harbor on the south side of Michipicoten Island. (6) Detrital beds—chiefly porphyry conglomerates and red sandstones—occur all through the series, having been seen all the way from the base to the summit, but they are rare in the lower third of the series, and as a rule increase in thickness and frequency towards the top, only one instance, to be noted hereafter, being known of a heavy bed at a low horizon.

The coarse gray gabbros, so largely developed in the Bad River region of Wisconsin, at the base of the series, present the appearance of a certain sort of unconformity with the overlying beds. These gabbros, which lie immediately upon the Huronian slates, form a belt, which tapers out rapidly at both ends, and seems to lie right in the course of the diabase belts to the east and west; since the latter rocks, both westward toward Lake Numakagon and eastward toward the Montreal River, lie directly upon the Huronian schists, without any of the coarse gabbro intervening. The great extent of coarse gabbro in Minnesota seems to sustain somewhat the same relation to the more regularly bedded formations of the series. The Minnesota gabbro, with its accompanying granite and granitic porphyry, occupies a belt from five to twenty or more miles in width, extending from the Saint Louis River, at Duluth, northward to and beyond the Cloquet, and thence eastward to the



Julius Bien & Co. lith

GEOLOGICAL SECTIONS ILLUSTRATING THE STRUCTURE OF THE PORCUPINE MOUNTAINS

Scale $\frac{1}{100,000}$ or 1 inch = 8333 feet.

region of Brulé Lake in township 63; but where the base of the series comes out to the lake at Grand Portage, the gabbro is absent, the regularly bedded diabases and amygdaloids resting directly upon the older slates.

For these reasons I was, at one time, somewhat inclined to place these gabbros with the Huronian, and to regard them as possibly the equivalents of the great flows that crown the so-called "Animikie" slates in the region of Thunder Bay. In the Bad River region, however, where the rocks all dip at a high angle to the northward, the coarse gabbro appears to cut across the Huronian at a very small angle, and in such a manner as to come into contact with successively lower members of the Huronian,[1] when the rocks are traced on the strike westward. This appears like an unconformity with the Huronian, and on this account, as also because of the close lithological relationship between the gabbros and the typical Keweenawan diabases, many of which approach gabbro in character, I prefer to regard these coarse rocks as the earliest of the Keweenawan flows. I have already referred to the possibility of their representing the slowly solidified and subsequently denuded reservoirs, from which the later flows might have been in part derived.

I have alluded above to an exception to the general fact of the thinness of the detrital beds at low horizons. The reference was to a set of dolomitic sandstones, running upward into red marly clays and limestones, which are largely developed in the peninsula between Thunder and Black bays, and reach a thickness, according to Bell,[2] of about 1,300 feet. These are the sandstones to which Hunt has proposed to restrict the term "Nipigon Group"[3] and which he considers as newer than the Keweenawan. I satisfied myself, however, on the ground, that Logan was correct in placing them directly beneath the whole mass of Keweenawan diabases and amygdaloids of the east side of Black Bay, and that they rest with slight discordance upon the nearly horizontal Thunder Bay slates, to which Hunt has applied the name of Animikie Group."[4] He regards the Animikie rocks also as newer than the Keweenawan proper, but I look upon them as beyond question the equivalents of the iron bearing or so-called Huronian rocks of the South Shore. The relations of these several groups are considered more especially on a subsequent page, and are merely mentioned here, because I know of no other instance in the entire extent of the formation of the existence of such a thickness of detrital rocks at so low a horizon. Only forty miles southwestward from their occurrence on the east side of Thunder Bay, at Grand Portage Bay, the intervening space being water-covered, the Keweenawan diabases rest directly upon the slates of the so-called Animikie Group, without any intervening sandstone.

[1] See map of Plate XXII, Atlas of the Geology of Wisconsin.
[2] Report of the Geological Survey of Canada for 1867-'69, p. 319.
[3] Second Geological Survey, Pennsylvania. "Azoic rocks" E., pp. 240, 241.
[4] *Loc. cit.*, p. 240.

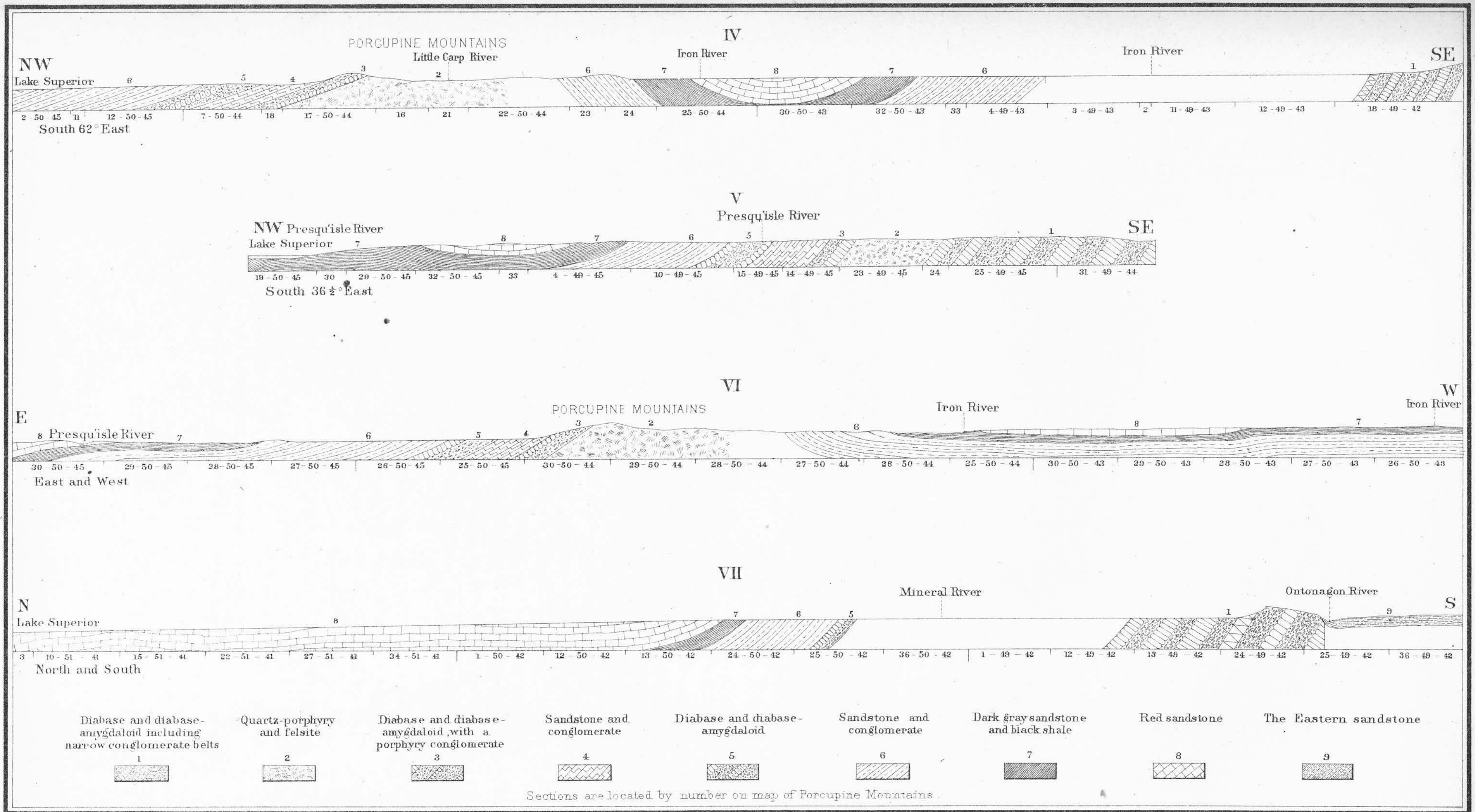
The thickness of the lower division is always enormous, and may be placed in round numbers at from 25,000 to 30,000 feet. From this figure there are, of course, some considerable variations; and yet, considering the way in which most of the series has been built up, the variations must be regarded as surprisingly small. With the exception of the unusually great and sudden thinning in the Bad River region of Wisconsin, it does not appear probable that throughout all of its geographical extent the thickness of the lower division sinks much below 25,000 feet.

In the eastern part of Keweenaw Point the maximum thickness of the lower division at surface is some 25,000 feet. This measurement, however, does not go to the base of the series, but only to the junction with a newer sandstone, which overlies both a repetition of more or less of the thickness included in the above 25,000 feet, and the downward continuation of the series. The amount to be added for this downward continuation can only be guessed at.

Eastward from the eastern part of Keweenaw Point to the Ontonagon River the total thickness of the lower division seen is from 12,000 to 17,000 feet, but in all this distance only the upper limit of this is in sight, the same fault and newer sandstone as met with on Keweenaw Point bounding the exposures on the south, and rendering uncertain the total thickness.

West of Lake Agogebic the Eastern Sandstone does not extend far, and the two ranges of Keweenawan rocks, which to the eastward bounded it on the north and south respectively, coming together, we have, for the first time, the whole thickness of the lower division at surface with its lower limit well defined. On the Montreal River, taking the surface width and dip angles together, the apparent thickness is as much as 33,000 to 35,000 feet; but how much of this may be due to the continuation westward of the Keweenaw fault, or whether this fault extends so far as this, it is impossible to say. It certainly does not extend much farther, and from its evidently rapid decrease in throw from the Ontonagon River westward it seems probable that its influence on the Montreal cannot be great.

On Bad River, eighteen miles southwest of the Montreal, the lower division has a surface width, from the Huronian slates below to the sandstones of the upper division, of only 17,000 feet. Since the dip here is perpendicular, or nearly so, the thickness is not much less than this. It is shown in the original memoir that this extraordinary thinning is connected with the presence below of a great belt of the coarse gabbro described in a preceding paragraph of this chapter. This coarse gabbro—whether with or without interbedded fine-grained beds is not now known—usurps most of the thickness, leaving only some 5,000 feet for the usual thin-bedded flows of the lower division. The explanation may be that, early in the history of the series there was poured out here an immense thickness of a rock which solidified into the coarse gabbro,



Julius Bien & Co. lith

GEOLOGICAL SECTIONS ILLUSTRATING THE STRUCTURE OF THE PORCUPINE MOUNTAINS.

Scale $\frac{1}{100,000}$ or 1 inch = 8333 feet.

while later in its growth the vents were removed from here to either side. The coarse gabbro mass must have stood up to a great height, and the later flows terminated against it on either side, until they had accumulated sufficiently to overflow its upper surface.

Twenty miles west of Bad River the coarse gabbro has thinned out, and beyond it to the west and southwest, all the way to the Saint Croix Valley, the lower division must have its old thickness of 25,000 feet, to judge from the country covered and dip angles observed.

On the west side of the Saint Croix Valley the thickness must be as great; the surface width from east to west on Snake and Kettle rivers being as much as nine miles, which, with the high easterly dips in the lower layers (45° to 70°), must mean a thickness of nearly 25,000 feet, without reaching either the upper or lower limit of the division.

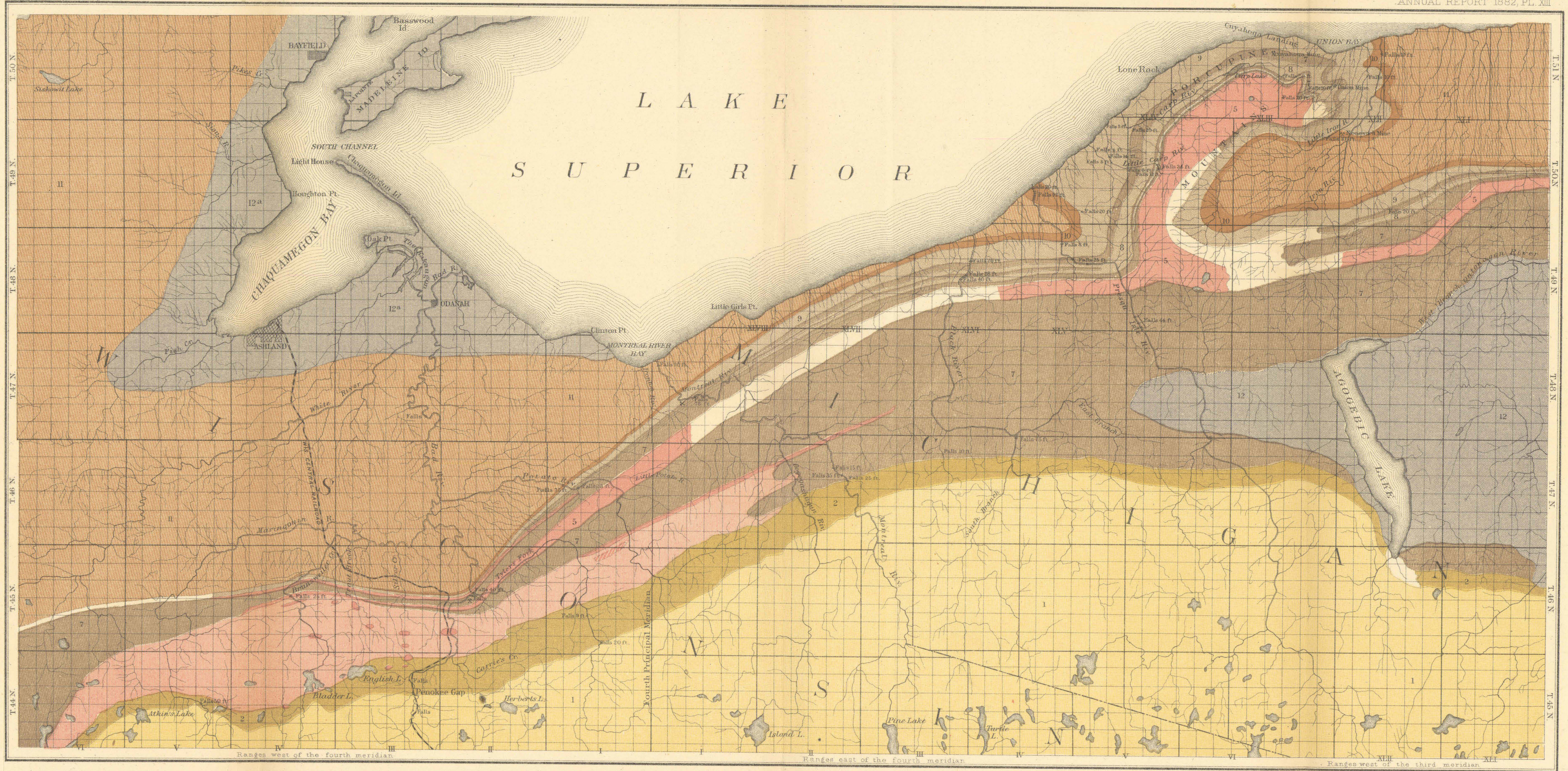
The copper range of Douglas County, Wisconsin, again, appears to indicate by its exposures nearly as great a thickness, for, although the belt of exposures is relatively narrow, its direction is oblique to the courses of the constituent beds. The dip of these beds is southeasterly, and in going along the range eastward one is steadily descending in horizon. Here again the lower limit must be several thousand feet below the lowest rocks seen.

On the Minnesota coast I estimate the total thickness above the Huronian or Animikie slates to be some 22,000 to 24,000 feet at the west end of the coast, and not more than 16,000 at the east end. This difference is due in large measure to the total disappearance of the coarse gabbro belt of the Saint Louis—a case analogous to that of the coarse gabbros of Bad River, in Wisconsin—but also to the thinning eastward of higher layers. Several thousand feet must intervene between the highest rocks of the Minnesota coast and the summit of the lower division.

Isle Royale is formed of a succession of beds dipping southward at an angle which increases in amount, as the series is crossed from south to north, from 8° to 10° to a much higher but undetermined figure. The southernmost or highest layers belong to the upper division, while most of the island is made up of layers of the lower division, with a total thickness which cannot be much less than 10,000 feet, and may be much more. To judge from the courses of the rock belts on Isle Royale and the eastern end of the Minnesota coast, the higher beds of the latter are the same as the lower of the island, and the two together seem to indicate a total thickness of as much as 25,000 feet.

About Black and Nipigon bays the Keweenawan flows dip at a low angle to the southeast and south, and reach a total thickness which does not exceed 7,500 to 8,000 feet, measuring from the older rocks upward. The greater part of the lower division must here be concealed beneath the lake.

Michipicoten Island, according to Macfarlane's measurements, displays a total thickness of 18,500 feet, all of which belongs to the lower division, neither limit of which is in sight. From the position of the island it appears that the whole thickness here must be 25,000 feet, or over. At the promontory of Mamainse, again, according to the same authority, there are 16,000 feet of Keweenawan strata displayed, all belonging to the lower division. This thickness is measured from the base of the series, and, judging from the lithological character of the Michipicoten and Mamainse successions, Macfarlane considers the rocks of the former to rise to a higher horizon by 4,000 feet, and so estimates the thickness of the Mamainse series at 20,000 feet, without any indication that the upper limit is reached.



GEOLOGICAL MAP OF THE REGION BETWEEN THE ONTONAGON RIVER, MICHIGAN, AND NUMAKAGON LAKE, WISCONSIN.

CHAPTER VI.

THE KEWEENAWAN ROCKS OF THE SOUTH SHORE OF LAKE SUPERIOR.

This chapter in the original memoir includes full local descriptions of the several districts south of Lake Superior, in which the Keweenawan rocks are developed, compiled from the reports of Foster and Whitney, Pumpelly, Marvine, Sweet, Strong, and Chamberlin, and from original observations. These descriptions are too lengthy to be inserted here. Throughout the chapter entirely new facts and conclusions are interwoven with the old. The descriptions of the earlier geologists have been studied on the ground, and extended microscopic studies made of the rocks of all the districts. Among the more important new points are: (1) the recognition of the red rock of Mount Houghton, of the Bare Hills of Keweenaw Point, and of the central area of the Porcupine Mountains as an eruptive felsitic porphyry; (2) the recognition of the essential identity, denied by Foster and Whitney, between the rocks of the Bohemian Range and of the more northern belts of Keweenaw Point; (3) the recognition of the rock of the Stannard's Rock Reef as a non-quartziferous porphyry, and therefore, as belonging to the Keweenaw series, and as indicating the southeasterly course, beyond Keweenaw Point, of the Keweenawan rock belts; (4) the recognition of the Nonesuch silver-bearing dark-colored sandstone as a continuous belt from near Gratiot River on Keweenaw Point to west of Bad River in Wisconsin; (5) the determination of the structure of the Porcupine Mountains; (6) the recognition of the rocks of the "South Range" and of Silver Mountain as part of the Keweenaw Series, and as separated from the Keweenaw Point range by a longitudinal fault, etc.

CHAPTER VII.

THE KEWEENAWAN ROCKS OF THE NORTH AND EAST SHORES OF LAKE SUPERIOR.

Like the preceding, this chapter comprises detailed descriptions of local developments of the Keweenawan rocks. It cannot, therefore, be quoted at any length. So far as the Minnesota coast is concerned, the facts and conclusions advanced are entirely new, while there is much new matter—more especially with regard to the lithological nature of the rocks described—mingled with the descriptions of the other Keweenawan districts of the north and east coasts. Some of the more general statements of this chapter as to the North Shore, and especially as to the Minnesota coast, are introduced here as of especial interest. These statements should be read in connection with plates III, XIV, XV, and XVI.

The north and east coasts of Lake Superior together form one of the finest lines of rock-exposure in the world. From Duluth to the Sault—a distance of over 600 miles, without taking into account any but the greatest indentations—the rocks are in nearly continuous exposure. Short pebble beaches, usually not more than a few rods in extent, and very rarely over a mile, here and there interrupt the absolute continuity of the exposure; but even in these places the rocks on either side of the gap may often be connected by outcrops in the woods behind, by islands in front, or by continuous rock surfaces not too far beneath the water. Frequently the exposures are abrupt cliffs rising from the water's edge to a height more commonly from 20 to 50 feet, less commonly from 50 to 1,000 feet. Only rarely are the exposures of soft rocks like sandstone; and for the most part they are of some sort of crystalline rock.

The North Shore thus stands sharply contrasted with the south in its scenic characteristics. Except over short distances between Marquette and Keweenaw Bay, on the north shore of Bête Grise Bay, and on the north side of Keweenaw Point, the south coast of Lake Superior shows only sandstone or conglomerate as the shore rock, while even these rocks are absent for fully 200 miles of the distance between Duluth and the Sault, counting only those interruptions to rock exposures which are more than two or three miles in length. Low cliffs of sandstone are met with at several points on the south shore, but the highest do not exceed 75 feet. Moreover, except on the eastern part of Keweenaw Point, and in the Huron and Porcupine mountains, there is either no high

GEOLOGICAL MAP OF THE NORTH WESTERN COAST OF LAKE SUPERIOR.

ground, or it is so far inland as to have little influence on the shore scenery.

From the head of the lake to Grand Portage Bay, or nearly to the national boundary line, a distance of about 150 miles, typical Keweenawan strata form the coast. At Grand Portage the slates, with interbedded and intersecting diabases and gabbros, which make up the so-called Animikie Group, or "lower division of the copper-bearing series" of the Canadian geologists, but which I take to be undoubtedly Huronian, rise from beneath the Keweenawan beds. These slates form Pigeon Point, the north and west sides of Thunder Bay, and the islands at its mouth, including Thunder Cape. Isle Royale is composed of Keweenawan strata, undoubtedly, in part the continuation of beds seen on the Minnesota coast. The peninsula between Black and Nipigon bays is composed chiefly of sandstones belonging at the base of the Keweenaw Series, while typical Keweenawan diabases, amygdaloids and interbedded sandstones, and porphyry conglomerates, with the usual massive porphyries, form the coast and its numerous flanking islands from Black Bay to the east end of the Battle Islands, a distance of some 75 miles. Beyond the Battle Islands the north and east coasts are formed chiefly of ancient gneisses and crystalline schists, some of which possibly belong with the Huronian, though, as indicated in a subsequent chapter, this must remain a matter of some doubt. Along the eastern coast, however, as far as the Sault, Keweenawan beds form now and then projecting headlands. Michipicoten Island is also made up by the same formation.

The Minnesota Coast.—Along this coast the rocks dip almost constantly lakeward, either trending with the general direction of the coast line, or cutting it at a small angle. The only exception to this rule is the group of beds in the angle of the lake at Duluth, where the strike is at first even slightly west of north, but rapidly changes to north and east of north within a distance of three miles along the coast, which here trends N. 50° E. Except in the same place, where the dips reach 45° eastward, lessening to 15° or 20° within a short distance, the lakeward dips are at a low angle. The same flat lakeward dips prevail for miles back of the coast line.

The actual western termination of Lake Superior is near the village of Fond du Lac, Sec. 8, T. 48, R. 15 W. In this vicinity, on both sides of the Saint Louis, are sandstones trending from north to north-northeast, with an eastward slant of 5° to 10°. Following the Saint Louis upwards these sandstones are found overlying slates of the Animikie Group (Huronian) on the southeast quarter of Sec. 11, T. 48, R. 6 W., three miles due west of the sandstone at Fond du Lac. The slates continue for many miles up the Saint Louis. Both slate and sandstone are described on a subsequent page. The same slates and sandstones appear on Mission Creek, north of Fond du Lac, beyond which, to the northeast, is a gap of three miles without exposures. Then begins a long series of bold rocky hills, which continue along the north side of the Saint Louis to Duluth. These are composed of gabbro, associated with which is much of two kinds of red porphyry. In the gap between the gabbro and the slate on the Saint Louis, the base of the Keweenaw Series lies concealed.

The Saint Louis River slates at Thompson, eight miles west of Fond du Lac, trend N. 85° E., and have a dip of some 30° to 40° southward. Farther down stream, towards the junction with the overlying sandstone, they trend somewhat more to the northeast. The gabbro does not exhibit any sign of bedding. However, the trend of the hills it forms in the southeast part of T. 49, R. 15 W., is about N. 45° E., and, nearer Duluth, still more to the north. Eighteen miles north of Duluth, on the Cloquet River, in the southern part of township 53, range 14 west, the same gabbro reappears. It seems to form a belt running at first northeast and then more and more to the north, until it finally takes a nearly northerly course. So far as these facts go, there is no definite evidence of unconformity between the gabbro and the Saint Louis slates. The appearance is rather the other way.

In the eastern part of the city of Duluth we begin to find plainly bedded rocks flanking the coarse gabbro on the east, and for the entire distance to Grand Portage Bay these bedded rocks prevail, and also back in the country for many miles. They are diabases of several kinds; amygdaloids; typical luster-mottled melaphyrs, or fine-grained olivine-diabases; coarse-grained gabbros, belonging chiefly to the orthoclase-free kinds, but including also orthoclase-gabbros; anorthite rock; felsites; quartz-porphyries; granitic porphyries; porphyry conglomerates, and red sandstones and shales; in other words, precisely the same rocks that characterize the Keweenaw Series on the South Shore. Detrital beds are here relatively rare, and the beds thin, as compared with those of the Keweenaw Point series; but we have here to do with quite low horizons, which are in general comparatively free from detrital layers.

At Duluth, as already said, the trend of the layers in sight on the coast is at first even slightly west of north, with an easterly dip of 45°. These are rapidly changed for a due northerly trend, and 25° easterly dip; and these again, by the time the mouth of the Lester River, which is 5½ miles below Duluth, is reached, for a 30° E. trend, and a 15° SE. dip. Between Lester and French rivers the strike direction makes more and more easting, becoming, finally, on French River, 12½ miles below Duluth, N. 50° E., the dip remaining at 15° SE. From Duluth to French River the coast line trends about N. 50° E.; so that in this distance the rock beds, running more to the north than the coast line, intersect it at an angle which varies from 45° near Duluth to nearly 0° at French River. One interesting result of this relation between the trends of the strata and of the coast line is the production of points projecting southwestward, and formed of the harder beds. It is these projecting points, with other smaller ones along the Minnesota coast, that have been represented by Norwood as formed of a series of dikes. As shown below, dikes exist here; but they are relatively very infrequent, and nearly always of small thickness. From Duluth to French River, then, there is a constant ascent in geological horizon, and the thickness crossed cannot be much less than from 8,000 to 9,000 feet.

From French River to Burlington Bay there is again a somewhat more northerly trend in the rock beds; but, since the coast line here also runs more around to the north, the dips at the same time flattening to 10°, and even 6°, there is not much added to the thickness above given in this distance. After Burlington Bay is passed, the strike begins to cut the coast more sharply, and by the time Split Rock River is reached, 45 miles below Duluth, fully 10,000 feet of thickness has been crossed.

In the vicinity of Split Rock River the layers strike nearly due north, cutting the coast at an angle of 35°; but half way between Split Rock River and Beaver Bay, coast and strata are again trending together at about 40° east of north. Below Beaver Bay, again, the strata turn away from the coast to the northward, and for some two miles below Baptism River strike only a very few degrees east of north, and by this time the coast must have crossed fully 16,000 feet in thickness of rock beds. Beyond the last point, however, both coast and strata begin curving more and more around to the east, the two coinciding at N. 50° E. somewhere between Petit Marais and Two Islands River. In the vicinity of Two Islands, Cross, and Temperance rivers are the highest strata met with anywhere on the Minnesota coast, or, indeed, on the entire north side of the lake, with the exception of Isle Royale. In the 80 miles between Duluth and Temperance River the coast line has crossed a rock thickness of some 17,000 feet.

Two miles below Temperance River, in Sec. 28, T. 59, R. 4 W., a descent of the coast line in geological horizon begins to be perceptible. This descent continues without interruption all the way to the end of the Minnesota coast, at Pigeon Point, a distance of 70 miles. From Temperance River to Grand Portage, both coast line and strata curve more and more to the eastward; but the strata change direction more rapidly than the coast line, so that they cut it at a small angle all the way, producing points like those described as characterizing the coast line west of Temperance River, but with the difference that the points now project eastward, instead of to the southwest. At Grand Portage, the Keweenaw beds striking out under the lake, the Huronian or Animikie slates appear from beneath.

The Minnesota coast line, looked at as a whole, presents a sort of flat crescentic shape, with the concavity towards the lake. The same is true of the courses of the strata; but the crescents formed by them have a much smaller radius, and hence intersect that formed by the coast line, trending more to the north at the Duluth end, and more to the east at the Grand Portage end. In following the coast, then, from Fond du Lac to Grand Portage, we ascend in geological horizon to a point near Two Islands River, and from a point just east of Temperance River descend again to the underlying slates at Grand Portage. Since the exposures are almost continuous, the coast line thus gives a complete cross-section of the whole thickness of Keweenawan beds present in northeastern Minnesota. Since the junction line between these Keweenawan strata and the underlying slates makes quite a large angle with the lake shore at both ends, and since the prevailing dips are so flat, it follows that the first-named rocks spread far back into the country. At the mouth of the Brulé River they extend some 12 miles back; at Grand Marais, 18 to 20 miles; at the middle of the crescent, near Manitou River, 30 miles; at about which distance they remain until near Duluth and the Saint Louis River. The underlying slates themselves have the same flat position, so that they in their turn spread over a wide belt of country.

Equally simple with the general structure, as thus laid down, is the general stratigraphical succession displayed on the Minnesota coast. Certain groups of beds are plainly to be made out, and in many cases minute stratigraphical measurements could be made in detail through thicknesses of thousands of feet. Of course, the greater the detail attempted, the greater would be the obstacles met with, in the way of faults—which are numerous—thinning out of beds, corrugations of beds, and similarity of lithological composition between different layers.

All of the Keweenawan beds of the Minnesota coast belong to the lower division of the series. The same statement applies to all of the Keweenawan rocks of the north shore, except a small area at the southeast corner of Isle Royale.

The following are the groups of beds recognized along the Minnesota coast, with a total thickness of upwards of 20,000 feet. The thickness of the first group is so uncertain, and, indeed, irregular, that it is difficult to give an approximately correct estimate of the total thickness. Above the lowest group, as already said, the thickness appears to lie between 17,000 and 18,000 feet. In all probability, 22,000 to 24,000 feet would be, as an estimate of the total thickness, not very far from the truth.

I. The Saint Louis River gabbro and associated red porphyries.—Chiefly coarse orthoclase-gabbro, but including also orthoclase-free gabbros, and a very few fine-grained diabase beds. Red augite-syenite and granitic porphyry occur in large areas, constituting at times the entire mass of hills. Felsitic porphyries occur, but more rarely. Similar rocks, similarly associated, occur at the same horizon, about the headwaters of Poplar, Cascade, and Brulé rivers, but are not found where they should appear at the Grand Portage end of the coast, though it is quite possible, and even probable, that some of the overflows of coarse gabbro found capping the slates of the Thunder Bay country belong here. The thickness of this group is difficult to estimate, but is probably not overstated at 6,000 feet.

II. THE DULUTH GROUP.—A succession of heavy but sharply defined beds of very fine-grained but aphanitic rocks, belonging to the ashbed type of diabases, and, to the diabase-porphyrites. A very few beds of rather coarse-grained orthoclase-free gabbro are included, and there is a little interleaved detrital matter. Thin amygdaloids of peculiar character cap many of the beds of the upper two-thirds of the group, but the amygdaloidal character never reaches so great a development as in some of the succeeding groups. This group is distinctly recognizable at both ends of the coast, and at points in the interior, wherever its course has been crossed. Its thickness lessens as it is followed eastward, but at Duluth it is not far from 5,000 feet.

III. THE LESTER RIVER GROUP.—A succession of heavy, distinct beds of fine-grained brown rocks, largely of the "ashbed" type. Diabase-porphyrites, some of the ordinary diabases, rare coarse-grained beds, and two or three belts of granitic porphyry are also included. Amygdaloids are almost unknown, and no detrital material has been observed. The rocks of this group are known at both ends of the coast, and at intervening points in the interior. The thickness is about 2,600 feet.

IV. THE AGATE BAY GROUP.—A succession of relatively very thin beds with very highly vesicular stratiform amygdaloids, which must make up two-thirds of the thickness of the group. The prevalent non-amygdaloidal rock is a fine-grained olivine-bearing diabase or melaphyr. Towards the base are a number of layers of diabase-porphyrite, also with strongly developed amygdaloids. Thin seams of reddish sandstones and conglomerate are also included. This group forms the coast line for a distance of some 35 miles below the mouth of Lester River, and has been traced some miles farther east by exposures in the back country; but it does not appear at the eastern end of the Minnesota coast, having apparently quite thinned out, in accordance with the general law of thinning towards the east, which is obeyed by all three groups below, and by the one above. The thickness of the group is about 1,500 feet.

V. THE BEAVER BAY GROUP.—This group is especially characterized by a predominance of black, coarse-grained, olivine-bearing gabbro in very heavy layers without amygdaloids, and by the great abundance and prominence of its included red felsitic porphyries and granite-like rocks. There are, however, very considerable thicknesses included of fine-grained ashbed diabases, with and without amygdaloids, while the ordinary fine-grained diabases with amygdaloids are not excluded, though rare. No detrital material has been observed. In following the coast line eastward, the beds of this group are crossed in ascending order between Split Rock and Baptism rivers, a distance of some 18 miles, and in descending order in the 28 miles below Grand Marais; besides which are also exposures of the same beds in the intervening country back of the lake shore. In its eastern extension this group does not exceed 4,000 to 5,000 feet in thickness, but to the west it must fully reach, if it does not exceed, 6,000 feet.

VI. THE TEMPERANCE RIVER GROUP.—A succession of very distinctly and thinly bedded fine-grained diabases and melaphyrs, with strongly developed amygdaloids, and several seams of detrital matter, in the shape of red shaly sandstone, and conglomerate, one sandstone layer exceeding 200 feet in thickness. Towards the base of the group are some layers of dense ashbed-diabase, and diabase-porphyrite. The rocks of this group form the coast-line from a point two miles below Baptism River to Grand Marais, a distance of 50 miles. They are the highest rocks on the Minnesota coast, and have a thickness in sight of some 2,500 to 3,000 feet.

CHAPTER VIII.

RELATIONS OF THE KEWEENAW SERIES TO THE ASSOCIATED FORMATIONS.

SECTION I.—TO THE NEWER FORMATIONS.

THE EASTERN SANDSTONE.

By this term is meant that sandstone which, as already indicated, fills the valley between the Keweenaw or Main Trap Range of Michigan and the so-called "South Range." The eastern end of this depression is occupied by the waters of Keweenaw Bay. The whole area has a characteristic flat appearance, and sandy soil, standing thus in strong contrast with the highlands of crystalline rocks on either side. On the northern edge of this depression the sandstone may frequently be seen exposed from the head of Bête Grise Bay, on Keweenaw Point, westward for a distance of a hundred miles, to beyond Lake Agogebic; and on the southern edge may be traced east and northeast from the vicinity of Lake Agogebic to the head of Keweenaw Bay. On the west side of this bay the sandstone is constantly exposed in cliff; but on the east side the older crystalline rocks come out to the water's edge. Gneiss and schists form the mass of the peninsula between Keweenaw and Huron bays, but, skirting the immediate shores of the lake, is a band of sandstone varying in breadth from a few rods to one or two miles, the older rocks only now and then reaching the lake. Similar conditions obtain from here to Marquette, beyond which point, to the eastward, sandstones form all of the shore cliffs as far as the Sault.

The sandstones of Keweenaw Bay and its vicinity, and eastward to White Fish River, are reddish and often highly argillaceous. At White Fish River the red sandstone is overlaid by light-colored sandstone, which is in turn succeeded by a magnesian limestone, in which are casts of *Pleurotomaria*,[1] and which is the Lower Magnesian of the Wisconsin reports, and the Calciferous Sandrock of the eastern states. That it is succeeded in regular order by the fossiliferous limestones of the Trenton, Cincinnati, and Niagara groups was long since shown, and has been demonstrated anew of late years by the labors of the geological surveyors of Wisconsin and Michigan. There thus seems little room for doubt as to the correctness of the view held for years by a succession of geological workers in the Lake Superior region, from Owen to Rominger, viz: that in the Eastern Sandstone we have to do with the same formation, or with its downward continuation, as the fossiliferous Cam-

[1] Geological Survey of Michigan, Vol. I, Part III, pp. 89, 90.

brian sandstone, which, in the Mississippi Valley, forms the base of the Paleozoic column.

There appears to be one way only in which this conclusion can be avoided, and that is by supposing that where, east of Marquette, the red sandstone is overlaid by the lighter colored, there is a discordance of greater or less extent; the red sandstone being thus separated by a relatively large time gap from that which overlies it. This view was indeed held at one time by Houghton, as long ago as 1841,[1] who, however, so completely altered his opinion in the next few years as to consider the red sandstone of Keweenaw Bay and Keweenaw Point the newer of the two, and as of Triassic age, while the light sandstones east of Grand Island were believed to antedate the Trenton limestone.[2]

It is needless to discuss the idea of a Triassic age for any of the Lake Superior rocks, since its incorrectness has been so abundantly and repeatedly proved from the time of Foster and Whitney down to the publication of the third volume of the Wisconsin reports, in which the demonstration is clinched by the descriptions of the perfectly plain relations of the fossiliferous sandstones of the Mississippi Valley and the western extension of the Keweenaw Point rocks in the region of the Saint Croix River. To judge from Rominger's account of the exposures in the vicinity of White Fish River the falsity of the idea of an uncomformable superposition of the lighter colored upon the red sandstone is equally well proven.[3] In the same connection allusion should be made to the long-known occurrence of an isolated patch of fossiliferous Trenton limestone within the area of the Eastern Sandstone. This limestone forms a line of bluffs extending through sections 13, 14, 23, and 24, of T. 51, R. 35 W., Michigan, 14 miles west of the head of Keweenaw Bay. The rock contains a number of well-known Trenton fossils.[4] In this occurrence we have demonstration of the former extension of the lower Silurian limestones far to the westward of their present limit.

The north shore of Bête Grise Bay, as shown on a previous page, is made by low cliffs of Keweenawan diabase and melaphyr, with some quartziferous porphyry, all dipping northward at a high angle, while the west shore of the bay lies in the lowland underlaid by the Eastern Sandstone. In the angle of the bay the two formations come together, and their contact may be followed for a long distance. The sandstone, of which a considerable thickness may be seen, dips southward at angles varying from 55°[5] at the contact to 30° and less at the point farthest removed from the contact. It is made up of alternating whitish, quartzose, fine-grained layers, and thinner ones of red shale, the latter running

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[1] Fourth Annual Report on the Geological Survey of Michigan, 1841.

[2] American Journal of Science, 1843, Vol. XLV, p. 160.

[3] Geological Survey of Michigan, Vol. I, Part III.

[4] Do. *Ibid.*, p. 69.

[5] Not 78°, as reported by Foster and Whitney, *op. cit.*, p. 112.

from a few inches to several feet in thickness. Some of these red layers are strongly conglomeritic, the pebbles being generally of small size and often angular, and composed in part of red felsite, but also in large measure of the ordinary Keweenawan diabase and melaphyr. All of the kinds of rocks represented by the pebbles are in place on the shore of this very bay. The junction line between the sandstone and these older rocks is quite irregular, and as the shore of the bay is followed eastward little patches of the sandstone are seen remaining in embayments of the older rocks on the cliff side. Underneath the clear waters of the lake the beveled edges of the alternating bands of red and white sandstone may be traced for hundreds of feet in great sweeping curves. On the south point of Bête Grise Bay, below the ship-canal, the sandstone lies horizontally.

As already shown, the contact-line of the sandstone and northward-dipping Keweenawan rocks west of Bête Grise Bay is plainly marked by a sharp break in the topography. At a number of points along this line phenomena similar to those observed at Bête Grise have been noted—*i. e.*, the sandstone inclining southward at an angle which lessens in amount very rapidly as one passes away from the contact. This may be seen, for instance, in the vicinity of Lac La Belle and Gratiot Lake and some of the head streams of Tobacco River. As long since shown by Foster and Whitney, the amount of southward dip lessens to the westward, so that in the vicinity of Torch and Portage lakes the sandstone lies horizontally at the contact, or at most inclines but a very few degrees southeastward.

This contact-line is crossed and exposed by several of the small streams entering Torch Lake on its west side. These streams run in quite deep gorges which are carved in the Eastern Sandstone, and end abruptly, often with a vertical wall, where they reach the more enduring rock of the "Trap Range." The gorges of two of these streams, the Hungarian and Douglas-Houghton rivers, were examined with some care. As the Hungarian River is ascended, the sandstone is first met with on the sides of the ravine and then in its bed also, where it forms several falls. Often the sandstone lies horizontally; at times it appears to have a slight northwesterly dip, and as often a slight southeasterly one. These deviations from horizontality are often plainly the result of the undermining on the sides of the ravine. At the uppermost fall the contact with the older rocks is seen. The occurrences here and for some distance below are as shown in the accompanying figure, in which B is the bank of the gorge, without exposures; A, sandstone layers projecting from the side of the bank; D, amygdaloid and pseudamygdaloid, dipping northwesterly; E, the continuation of the amygdaloid in a crumbling condition; C, porphyry conglomerate; and F, diabase. G, at the very foot of the fall, is a smoothed surface of sandstone jointed in two directions, the joint surfaces dipping NW. 25° and SE. 20°, and a few steps farther down stream the sandstone is seen lying perfectly flat. In the same vicinity true bedding lines, as shown by differences in the coarseness and coloring of the sandstone, gave dips of 10° NW., 20° SE., 20° NE. These irregularities are plainly in a measure due to the undermining on the sides of the ravine, but are also somewhat analogous to those described and figured on a previous page as occurring on the gorge of Black River, Douglas County, Wisconsin—*i. e.*, are the product of faulting motion.

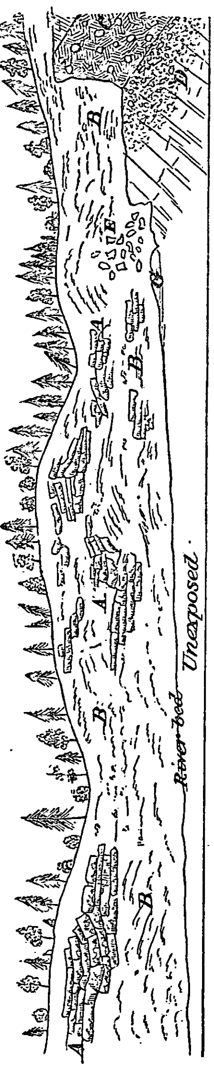


FIG. 41.—Section on the Hungarian River, Keweenaw Point, Michigan.

In his account of the occurrences on the Hungarian River,[1] Wadsworth has represented the Eastern Sandstone as presenting a gradually increasing northwesterly dip as followed up stream, until it is plainly seen plunging beneath the Keweenawan diabase and interbedded conglomerate. But we failed to find any evidence either of the increasing northwesterly dip or of the subordinate position of the sandstone to the diabase. Northwesterly dips are found in the sandstone for some distance below the contact, but southeasterly ones just as often, or oftener, and both are distinctly subordinate to a general horizontality. Again, sandstone does lie vertically beneath an amygdaloid, but the mass of sandstone appears to be a fallen one, and if it is not, the crumbling amygdaloid certainly is.

The occurrences on the Douglas-Houghton River are much like those seen on the Hungarian, with the exception that the true Keweenaw beds extend down stream for some 300 paces from the head of the ravine, for the reason that they include just here a considerable thickness of soft conglomerate. Below the last of these beds is a gap of some 200 paces, when the horizontal layers of the Eastern Sandstone come in, here and there with a slight northwesterly dip (2° to 5°), but more often with a southeasterly one, and these conditions obtain for a mile or more down the stream. Wadsworth has also described the exposures on the Douglas-Houghton, and correctly, so far as showing, which he was the first to do, that the conglomerate for some distance below the falls does not belong with the Eastern Sandstone, but is really interbedded between diabases of the Keweenaw Series. When he represents, however, the sandstone still farther down stream as passing beneath the last Keweenawan dia-

[1] Bulletin of the Museum of Comparative Zoology, Geological Series, Vol. I, No. 1. Notes on the Geology of the Iron and Copper Districts of Lake Superior.

base, he bridges in his imagination a covered gap of several hundred paces, beyond which to the eastward the sandstone lies flat or inclines variously and indifferently, slightly to the northwest, southwest, or southeast, not showing any sign of a persistent and gradually decreasing northwestern dip. Nevertheless, were this ravine the only place where the Eastern Sandstone could be seen in proximity to the north-dipping Keweenawan beds, and were there not other considerations rendering such a conclusion untenable, the idea that Wadsworth has advanced would suggest itself as a possibility, although, so far as the exposures here are concerned, it could be nothing more. Even then there would remain, as looking the other way, a marked lithological difference between the intercalated sandstone and that farther down stream, the latter being a much more purely quartzose rock, and not made up in any but minor quantity of the porphyry detritus which composes the usual interbedded sandstone of the trappean series.

About a mile southeast from the head of the Douglas-Houghton ravine, on the line of the Torch Lake Railroad, is a large quarry in the Eastern Sandstone. The sandstone here is disposed horizontally in heavy massive layers. It is nearly white, and almost wholly composed of rolled quartz grains. It also contains here and there grains of feldspar somewhat altered, but on the whole is singularly fresh for such a rock, some particles showing the twin lamellation very beautifully. A very minute quantity of a brownish cement is present, and in each thin section may be seen two or three grains worn from some of the fine-grained diabases of the Keweenaw Series. Not a trace is, however, is to be seen of anything like the fragments of porphyry matrix so abundant in the Keweenawan sandstones; nor was I able to discover any indication that the quartz grains were the quartzes of the quartziferous porphyries. Rare pebbles of quartz of some size are contained in this sandstone, and patches and lines of red clayey substance, which do not show any persistent inclination in any one direction. The clayey material often expands into large bunches of red clay, forming the usual "clayholes" so characteristic everywhere of the Eastern and Western horizontal sandstones.

Southwestward from the vicinity of Torch Lake, the Eastern Sandstone may be seen in close proximity to the Keweenawan diabases at a number of points, and always with the same relatively quartzose character, and horizontal position or southeasterly dip. Pumpelly figures such an occurrence, for instance, in the northwest quarter of Sec. 6, T. 54, R. 33 W., on the south side of Portage Lake.[1] Again, the streams in sections 22 and 23, of T. 54, R. 34 W., run over horizontal quartzose sandstone, and the same is true of the streams in the central and southeastern parts of T. 52, R. 35 W., where the exposures are quite large. But still farther west, and near the Ontonagon River, much larger and

[1] Atlas, Geological Survey of Michigan, Plates XIV and XV.

more instructive exposures of the Eastern Sandstone are to be found. The occurrences here are like those on Bête Grise Bay, *i. e.*, the sandstone dips away southward from the north-dipping Keweenawan diabases, at quite a high angle near the contact, and rapidly grows flatter as the contact is receded from. Further west, again, as far as Lake Agogebic, the west branch of the Ontonagon River has its course just under an overhanging bluff of diabase, following closely the junction line of the two formations. Here and there it exposes sandstone under conditions like those just described. Exposures of horizontal sandstone are also often met with in the country south of this line.

Along the north face of the South Range, eastward from Lake Agogebic, the sandstone is not unfrequently met with in exposures. The principal point of interest in this connection is the way in which it completely overlaps the Keweenawan rocks, which, as previously shown, constitute this range. This overlapping is not merely an inference from the supposed continuation of the South Range Keweenawan beds beneath the sandstone, but may be directly demonstrated by closely approximated exposures of the three formations concerned. This was first shown by Pumpelly from exposures examined by him on the west branch of the Ontonagon River, in the northwest part of township 46, range 41 west.[1] This place was subsequently visited under my directions by Mr. Robert McKinlay, who found here a south-facing cliff, 60 feet high and 350 feet long, of reddish, very coarse, horizontally-bedded sandstone, composed almost entirely of rounded grains of quartz. One hundred paces from the foot of this cliff are reddish crumbling schists of the Huronian, trending northeast and dipping 45° to 60° southeast. Seven hundred paces northeast, near the southeast corner of section 11, is a small bed of a dark brown, weathered, medium-grained diabase, and in the northeast part of the same section and running thence through sections 10 and 9, and terminating in the southeast quarter of section 8, is a series of exposures of diabase pseud-amygdaloid and amygdaloid. Farther west, and again east, of the sandstone are other exposures of amygdaloid, while for 60 miles to the westward the Keweenawan and Huronian belts sustain the same relation as observed here, so that there can be no question whatever that the Eastern Sandstone here lies directly across the course of the Keweenawan belt.

Four different views have been held since Foster and Whitney as to the relations of the Eastern Sandstone to the northward-dipping rocks against which it abuts.

Foster and Whitney's view was evidently that the Eastern Sandstone and that which, with a very great thickness, forms the west side of Keweenaw Point, were originally the same, but were separated by a longitudinal fault extending from Bête Grise Bay to Black River. In the region of Bête Grise this fault was supposed to be accompanied by

[1] Geological Survey of Michigan, Vol. I, Part II, p. 4.

the protrusion of the mass of the Bohemian Range. To the elevation of this range was attributed the inclination northward of the whole succession of bedded traps, which, with the overlying conglomerate and sandstone, constitute the greater part of Keweenaw Point, and the incilnation southward of the Eastern Sandstone in the Bête Grise region, the Bohemian Range being then taken as the middle line of an anticlinal. Farther west this fissure was supposed to have been unaccom panied by any outflow, and the Eastern Sandstone to have been left horizontal.

I have shown in Chapter VI of the memoir that the rocks composing the Bohemian Range are simply the downward continuation of the Keweenaw Point series, being made up of the usual flows, and that there is no evidence of anticlinal structure. Otherwise, the theory of Foster and Whitney has some plausibility in it. I have myself already argued in favor of the view that the southern escarpment of the Keweenaw Range is a fault line, with entirely different reasons from those appealed to by Foster and Whitney. In its quartzose character the Eastern Sandstone has, too, something in common with the uppermost layers of the sandstone of the western side of Keweenaw Point, where a distinct tendency to become more quartzose is to be seen. It would also be easy to see how to the eastward this uppermost sandstone might, by overlap, pass on to the older rocks with a small thickness, while to the west it constitutes only the uppermost member of a great series.

There are great difficulties, however, in the way of an acceptance of this view. The throw of the fault would have to be enormously great —fully 35,000 feet—and much greater than is needed for the fault which I have supposed to exist along this contact line. But a much more serious difficulty is found in the way in which the Eastern Sandstone crosses the course of the beds of the South Range east of Lake Agogebic. Were it merely an upper member of a series of which the last-named beds form the bottom portions, the two formations could not possibly sustain any such relation as they do here.

Pumpelly's view was that the junction line between the Eastern Sandstone and the inclined beds of the Keweenaw Range was an old shore cliff, instead of a fault line, against which the sandstone was deposited. This conclusion was supposed to be corroborated by the finding of abundant pebbles of the Keweenawan diabase in the Eastern Sandstone near the contact on the Douglas Houghton River. But it is not improbable that both he, and Agassiz before him, did, as Wadsworth argues, mistake a bed intercalated with the Keweenaw Series as part of the Eastern Sandstone. However, on Bête Grise Bay, where there can be no possibility of doubt, the Eastern Sandstone at the contact contains layers in which diabase and amygdaloid pebbles are abundant, along with others of red felsite and quartziferous and granitic porphyries. In advancing this view, Pumpelly was simply attempting to carry to demonstration what had before been suspected by Logan and other earlier geologists.

In abandoning the idea of a fault along the south side of Keweenaw Point, he saw that it would be necessary to account for the disappearance of the seven miles in thickness of rock constituting Keweenaw Point—of which fully two miles are red sandstone and conglomerate of unquestioned sedimentary origin—in the few miles intervening between the point and southern end of Keweenaw Bay, where the Eastern Sandstone lies directly upon the Huronian slates. This he did by supposing an enormous pre-Cambrian erosion, thus making the break between the Keweenaw Series and the Eastern Sandstone a very great one.

Recently Wadsworth has advanced the idea, in which he was, to some extent, preceded by Credner,[1] that the Eastern Sandstone passes underneath the entire Keweenaw Series, forming its lowest member, or at least its lowermost member in sight. This conclusion he rests on observations made on the Douglas-Houghton and Hungarian rivers. I have already shown that the exposures on the Hungarian River will not admit of any such explanation, while those on the Douglas-Houghton taken alone could only be thus explained by imagining an appropriate structure within an interval where there are no exposures. But there is no necessity of going to these streams to prove the complete untenableness of Wadsworth's supposition, although he considers that it "settles the long-disputed question of the relative age of the traps and eastern sandstone of Lake Superior."[2] The large exposures of south-dipping sandstone on Bête Grise Bay, at the contact with the Keweenawan diabases, and the similar exposures on the south side of the Trap Range in the vicinity of the Ontonagon River, are enough to disprove absolutely any such structural theory.

Moreover, there are general considerations which would make this view very difficult of acceptance, even were the occurrences at the contact not so conclusively against it as they are. If the whole mass of the Keweenaw Series overlies the Eastern Sandstone, what has become of this seven miles of rock-thickness to the eastward? It will not do to say that we are dealing here with eruptive rocks which thicken and thin suddenly, and cannot, therefore, be reasoned about in the same manner in which we would deal with beds of sediment. No eruptive agencies ever piled up seven miles of rock, leaving a vertical wall of that height extending over one hundred miles in length. Moreover, in this case, the eruptive beds or flows are structurally just like beds of sediment, which thicken and thin also. Yet more, fully two miles of the thickness *is* of sediment. Nothing but an immense erosion, on Wadsworth's view of the inferior position of the Eastern Sandstone, can explain the disappearance of so great a thickness of strata. But an erosion which stops suddenly on so sharp a line, parallel to the general trend of the layers, and one which has left nowhere behind this line a trace of the former extent south and east of this immense thickness of beds, is a thing utterly unknown in any other region, and is, in fact,

[1] Elemente der Geologie, 4th ed.
[2] *Op. cit.*, p. 115.

incredible. Again, east of Marquette, the Eastern Sandstone appears to pass upwards insensibly into the beds of the Calciferous. Yet, on Keweenaw Point, only a few miles away, this theory supposes that between these horizons there exists a thickness of seven miles, of which two are of purely sedimentary material. Of all the theories that have been advanced with regard to the relations of the Keweenaw beds and the Eastern Sandstone, this is the most completely fanciful and most easily disposed of.

It appears to me that the south face of the Keweenaw Range is both a fault line and a shore cliff, against which the newer Eastern Sandstone was laid down, but not until after a large erosion; and that faulting took place again after, or else continued until after, the deposition of the sandstone. The original faulting on this line seems to be demanded by the general structural relations of the Keweenaw and South ranges, as shown on a previous page, and by the absence of outliers of the immense thickness of rocks of the Keweenaw Range to the southward. That the Eastern Sandstone was deposited subsequently to this first faulting is evidenced by its containing conglomerate layers in which the pebbles are frequently of Keweenawan diabase (Bête Grise Bay), and by the way in which it cuts across the course of the range of the South Range belts. That faulting took place along the fault line after the deposition of the Eastern Sandstone, or continued throughout its deposition, is evidenced by the way in which the sandstone dips southward along the junction at the south side of the Keweenaw Range.

THE WESTERN SANDSTONE.

The Apostle Islands and the adjoining coast of Bayfield County, Wisconsin, are composed of a horizontally-placed sandstone closely resembling in character the Eastern Sandstone of Keweenaw Point. I have described this sandstone somewhat fully in another place.[1] From the head of Chaquamegon Bay eastward there are no rock exposures on the coast until Clinton Point is reached, four miles above the mouth of Montreal River. Here are flat ledges of sandstone of some size, at the water level. I take them to mark the easternmost point of the Western Sandstone, though this cannot, from their position only, be regarded as certain. At the mouth of the Montreal River occur the vertically-placed sandstones of the upper division of the Keweenaw Series with an immense thickness, as already described. Westward from the Apostle Islands the horizontal sandstone has been traced to the head of the lake, and in Douglas County, Wisconsin, may be seen at a number of points in direct contact with the south-dipping Keweenawan diabase. In all of this region this sandstone preserves its quartzose character, being at times just like the darker-colored portions of the quartzose sandstone of the central part of Wisconsin.

The phenomena of the contact along the Douglas County Copper Range

[1] Geology of Wisconsin. Vol. III, p. 207.

are described in some detail in Chapter VI of the original memoir, where I have also shown that the Western Sandstone in all probability sustains the same relation to the Keweenawan diabases against which it rests as does the Eastern Sandstone of Keweenaw Point to the north-dipping beds of that typical region, this similarity of relation being carried out even to the faulting that I have shown to obtain in the latter district.

Such a similarity in structural relations, taken together with similarity in lithological character, renders it very probable that the Eastern and Western sandstones are geologically equivalent. But they are nowhere connected, and the Western Sandstone has not been traced to any point where its relation to any of the Mississippi Valley fossiliferous formations can with certainty be made out, although the appearances in northwestern Wisconsin are decidedly in favor of its being the downward continuation of the Mississippi Valley Cambrian sandstone.

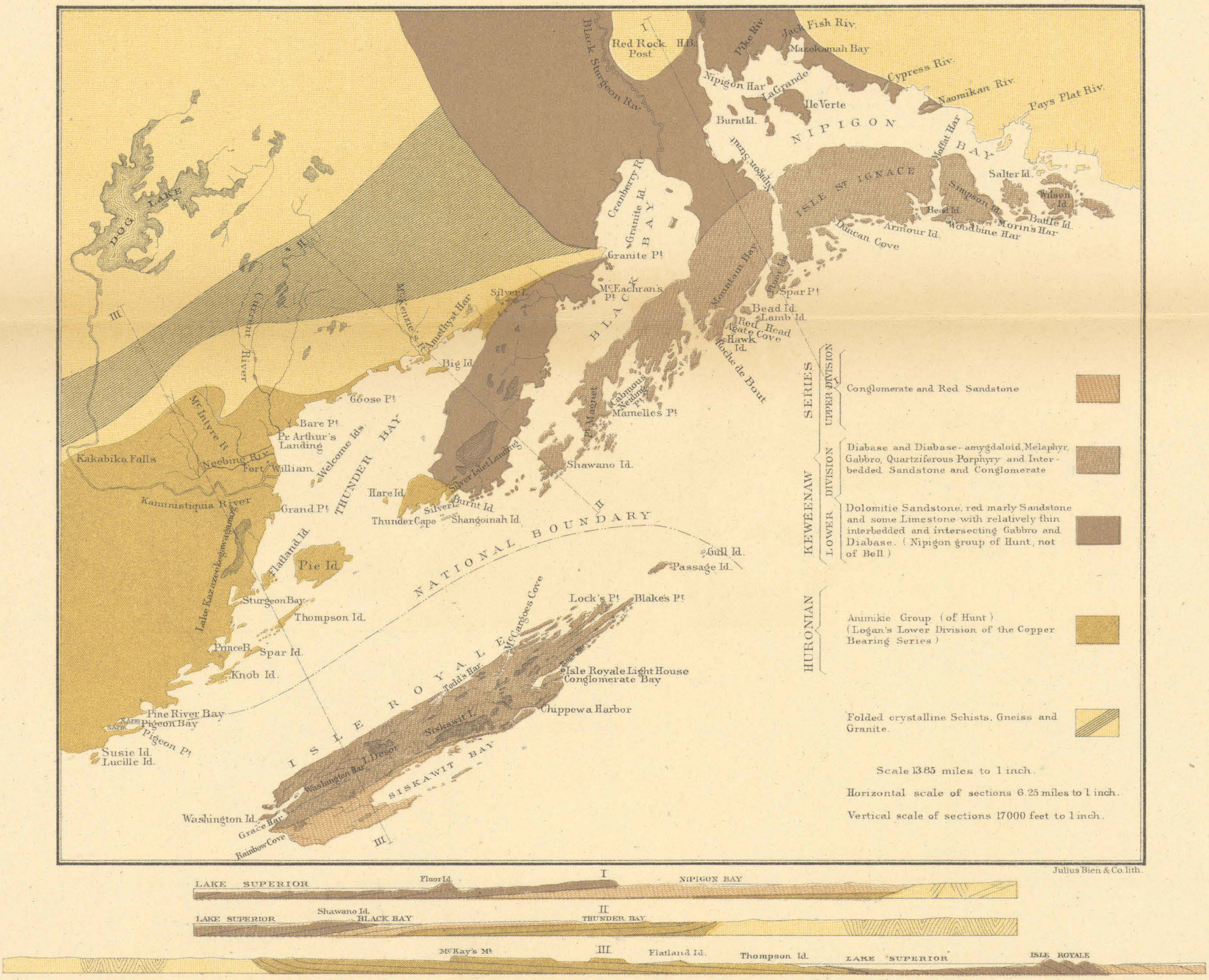
THE MISSISSIPPI VALLEY CAMBRIAN OR POTSDAM SANDSTONE.

In Chapter VI of the original memoir it is shown that the Keweenawan diabases and interbedded conglomerates are traceable mile by mile from the typical region of Keweenaw Point to the Saint Croix River on the west side of Wisconsin, and that here they underlie the fossiliferous Cambrian sandstone of the Mississippi Valley in such a manner as to render certain the tilting and great erosion of the Keweenawan beds before the deposition of the sandstone. Whatever difficulties may hang about the determination of the structural relations of the Eastern and Western sandstones of Lake Superior to the Keweenaw Series, there are here none. So unmistakable is the structure in this region that any geologist still doubting the separation of the Keweenawan rocks from the overlying Cambrian sandstones by an intervening disturbance and erosion should feel himself debarred from denial until he has thoroughly examined the facts in the field.

SECTION II.—TO THE OLDER FORMATIONS.

An attempt to determine the relations of the Keweenawan rocks to the older formations with which they are associated meets with one great obstacle. I refer to the imperfect and confused condition of our knowledge of these older rocks themselves.

The text-books group them all into Huronian and Laurentian, terms adopted from Sir William Logan's Geology of Canada, in which they were applied not only to the rocks of the eastern portions of Canada, but also to those adjoining the northern shore of Lake Huron and the eastern and northern shores of Lake Superior, the typical Huronian occurring, in fact, along the north shore of the former lake. But when we come to examine more closely into the applications of the terms by



GEOLOGICAL MAP OF ISLE ROYALE AND NEIGHBORING MAINLAND various geologists who have studied the crystalline schists of the Lake Superior region we find the greatest confusion prevailing. The term Huronian, for instance, is used by one geologist to cover formations regarded as wholly distinct and separate by another. One would class as Huronian all the distinctly schistose rocks, and as Laurentian only the granites and the less schistose gneisses, while another would use the term Huronian to cover only such rocks as present a pronounced and unmistakable unconformity to an older set of crystalline schists. Moreover, this confusion appears to a great degree in the publications of the Canadian Survey itself. Even Sir William Logan was plainly very much in doubt as to whether certain rocks in the Thunder Bay region of Lake Superior should be referred to his Huronian or to the series including the copper-bearing rocks of Keweenaw Point. The whole subject of the Archæan rocks of the northwest must be opened anew and thoroughly revised before we can hope for a removal of this confusion.

The following pages of this chapter include a brief presentation of the facts, as I now know them, with regard to these ancient rocks, and such conclusions as they appear to me to warrant. In presenting these conclusions I have been careful to indicate the degree of probability pertaining to each. Some of them are novel, and doubtless will not meet with ready adherence in all quarters, but it is precisely those which are most novel as to whose truth I feel best satisfied. The original memoir, it should be said, includes a detailed account of the facts upon which some of these conclusions are based. This discussion of formations outside the limit of the series which forms the subject of this memoir is rendered necessary, both in order that we may so far as possible determine the geological relations of the Keweenaw Series, and because some of these formations have been regarded by good authority as belonging to the Keweenawan itself.[1]

THE ANIMIKIE GROUP.

At Grand Portage Bay, at the east end of the Minnesota coast, there rise, from beneath the typical Keweenawan diabases, beds of slate and quartzite. These beds are finely seen immediately behind the Indian village of Grand Portage. Here is exposed a large thickness of a thin laminated dark-gray to black slate, which is now aphanitic and clay-slate like, and now distinctly arenaceous, and the whole exposure is in striking contrast to anything in the Keweenaw Series above. A great dike of fine-grained black diabase, standing vertically and trending east and west, with a width of 75 feet, cuts the slate, which for a long distance is weathered away, leaving the dike standing as a bold wall, in places over a hundred feet in height. This slate dips southeastwardly at an angle of 10°, striking N. 70° E., or, in other words, is entirely conformable with the immediately overlying Keweenawan diabase flows. This conformity is strikingly displayed at the northeast end of the large

[1] See Plate III.

island in the mouth of Grand Portage Bay. The greater portion of this island is made up, as is indicated in the accompanying sketch, of great flows of a fine-grained, typically Keweenawan diabase; but at the northeast corner the underlying slates, here quite arenaceous and even pebbly, come to view.

To the eastward of Grand Portage Bay the slates—at times arenaceous, in other cases hard, ringing quartzite, again true clay-slate, and in yet other places of an intermediate nature—cut by a grand system of dikes, are constantly in view to the easternmost end of Pigeon Point. The dike-rocks are in part very coarse olivine-gabbros and in part finer orthoclase-gabbros, entirely identical with the gabbros of the Keweenaw series already described. Throughout this distance the dip continues to the southeastward at angles of from 8° to 20°.

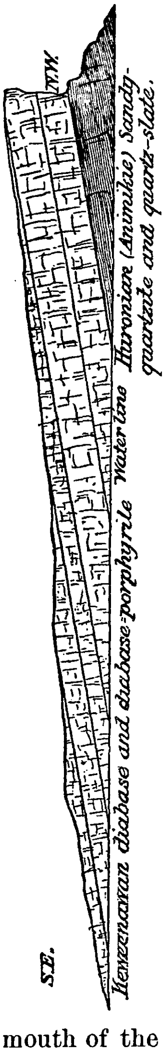


FIG. 42.—Profile section of Portage Bay Island, Minnesota coast of Lake Superior.

The deep bay on the north side of Pigeon Point receives the waters of Pigeon River. Following this river upwards, slates and slaty quartzites are found all the way to the head of the stream, and beyond to Gunflint Lake on the national boundary line. The general dip of these rocks, which have never been examined in detail, is to the southeast, at an angle of some 10°, which would give a total thickness of about 10,000 feet for the slate series, as here developed. Peculiar cherty layers are met with at low horizons in the slates of this region, and also banded, lean, magnetic iron ores, identical with those of the Penokee region of Wisconsin. By all geologists who have traversed the Pigeon River country[1], these slates are described as cut by great numbers of large sized dikes, whose outcrops often form bold linear ridges several hundred feet in height, crossing the country in two or three different directions. Two of these great dikes, composed of coarse olivine-gabbro, are finely exposed at the first great falls of Pigeon River, two miles above its mouth.

Following the west shore of Thunder Bay from Pigeon Point, the same slates, associated with the same diabases and gabbros, in interbedded layers and great overlying masses, and dikes of the same rocks, are displayed on a grand scale. The numerous islands in the mouth of the bay are composed also of the same rocks. The smaller islands show usually only dike rock, a long line of islets marking sometimes the course of a single dike. All along the western shore of Thunder Bay, south of the valley of the Kaministiquia, great overhanging cliffs are met with, 500 to 800 feet in height, and composed of slate and gab-

[1] Norwood, Bell, N. H. Winchell.

bro. The dip of the slates continues to the southeast in this distance, the trend growing, however, more and more northerly as the Kaministiquia is approached, while the dip is usually flatter than 10°, being often as little as 2° or 3°.

The researches of Bell and Logan have shown that the area lying to the west of Thunder Bay, and bounded on the north by a line from Gunflint Lake on the national boundary line to the Grand or Kakabika Falls of the Kaministiquia, is everywhere underlaid by the same rocks that are seen along the west side of Thunder Bay. Dike-formed, linear ridges traverse the country in great walls, while overflows of gabbro form often the tops of table-like elevations. Among the boldest of these is the line of bluffs skirting the south side of the lower stretch of the valley of the Kaministiquia, "McKay's Mountain," a portion of this elevation, rising to the height of 1,000 feet. Through all this area the flat southeasterly dip continues to prevail, though there is often little variation from horizontality. It is of the greatest interest in this connection that Bell reports the existence, as part of the slate series and near its base, of "thinly-bedded, flaggy, hard, dark-gray sandstone, largely composed of particles of magnetic iron, and weathering to a rusty coloring. * * * The same highly ferruginous sandstone, dipping very slightly east-northeast, is again exposed on the banks of a brook, * * * rather more than a mile north of the Algoma mine."[1] The same interest attaches to the occurrence at numbers of places of concretionary chert, bands of reddish jasper, and dolomite.

Bounding this slate region on the north is a district or belt of granite and contorted gneiss. From Kakabika Falls the southern boundary of this gneiss is "roughly indicated by a line drawn from the Great Falls to a point on the shore of Thunder Bay, about 6 miles east of the mouth of Current River." All along this shore of Thunder Bay I found the conditions observed on the west shore repeated, save that the great bluffs of slate and gabbro are wanting. Numerous interbedded layers of black diabase were observed, however, the whole series dipping 5° to 10° southeast. East of Goose Point, and thence to the head of Thunder Bay, the older gneiss and granite are generally seen at the bottoms of the coves, while the points and outlying islands are formed of the slates with their interstratified diabases. Still nearer the head of the bay come in the dolomitic sandstones of the overlying Keweenaw Series. Where first seen these sandstones are often conglomeratic, with pebbles derived from the underlying slates, and especially from the chert layers upon which they immediately rest. Along the southeast shore of Thunder Bay the slates here and there appear at the water's edge, but above them the cliffs of the newer sandstone, with beds of chert conglomerate, rise to a height of 200 feet. These conditions continue for a number of miles.

[1] *Op. cit.*, p. 322.

At the deep bay just above Thunder Cape the white sandstones swing away from the bay shore to the southeastward, reappearing on the coast of the main lake near Silver Islet Landing, and leaving between them and the extremity of the cape a triangular area which is occupied entirely by the same slates that form the west coast of Thunder Bay. Here the slates are capped by an immense overlying mass of olivinitic gabbro, upwards of 200 feet in thickness. The whole height of Thunder Cape is over 1,000 feet, and from 700 to 800 feet of this must be occupied by the slates, which thus rise entirely across the horizon of the sandstone just described. Such a relation can only be explained by supposing, as Logan did, a great fault, by which the slates are brought up to an abnormal height, or by supposing an erosion to have intervened between the times of deposition of the slates and overlying white sandstones. In the latter supposition it appears to me the true explanation is to be found. Still further suggestive of an unconformity between the slate and sandstone is the fact that, a few miles to the east, on Black Bay, the sandstone lies directly against the older gneisses without the intervention of any slate.

So far, then, as I have been able to learn, by original observation in the field, and by reading in the light of these observations the published accounts of others, the Animikie rocks of the Pigeon River-Thunder Bay region form a great series, probably upwards of 10,000 feet in thickness, of quartzites, quartz-slates, argillaceous or clay-slates, magnetitic quartzites and sandstones, and beds of cherty or jaspery material, with which are associated, in great volume and in both interbedded and intersecting masses, several kinds of coarse gabbro and fine-grained diabase, all of types well known in the Keweenaw Series.

A reference to the descriptions of the Thunder Bay region, published by Logan, Macfarlane, and Bell, will show at once that in the statements of the last paragraph I have departed widely from the conclusions of these geologists as to the thickness and composition of the Animikie group. Their descriptions are, however, misleading on these points, having been based almost entirely upon what may be seen on the shores of Thunder Bay, which lies where only a relatively small thickness is exposed, and where the rocks sometimes come nearer to being "sandstones" and "shales"—the terms used by them—than elsewhere.[1] Logan, moreover, while placing the Animikie rocks for the most part with the Keweenaw Series, evidently took as Huronian that part of the group which occupies the northern coast of Thunder Bay for a distance of 10 miles immediately below the mouth of the Kaministiquia River. Bell includes these rocks with the rest of the Animikie group, and beyond question correctly.

Bell's scheme of stratigraphy[2] for the Animikie Group, to which he

[1] Even on the west side of Thunder Bay, however, many hundred feet of ringing quartzite and hard clay slate are to be seen.

[2] Report of the Geological Survey of Canada for 1866-'69, p. 318.

assigns a thickness of only a few hundred feet, is obtained by building up from the gneiss in the northeast corner of Thunder Bay. But the gneiss does not always come against the same horizon of the Animikie slates, so that such a scheme would be unsatisfactory in any case, even were its truth not directly disproved by the occurrences along Pigeon River and thence west and south, where it is plain, from the constant southward dip and broad area occupied, that there is a thickness of fully 10,000 feet. Even at the Silver Islet mine the hard quartzitic slates have already been carried down 1,000 feet or more below the lake level, which makes the total thickness actually measurable in that vicinity far beyond Bell's total.

There are other serious objections to Bell's stratigraphical scheme. Among these I may mention his failure to recognize the quartzitic character of the body of the formation, and his placing the magnetitic arenaceous rock of the township of Neebing near the summit of the series, and as equivalent to the Thunder Cape beds. I would, on the contrary, place these magnetitic beds many thousand feet lower down, and would regard them as the same as those of Gunflint Lake, of the Mesabi Range of Minnesota, and of Pokegoma Falls on the Mississippi River. It is very difficult to see how Bell could parallelize the Thunder Cape beds, manifestly near the top of the formation, with beds lying 20 miles to the northeast, and at a somewhat lower altitude, while at the same time admitting a general southeasterly dip throughout the whole area. Then, again, he almost entirely ignores the great beds of included gabbro and diabase. Such of these beds as are seen along the west shore of Thunder Bay, and thence westward to Pigeon River, must aggregate over 1,000 feet. Still another error, which may possibly in part explain the last, is the placing of all of the masses of gabbro found capping the bluffs of the Thunder Bay region in one great bed. This bed is given the name of the "crowning overflow," and is supposed to have been formed not merely after all of the associated slates, but after the removal from them by erosion of many thousand of feet of newer strata. I can find no evidence of any such general overflow, but much evidence against its existence.

As already indicated, the Animikie slates have been traced along the national boundary as far as Gunflint Lake by Bell,[1] and more recently by N. H. Winchell.[2] Southwestwardly from the vicinity of Gunflint Lake the region traversed by these rocks has not been examined for a distance of many miles. But their continuance here cannot be doubted, for in the Mesabi Range of Minnesota, T. 60, R. 13 W., they show in full force. According to Prof. A. H. Chester, to whom I am indebted for a full description of this place, together with an illustrative col-

[1] Report of the Geological Survey of Canada for 1872-'73.

[2] Eighth and Ninth Annual Reports of Geological and Natural History Survey of Minnesota.

lection of specimens, the prevailing rock here is an arenaceous magnetitic quartzite, disposed in nearly horizontal layers, which dip at the most not more than 2° or 3° to the southeastward. Many of Professor Chester's specimens are indistinguishable from the magnetitic quartzites of the Penokee Range, while the detailed descriptions of exposures with which he has furnished me would do as well, save as to the direction and amount of dip, for hundreds in the last-named district. Immediately to the north of the Mesabi quartzites the rock is granite, still beyond which come in the highly-folded schists of the Vermillion Lake basin.

As already stated, arenaceous magnetitic quartzites, entirely similar to those of the Mesabi Range, appear at the Pokegoma Falls on the Mississippi River. The line drawn to these falls from the Mesabi Range indicates approximately the northern limit of the Animikie rocks in this region. What becomes of these rocks still farther west-southwest is as yet unknown. South of this line, however, are immense exposures of slate along the Saint Louis River, in T. 49, R 17 W., and T. 48, R 16 W. These slates dip constantly southward, more often at a greater angle than 45° than at a lower. The strike is not exactly east, but more or less north of east, the northing increasing in amount to the eastward. Throughout, the slate is affected by a strong transverse cleavage. The whole thickness of slate here exposed appears to be very great, but there are probably some folds. South and west from the Saint Louis the slates are known to continue for some miles, but their extent in that direction has not as yet been exactly worked out. As to lithological character the Saint Louis slates are essentially identical with the Thunder Bay slates, which they further resemble in being intersected by great dikes of gabbro, and from which they differ only in being affected by a tranverse slaty cleavage.

The rock series thus described under the name of the Animikie Group—a term first used by Hunt, and referring to the Indian name of Thunder Bay—has been placed by Logan and Bell at the base of the copper-bearing series, the former geologist, in this geology of Canada, speaking of it as the "Lower Group of the Upper Copper-Bearing Rocks." Macfarlane and Hunt, on the other hand, regard the Animikie rocks as altogether newer than the Keweenaw Series, and as unconformably placed upon it. Hunt says that they, along with the overlying sandstone of the east side of Thunder Bay, may even be Triassic, for all the evidence there is to the contrary. There can be no doubt, however, that Logan and Bell are correct in placing the Animikie rocks beneath the copper-bearing or Keweenawan rocks proper. This is plainly enough to be made out from the exposures on the east side of Thunder Bay, and thence to Black and Nipigon Bays, but to any one approaching Thunder Bay from the southwest, along the Minnesota coast, becomes so absolutely certain as to admit of no question at all. Not only does one in descending the lower part of the Minnesota coast constantly cross the Keweenawan beds in descending order, until the Animikie slates are reached at Grand Portage Bay, but on the large island at the mouth of this bay he may see slates underlying the Keweenawan diabases in a continuous cliff exposure.

So far, then, I agree with Logan and Bell, but from their view that the Animikie rocks are but the downward continuation of the Keweenaw series, I must dissent altogether. The erosion which intervened between the two formations, as indicated by the already described occurrences on the east side of Thunder Bay, and again by those at the east end of the Minnesota coast, and the pronounced lithological contrast between the sedimentary beds of the two groups, all bear heavily against any such view. Moreover, the essential identity between the Animikie rocks and those of the Penokee region of Wisconsin, and the iron-bearing schists of the South Shore generally, makes it plain to me that we are dealing here with the North Shore equivalents of the South Shore iron-bearing formation. We have in the Animikie Group, as in the South Shore Huronian, siliceous schists, quartzites, dolomites, chert beds, and magnetite-bearing quartzites and quartz-slates. In the Animikie Group these alternate with great interbedded flows of diabase and gabbro, and are intersected by great numbers of dikes of the same rocks, the equivalents of which are to be found in the diabases of the South Shore Huronian. The thickness, also, of the Animikie rocks is a great one, comparable only with that of the South Shore Huronian.

The affinity of the Animikie rocks is especially strong with the schists of the Penokee Range of Wisconsin, and these, as I have elsewhere shown, are essentially the same with the iron-bearing schists of Marquette. The Animikie Group presents the smallest number of rock kinds, the Penokee series a larger number, and the Marquette and Menominee Huronian the most. Some of these differences may be made to disappear on more minute study of the still quite imperfectly known Animikie rocks, while much of the greater variety in rock kinds of the South Shore is the result of metasomatic change upon the included eruptive rocks. Even the "diorites" of the South Shore Huronian are in all probability merely altered diabases. The greater variety in the kinds of schistose rocks is directly connected with a greater amount of disturbance, and is perhaps the result of the obscure and ill-understood process known as metamorphism.

THE ORIGINAL HURONIAN.

The original Huronian of Logan and Murray occupies the entire north shore of Lake Huron from the Saint Mary's River eastward. Logan's descriptions of 1863[1] make these rocks have a total thickness of 18,000

[1] Geology of Canada, 1863, p. 55.

feet, comprised as is indicated in the following scheme, which is given in ascending order:

		Feet.
1.	Gray *quartzite*	500
2.	Greenish chloritic and epidotic *slates*, with some *trap-beds*	2,000
3.	Granular to vitreous white *quartzite*, often conglomeratic, with intercalated *greenstones*	1,000
4.	*Slate conglomerate*, *i. e.*, a conglomerate composed of pebbles and bowlders of gneiss, jasper, quartz, &c., imbedded in an "argillo-arenaceous cement," in which is much chlorite, including intercalated *greenstones*	1,280
5.	Compact green, drab, and dark-gray *limestone*	300
6.	*Slate conglomerate*, with intercalated greenstones	3,000
7.	Granular, red *quartzite*, often conglomeratic, with intercalated greenstones	2,300
8.	Red *jasper conglomerate*, the pebbles of quartz, jasper, hornstone, &c., with intercalated *greenstones*	2,150
9.	*White quartzite*, with cherty layers and intercalated *greenstones*	2,970
10.	Yellowish *chert*, with thin intercalated *limestones*, and one *sandstone* layer	400
11.	White *quartzite*	1,500
12.	Yellowish *chert* and impure *limestone*	200
13.	White *quartzite*	400
		18,000

The greenstones of this series, according to Logan, occur both as interbedded and as distinctly intrusive masses, a few of the interbedded layers assuming something of an amygdaloidal character. He also speaks of intrusive granites and red granite-like rocks. With regard to the nature of these greenstones it is to be said that, no microscopic analyses having been made of them, they are probably diabases, while the descriptions of kinds carrying much red feldspar are strongly suggestive of the orthoclastic-gabbros of Chapter III of this memoir. The red granitic rocks mentioned as intrusive are also suggestive of the red granite-like rocks of the Keweenaw Series. Similar granites or granitic porphyries, according to Norwood and Winchell, are found among the Animikie slates of the Thunder Bay country. The rocks of Lake Huron, according to Logan's sections, are bent into gentle folds.

The whole aspect of the original Huronian, as thus described by Logan, is strongly suggestive of the Animikie Group of the North Shore. Both series are made chiefly of quartzites and slates, with some limestone and chert beds and interbedded greenstones and intersecting greenstones and red rocks. Some of this similarity was seen by Logan, who, however, could not have realized how strong it was, since he was not aware that the Animikie Group is prevailingly quartzitic. However, on account of the similarity as he saw it, he maintained for many years the equivalency of the Lake Huron rocks with the native copper-bearing rocks of Lake Superior.[1] Subsequently this view was abandoned, and since the Thunder Bay slates were now regarded as merely the downward continuation of the copper rocks, these, too, were now

[1] Report of progress of Geological Survey of Canada for 1848, p. 29.

considered as newer than the Huronian.[1] Yet so striking was the resemblance even then made out between some of the Animikie beds and those of the original Huronian that a strip of rocks along the north shore of Thunder Bay, which are most plainly part of the Animikie slates, were still separated from them by Logan and put down as Huronian.[2]

To me it appears more than probable that the original Huronian of Lake Huron, and the Animikie slates of Thunder Bay, and thence southwestward to the Mississippi River are one and the same formation. The Keweenawan rocks, as shown later, are newer than either.

THE PENOKEE HURONIAN.

In the third volume of the Geology of Wisconsin I have described in some detail the rocks of the Penokee Range, which extends from the vicinity of Lake Agogebic, Michigan, to Lake Numakagon, in Wisconsin, a distance of some sixty miles. The following is the succession of the strata as given in that volume:

		Average thickness. *Feet.*
FORMATION I.	Tremolitic crystalline *limestone*	90
II.	(A) Arenaceous white *quartzite*, often brecciated, 35 feet; (B) *magnetitic quartz schist* 5 feet	40
III.	*Siliceous slaty schists;* including quartzite, "argillitic" mica-schist, and novaculite; all having much quartz, and none ever showing any amorphous material	410
IV.	*Magnetic belt;* including: (*a*) banded magnetic quartzite, gray to red quartzite, free from or lean in iron oxides, banded with seams from a fraction of an inch to several inches in width, of pure black granular magnetite, only rarely mingled with the specular oxide; (*b*) magnetitic quartzite, the magnetite in varying proportions, pretty well scattered throughout, and mingled with specular oxide in proportions varying from nothing to a predominating quantity; (*c*) magnetitic quartz-slate, the magnetite pervading the whole and mingled with the specular oxide as before; (*d*) slate, like (*c*), but largely charged with tremolite or actinolite; (*e*) arenaceous to compact and flaky quartzite, free, or nearly so, from iron oxides; (*f*) thin laminated, soft, black magnetitic slate; (*g*) hematitic quartzite, the iron oxide the red variety; (*h*) garnetiferous actinolite-schist or eclogite; (*i*) diorite, which is restricted to the western end of the Huronian belt. Kinds (*a*) to (*d*), all carry much pyrolusite, or other manganese oxide. These varieties have no persistent stratigraphical arrangement, and are named here in order of relative abundance. Total thickness about	780
V.	*Black feldspathic slate;* consisting of orthoclase grains imbedded in a paste of biotite, pyrite, limonite, and carbon	180
VI.	Unknown, always drift-covered	880

[1] See T. S. Hunt in Second Geological Survey of Pennsylvania. Special report on the Trap Dikes and Azoic Rocks of Pennsylvania, Part I, p. 69.

[2] Geology of Canada, 1863.

Formation	Description	Average thickness. *Feet.*
FORMATION VII.	Dark-gray to black, aphanitic *mica-slate*, having a wholly crystalline base of quartz and orthoclase, with disseminated biotite scales	120
VIII.	Unknown, but probably in large part same as VII	290
IX.	Chloritic, pyritiferous massive *greenstone*	150
X.	Black, aphanitic *mica-slate*, like VII	25
XI.	Covered, but probably mica-slate	280
XII.	*Black mica-slate*, aphanitic; at time chiastolitic	225
XIII.	Chloritic *greenstone-schist*	35
XIV.	*Black mica-slates*, like XII, often chiastolitic	375
XV to XVIII.	Alternations of black *mica-slates*, with *quartzites* and *quartz-schists*	675
XIX.	*Greenstone;* aphanitic; the hornblende and plagioclase much altered	260
XX.	Covered, but probably like XXI	525
XXI.	*Mica-schist;* from aphanitic to medium grained; including bands of light gray quartz-schist, the mica being subordinate; all varieties having a background of quartz; the mica wholly biotite; penetrated by veins and masses of very coarse pink to brick-red biotite granite; total on Bad River, 4,960 feet. Seen further east, higher layers, 2,500 feet; in all	7,460
	Total	12,800

Later investigations have shown that some, at least, of the greenstones of the above series are diabasic rather than dioritic. Here again the resemblance to the Animikie rocks is very strong. The magnetitic quartzites, other quartzites and quartz-slates, and the argillaceous slates of the Animikie and Penokee series are identical in character, while much of the upper mica-schist member of the Penokee Huronian is very close to the mica-bearing quartzites of the Animikie. In each of the groups the magnetitic quartzites are near the base of the series, and in both there are interstratified greenstone beds. In both the same relations obtain to the newer Keweenawan and older gneisses. The two groups are plainly enough the same.

THE MARQUETTE AND MENOMINEE HURONIAN.

The iron-bearing schists of the well-known iron regions of the northern peninsula of Michigan present one point of strong contrast to the Animikie and Penokee Huronian, in that, instead of dipping uniformly lakeward, they are intricately folded in troughs whose sides are gneiss and granite. At first glance the greater number of rock kinds characterizing the Marquette and Menominee Huronian as compared with those of the Penokee region might seem a further difference. There is, however, so plainly a general stratigraphical equivalency between the two series, as I have shown elsewhere,[1] that there can be no doubt of their belonging together. There is probably even a direct continuity between the two. Moreover, the lithological differences in a large measure disappear on closer study.

[1] Geology of Wisconsin, Vol. III, p. 163.

According to Brooks the rocks making up by far the greater part of the Marquette and Menominee Huronian are quartzites, magnetitic quartzites, rich iron ores, limestones, dolomites, clay slates, mica-slates, and greenstones. The greenstones are for the most part diabase and gabbro, with rarer peridotite. From Wichmann's microscopic descriptions I judge that the same kinds of diabase and gabbro are to be found here as in the Animikie Group, though for the most part more altered, *i. e.*, the orthoclastic and non-orthoclastic kinds, while the olivinitic kinds are here represented by the altered serpentinitic peridotites.

So far the resemblance to the Penokee and Animikie rocks is striking. It is among the remaining less abundant kinds named by Brooks that the seeming lithological differences between the schistose systems of these several regions are found. These less abundant kinds are diorite, among the "greenstones"; syenite, gneiss, granite, sericite-schist, jasper-schist, chert-schist, amphibolite—including actinolite schist, magnetitic actinolite-schist, and hornblende-rock and schist—augite-schist, chlorite-schist, and talc-schist.

The diorites of this list are in all probability merely uralitic diabases. I suspect this on account of the frequency of a uralitic change in the orthoclastic diabases of the Lake Superior region generally, and my suspicion is confirmed by the fact that Wichmann finds both augite and uralite as constituents of his diorites, and speaks distinctly of a gradation between the diabase and diorite. Moreover his descriptions of the diorites make them in other points very similar to the uralitic orthoclase-diabases and gabbros that I have examined from the Keweenaw Series and from the Animikie Group. These points are the presence of orthoclase in greater or less quantity, of titanic iron and its gray decomposition product, of a little quartz, and of very abundant apatite. Moreover, the quartz is described by Wichmann as occurring in such a way as to recall the "Lapis Hebraicus," a mode of occurrence which renders its secondary origin evident[1] and thus renders extremely probable the complete identity of these diorites and my uralitic orthoclase-diabases. The syenite mentioned by Brooks and Wichmann as occurring at only one point near Marquette, their descriptions show to be merely a phase of the diorite rich in orthoclase, and therefore inferentially a uralitic orthoclase-gabbro or diabase. Gneiss may be excluded from the list as being more than doubtfully Huronian when a true gneiss, or as being a mere phase of the mica-schists, such as occur also among the Penokee upper mica-schists. Granite only occurs in the Menominee region, where its Huronian age is very doubtful. The sericite-schist appears to be very close to some of the rocks of formation III in my descriptions of the Penokee Huronian,[2] and is very probably represented among the slates of the Animikie Group on Pigeon River. The jasper-schist and chert-schist are, of course, found also in both the

[1] Geology of Wisconsin, Vol. III, p. 629, §9.
[2] Geology of Wisconsin, Vol. III, p. 111.

Animikie and original Huronian. Of the amphibolites the actinolite-schist and magnetitic actinolite-schist are known also in the Penokee region. Hornblende-rock has also been described as occurring in the Penokee region, but a schistose hornblende-rock has not been noticed there. Whether any of the massive hornblende rocks here included are altered or uralitic diabases I am at present unable to say. Augite-schists are also mentioned as occurring at one point in the Marquette region.[1] Whether the hornblende-schists have any relation to them or not is not known. The chlorite-schists of the Marquette region belong to two distinct classes, of which one type plainly belongs with the greenstones as an alteration form, while the other may be connected with the true micaceous and hornblendic schists.

It thus appears that the Marquette and Menominee iron-bearing schists are essentially the same lithologically with those of the Penokee region and of the Animikie Group of the north shore. Of the few unusual kinds of the Marquette and Menominee regions some may be attributed merely to metasomatic changes, while the remainder are possibly to be attributed to the yet ill-understood process known as metamorphism, which in turn may be connected with the complex folding of the rocks in these districts as compared with the unfolded condition of the Penokee and Animikie beds.

CRYSTALLINE SCHISTS OF DOUBTFUL RELATIONS IN THE LAKE SUPERIOR COUNTRY.

The original Huronian, the Animikie slates, the Penokee iron rocks and the iron-bearing rocks of the Marquette and Menominee regions appear to me, then, plainly to belong together, and may hence very properly be called Huronian. In each of the regions mentioned, the areas of Huronian schists are limited by granite and gneiss. Commonly, when a contact of the schists with the gneiss and granites is to be seen, there is more or less strong evidence of unconformity, and in all cases—save that of the so-called Huronian granite of Brooks and Wright in the Menominee region of Wisconsin—the gneiss and granite plainly rise from beneath the schists. There are, however, a number of other areas and belts of crystalline schists on all sides of Lake Superior whose relations to the Huronian and to the older gneisses are in greater or less doubt. The doubt arises in some cases from a very imperfect knowledge of the rocks in question, but in others comes either from the structural difficulties involved in connecting these areas with the undoubted Huronian, or from the real or apparent conformity of some of them with the older gneiss, or from greater or less contrast lithologically with the recognized Huronian.

The positions and sizes of these areas of crystalline schists whose relations are doubtful will be best gathered from the map of Plate III. In the Thunder Bay country, between the northern limit of the Animikie Group and the vicinity of Dog Lake, schists, called by them

[1] Geology of Wisconsin, Vol. III, p. 645.

Huronian, have been studied by Murray, Logan and Bell. These schists appear nearly always, if not always, to be separated from the Animikie rocks by a belt of gneiss and granite, which is, however, at times very narrow. Isolated areas of gneiss and granite occur within the schists, which are bounded on the north again by a large area of gneiss and granite. Still further west and northwest, at about the west end of Lake Shebandowan, are other schists, succeeded again in turn by gneiss and granite. These so-called Huronian rocks consist, according to Bell, "of slates, some of them dark-green and composed of hornblende, some grayish-green and dioritic; others are light-colored, fine-grained, quartzose, somewhat nacreous micaceous schists; while dioritic slate conglomerates, quartzites, fine-grained felsites, massive diorites, ribboned jasper and iron ore also occur." These descriptions are of course not based on microscopic study, and are to be taken as representing the nature of the rocks only in the most general way. Bell describes these schists as always standing at a high angle, with a strike varying between N. 25° E. and N. 80° W. The quartzites, chert, and ribboned jasper and iron ore of these rocks certainly have much the look of the recognized Huronian. With regard to the rest of the rocks, it is impossible to draw any conclusions from the very general descriptions given, while there is no evidence presented showing that part of the so-called Huronian rocks might not really belong with the gneiss, which is in some places said to grade into mica-schist.

From the statements of Bell, Winchell and Chester, it is plain that the schistose belts (or belt) of the Thunder Bay region continue for over two hundred miles to the southwestward, at a similarly short distance north of the northern boundary of the Animikie rocks, and similarly involved with gneiss and granite. Still further north, in the vicinity of Rainy Lake, schistose bands occur again, as shown by Bigsby, Bell and others. The band of schists running west and south from the northern part of Saganaga Lake on the national boundary, for instance, is described by Bell[1] as consisting of "rusty brown, altered sandstone, * * * containing small white quartz pebbles," "soft green argillite," "dioritic schist," "cherty felsitic slate," "siliceous schist," "chert rock," which "resembles the chert near the base of the upper copper-bearing series"—*i. e.*, the Animikie Group—"gray granular quartzite," and "fine-grained glossy clay slate." All of these rocks are said to stand nearly vertical, inclining slightly on one side or the other, and to strike from 15° to 80° west of south.

Schistose rocks were crossed further west by N. H. Winchell in making a canoe trip from Bois Blanc Lake, on the national boundary, to Vermillion Lake, in 1879.[2] He speaks of these schists as soft greenish slates, siliceous slates, and hornblende-rocks of several kinds, all trend-

[1] Report of Progress of the Geological Survey of Canada for 1872–'73, p. 93.

[2] Ninth Annual Report of the Geological and Natural Historical Survey of Minnesota, p. 91, *et seq.*

ing in a general southwesterly direction and standing always at a very high angle, and apparently conformable with the associated gneiss. By Professor Chester's kindness I am in receipt of a large number of specimens collected by him around the east and south sides of Vermillion Lake for several miles, and thence southward to the Mesabi Range, in township 59. From these specimens, and from the notes accompanying them, I gather that there is here a broad belt of schists trending in a general way something south of west, with a very high dip a little on one or the other side of vertical, and intricately folded. Professor Chester's specimens include clay-slate, which he reports as largely exposed about Vermillion Lake; silvery mica-schist, running into greasy-surfaced aphanitic siliceous schist, which often suggests the rock of No. III of the Penokee series,[1] and is commonly very much altered and charged with red hematite to such an extent as to constitute beds of soft hematite analogous to those of the Marquette region; quartzites of several kinds; gray crystalline limestone associated with white quartzite, and precisely similar, both in nature and in this association, to the beds in the Penokee, Marquette and Menominee regions; gray cherty schists like those of the Animikie Group; banded jaspery and cherty magnetitic schists, banded quartzite and magnetic iron, and lean slaty magnetites, precisely like those of the Animikie Group at the Mesabi Range, already described, and like those of the Penokee and Marquette regions; and rich specular iron ores. Between these schists and the flat-lying beds of the Animikie Group in the Vermillion Lake region is a broad belt of gneiss and granite, which is plainly the one crossed by Bell between Gunflint and Saganaga Lakes.

The strong lithological similarity between the Vermillion Lake iron-bearing rocks and those of the Animikie Group and the South Shore Iron-bearing rocks generally makes it almost certain that the first-named rocks also are Huronian. But the connection of the Vermillion Lake schists with the schistose rocks northeast as far as Thunder Bay renders it nearly as certain that these, too, are Huronian in large measure. Now this decision—viz: that both the flat-lying Animikie slates and the more northern folded iron-bearing schists are Huronian—renders it necessary that I should present some suggestion as to the structural relations of the two. Though my knowledge of the region and of the nature of the older rocks is yet too limited to allow of very confident generalization, I strongly suspect that the relation is some such as indicated in the following diagram. That this is the true relation is rendered probable, not only by the lithological similarity and present altitudes of the two groups, but also by the fact that at several points a curving upwards of the otherwise very flat Animikie beds where they come into contact with the underlying granite and gneiss has been observed. I saw this myself on the north shore of Thunder Bay, where the two formations

[1] Geology of Wisconsin, Vol. III, p. 111.

come together. N. H. Winchell, if I have understood him correctly, observed something of the kind on the national boundary, and Mr. Geo. Stuntz again at the Mesabi Range. Moreover, the same sort of relation must certainly exist on the South Shore, between the eastern extension of the unfolded rocks of the Penokee Iron Range and the highly-folded iron-bearing schists of the Menominee region.

On the South Shore the relations of the different schistose rocks have been more satisfactorily worked out, though there are many doubtful minor points, and doubtless some schistose rocks have been called Huronian that are not certainly so. However, it is certain that here we have genuine schists interbedded with the older gneiss in such a way as to admit of no doubt of their being subordinate to it. Brooks has observed this in the Menominee region, and I have found it so in the Penokee region and in the region of the Wisconsin River Valley. In this valley, in the vicinity of Wausau, is found a southwestward extension of the Menominee Huronian in the shape of a series of chert-schists, mica-schists, quartz-schists, quartz-porphyries, and greenstones (including diabase, gabbro and peridotite.) Genuine hornblendic schists are unknown in this region in the Huronian, while they are frequently associated here with the gneiss. Hornblendic rocks have been heretofore regarded as characteristic of the Huronian series. But I have already shown good reason for suspecting that all the so-called diorites, syenites and hornblende-rocks of the Marquette and Menominee regions are in all probability but uralitic diabases, while the hornblende-schists may be, in part at least, altered augitic schists.

On the east shore of Lake Superior—at Batchewanung Bay, at the mouth of the Michipicoten River, on the coast north from Michipicoten Island, and at the extreme northeast corner of the lake in the region of the Pic River—are again crystalline schists associated with more or less greenstone, which have been described as Huronian by Murray, Logan and Bell. That some of these rocks are the equivalents of the original Huronian there can be no doubt, but how far they are so is wholly uncertain.

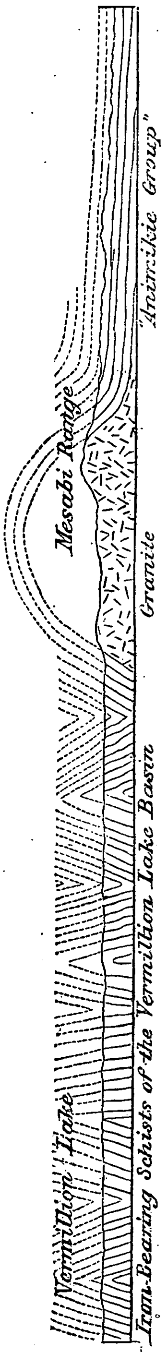


FIG. 43.—Ideal section, designed to show hypothetical structural relations of the Animikie Group, and Vermillion Lake schists.

RELATIONS OF THE KEWEENAWAN AND HURONIAN IN GENERAL.

In attempting now to determine the relations of the Keweenawan to the Huronian we have two classes of data to build upon, namely, the lithological similarities and dissimilarities obtaining between the two systems of rocks, and the structural relations of the two where they are found in proximity to each other.

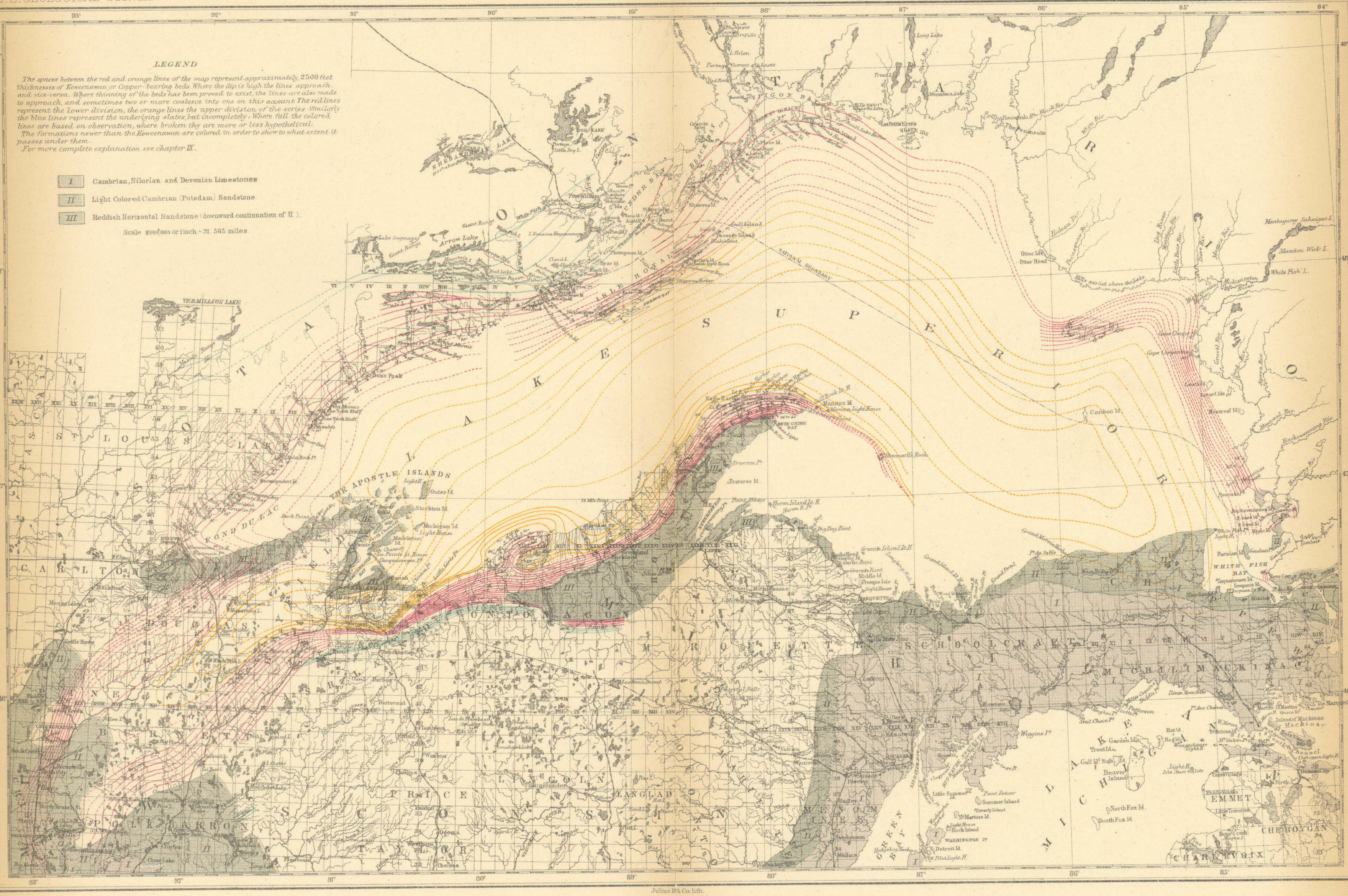
If the basic eruptive rocks of the two groups are alone considered there is undoubtedly a close lithological similarity. The vesicular or amygdaloidal character so common in the Keweenawan rocks is indeed almost entirely wanting in the Huronian, as are also the pseud-amygdaloids and the peculiar fine-grained brownish and purplish diabases so often met with in the upper part of the first-named series. The basic eruptives of both groups, however, are diabases, while the more massive rocks of both are for the most part identical even in microscopic characters. So close is this identity, that, so far as the more massive rocks are concerned, the classification given in Chapter III for the Keweenawan basic eruptives would apply nearly as well to those of the Huronian, the so-called diorites of the Huronian being taken as uralitic diabases.

Passing now to the acid eruptives of the two groups the similarity no longer holds. We look in vain throughout the entire Lake Superior region outside of the Keweenaw Series itself for the great flows of red felsite and quartziferous porphyry which constitute in it so marked a feature. It is not so certain that the granitic porphyries and augite-syenites of the Keweenawan are wholly wanting in the Huronian. Some of Logan's descriptions of the north shore of Lake Huron suggest their occurrence there, and the same is true of some of Norwood's statements with regard to the Animikie rocks of the Pigeon River country.

Between the laminated or sedimentary rocks of the two groups the contrast is strong. The Keweenawan red sandstones and shales have little in common with the quartzites, slates and schists of the Huronian, even where the latter are most distinctly of a fragmental origin.

So far then as lithological characters go, the Keweenawan is linked to the Huronian by a similarity between certain of the basic eruptives, but is separated from it by the absence of vesicular forms in its basic rocks, by their more frequent occurrence in it as dikes, by the rarity in it of acid eruptives, and by the dissimilarity between the sedimentary members of the two groups.

When we turn to the structural relations of the two series of rocks, we find, for the most part, the same partial separation indicated. So far as the western half of the Lake Superior basin is concerned, we find the two formations on both South and North Shores in approximate conformity as to parallelism of strata, but separated distinctly by an intervening erosion. On the North Shore, from the Saint Louis to Thunder Bay, the Keweenawan and Animikie Huronian are in close conformity. At the eastern end of this coast both incline lakeward, at an angle of 10°, the contact of the two being in sight along with some hundreds of feet in thickness of each. The same perfect parallelism at a still flatter angle is to be observed on the east side of Thunder Bay, where the overlying Keweenawan has at its base several hundred feet of sandstone.



MAP OF THE LAKE SUPERIOR BASIN DESIGNED TO SHOW THE STRUCTURE AND EXTENT OF THE KEWEENAWAN TROUGH.

Indicative of an intervening erosion between the two groups in this region is the absence of this sandstone where the two formations come together at Grand Portage Bay, while the relations of the sandstones and slates in the vicinity of Thunder Cape amount, as already shown, to a demonstration of this intervening erosion.

Thus far, however, I have considered the structural relations of the Keweenawan to the unfolded Huronian only. There has yet to be considered whether the folding of the folded Huronian preceded entirely the Keweenawan deposition and eruption, was contemporaneous with them, or wholly subsequent. The solution of this problem can only be fully reached when the Huronian rocks themselves have been fully studied. The folded Huronian and the Keweenawan approach each other in the Keweenaw-Marquette region, and in the vicinity of the promontory of Mamainse on the east coast. According to Bell, they are in contact also in the Nipigon Lake basin, but the rocks of this basin which he calls Huronian are only very doubtfully so. So far as the two former of these regions are concerned, as I have shown at some length in the original memoir, the folding of the Huronian may have taken place during, or even after, the Keweenawan period. If Bell's reference, however, of the schists of the Nipigon Lake basin to the Huronian is correct, the folding must have entirely preceded the Keweenawan period.

In conclusion, then, it is to be said that the Keweenaw or Copper-bearing Series stands clearly out by itself. It is pre-Cambrian and post-Archean. The time-gap between it and the Cambrian was far too great to allow of its being classed as lower Cambrian, and, while we are still uncertain as to whether the gap between it and the Huronian was long enough to cover the folding and alteration of the latter, we are certain that it was too long to allow the classing of the Keweenawan as later Huronian.

CHAPTER IX.

STRUCTURE OF THE LAKE SUPERIOR BASIN.

Foster and Whitney first pointed out the probability that a synclinal depression exists underneath the waters of Lake Superior, between Isle Royale and Keweenaw Point;[1] being led to this view by the lakeward inclination of the rocks on both Isle Royale and the point, and by the fact that on the lakeward side of each sandstone and conglomerate prevail, while on the side away from the lake the rocks in each case are prevailingly crystalline.

During my first season's work on Lake Superior for the Wisconsin State Geological Survey, in 1873, I collected facts in the Bad River country of Wisconsin, going to show that to the westward the Isle Royale-Keweenaw Point synclinal runs on to the South Shore, the rocks being found there dipping both ways. The observations of my assistant, Mr. E. T. Sweet, made during the same season on the "Copper Range" of Douglas County, Wisconsin, tended very strongly to confirm this conclusion, since the rocks of this range were found to dip southward. My conclusions from the data then in hand were published in 1874, along with an outline map and section.[2] The subsequent work of the Wisconsin Survey during the years from 1874 to 1878, by Sweet, Strong, Chamberlin and myself, served to place beyond question the truth of the main points of my conclusions of 1873, while at the same time modifying them in some respects, and developing a number of new facts with regard to the structure and course of the synclinal.[3]

The most important modification was with regard to the supposed occurrence of horizontal Potsdam or unconformably overlying sandstone in the trough of the synclinal. On my map of 1874 I had marked such a sandstone as occurring along the upper Saint Croix, as indicated by the descriptions of Dr. D. D. Owen,[4] but this sandstone was subsequently shown by Sweet[5] to belong in the upper division of the Keweenaw Series, it being in fact but the westward continuation of the south-dipping sandstone of White and Bad Rivers. The upper Saint Croix was again further examined by Sweet and Strong in 1876, and the sandstone in question found to be underlaid conformably by fine-grained

[1] Report on the Lake Superior Land District.

[2] "On the Age of the Copper bearing Rocks of Lake Superior, and on the Westward Continuation of the Lake Superior Synclinal." American Journal of Science and Arts, Vol. VIII, July, 1874.

[3] Geology of Wisconsin, Vol. III.

[4] Geological Survey of Wisconsin, Iowa, and Minnesota, p. 161.

[5] Notes on the Geology of Northern Wisconsin, by E. T. Sweet: Trans. Wis. Acad. Sci., Vol. III, 1876.

idabases and melaphyrs, with interbedded conglomerate and sandstone. My map and section of 1874 had also shown horizontal sandstones filling the trough of the synclinal in the Bad River region. This conclusion was based on an observation by Dr. I. A. Lapham, which subsequent examination by myself failed to verify. There then remained to indicate the presence of this newer sandstone in the trough of the synclinal only an exposure of flat sandstone on the shore of Lake Superior, at Clinton Point, four miles west of the mouth of Montreal River, and this, as shown in the previous page, is rather to be regarded as the eastern termination of the horizontal sandstone of the Apostle Islands and the coast of Bayfield County.

The chief new developments as to the structure and course of the synclinal, resulting from the work of the Wisconsin Survey, were, (1) the connection by Strong of the Keweenaw Range of north-dipping rocks with the similar rocks of the Saint Croix, by exposures all across the previously wholly unexamined interval between that river and Numakagon Lake; (2) the determination of the comparative flatness of the northward dip across the interval; (3) the determination by Chamberlin of a curve to the southward of the belts of this range, with a flat westerly dip, in the immediate vicinity of the Dalles of the Saint Croix, and the consequent probability of a southerly direction to the axis of the synclinal near its final termination; and (5) the determination by Sweet of the existence of a southward dip in the Saint Louis River slates, and the consequent probability that the Huronian rocks form the bottom beds of the synclinal.

In Vol. III of the Geology of Wisconsin, published in 1880, I embodied all of these points in a brief discussion of the structure of northern Wisconsin, accompanied by a map which I modify now only as to the exact extent of the upper sandstone of the Keweenawan, and as to the western extension of the horizontal sandstone of the lake shore, which on the map of 1880 was made by misprint to extend to the north side of the Saint Louis River at Duluth. No such sandstone is to be seen near Duluth.

At the beginning of my study for the present memoir, north Wisconsin had, then, been shown to be traversed by a broad synclinal in the Keweenawan rocks, possibly also in the Huronian, which was presumably the continuation of the Isle Royale-Keweenaw Point depression. The exact nature and position of the western termination of the synclinal, the relation to the synclinal of the rocks of the Minnesota coast and of the Porcupine Mountains, and the behavior of the depression to the eastward of Isle Royale were all points left in doubt, though it appeared exceedingly probable that the entire western half of the Lake Superior basin is a synclinal depression affecting both Huronian and Keweenawan rocks.

Now, however, I feel able to announce with confidence that the entire lake basin, including not only the western half, but the eastern half as well, is a synclinal depression; that this depression certainly affects the Keweenawan rocks throughout their entire extent; that it as certainly affects in a very large measure the underlying Huronian rocks; which, while they are greatly folded where extending without the limits of the depression, within its limits form without folds its bottom layers; that the axis of the depression has, like the lake itself, at first a northwesterly and then a southwesterly direction, with minor bends corresponding to the several bends in the axis of the lake; that the eastern termination of the depression is buried beneath the newer formations in the vicinity of the Sault St. Marie; that the western extension passes on to the south shore of Lake Superior, with a course curving more and more to the southwest until at the termination in the Saint Croix valley, and, therefore, without the present hydrographic basin of Lake Superior, it becomes nearly due south, the exact termination here again being buried beneath the newer horizontal Cambrian formations; that in the region of the Porcupine Mountains of Michigan and the Douglas County copper range of Wisconsin, there are minor folds superinduced upon the grand synclinal; and that, in the former case at least, the minor folds are further complicated by faulting.

The evidence upon which these conclusions are based is to be found in the nearly constant dip inwards towards the middle of the basin of the Keweenawan strata; in the frequent similar dip of the Huronian; in the constant order of Upper Keweenawan, Lower Keweenawan, Huronian, and gneiss with granite and folded crystalline schists, met with on all sides on going from within the supposed trough outwards; and in the parallelism between the courses of the Keweenawan belts of the North and South Shores, and of the shore line with these belts.

The details of the evidence under the first three of these heads are given in full in Chapters VI and VII of the original memoir, and are briefly alluded to in previous pages of this abstract, but their repetition here would occupy too much space. Many of these details are embodied in the maps and sections accompanying this abstract.

The evidence under the fourth head needs some explanation. In the first place it is to be observed that the accompanying maps of Lake Superior, Plates III and XVI, are much more accurate than any previously printed with geological data, being compiled directly from the maps of the United States Lake Survey, from Captain Bayfield's chart, and from the United States Land Office plats, and that, consequently, correct ideas may be obtained from them as to the courses of the coast and other topographical lines, and of rock belts.

Directly north of the east and west portion of Keweenaw Point, between Agate Harbor and Copper Harbor, with its east and west rock belts, dipping north, we find the east and west part of Isle Saint Ignace again made up of east and west rock belts, which now, however, dip to the southwestward. From Agate and Eagle Harbors on Keweenaw Point the coast line of the point and the course of the constituent rock belts swing around to the southwest. Correspondingly, we find, on the North Shore, a southwest trend (participated in by rock belts, coast lines, and lines of islands), beginning in the western part of Isle Saint Ignace, and continuing through the peninsula which forms the south side of Black Bay, through the adjoining islands, and through Isle Royale.

Isle Royale does not lie on a straight course, but on a curving one, its outlines, projecting points, ridges and rock-belts at the western extremity trending 10° to 12° more to the south than at the eastern extremity. This curvature to the westward is continued to a nearly due westerly direction in the rock-belts and projecting points and other topographical features of the Minnesota coast between Pigeon River and Grand Marais, although the coast line in this distance trends as a whole some 20° south of west. The counterpart of this swing to the west is found on the south shore of Lake Superior in the course of the "Main-Trap Range" and its constituent rock-belts, and of the coast line between Fourteen-mile Point and Black River.

West of Black River, the "Main-Trap Range" of the South Shore and its rock-beds curve again to the south of west, and, as Bad River is neared, the direction is only some 30° west of south. The corresponding curvature on the North Shore is to be found in the distance between Grand Marais and Split Rock River. For much of this distance the coast line follows the trend of the strata, until the latter comes around to only a few degrees west of south, when the rock-belts depart from the coast and run with a westward curvature over to the South Shore. Still farther west, both sides of the synclinal are on the South Shore, the strata, and with them many topographical features on both sides, trending at first well around to the west, and then more and more towards the south, until the termination is reached in the Saint Croix Valley.

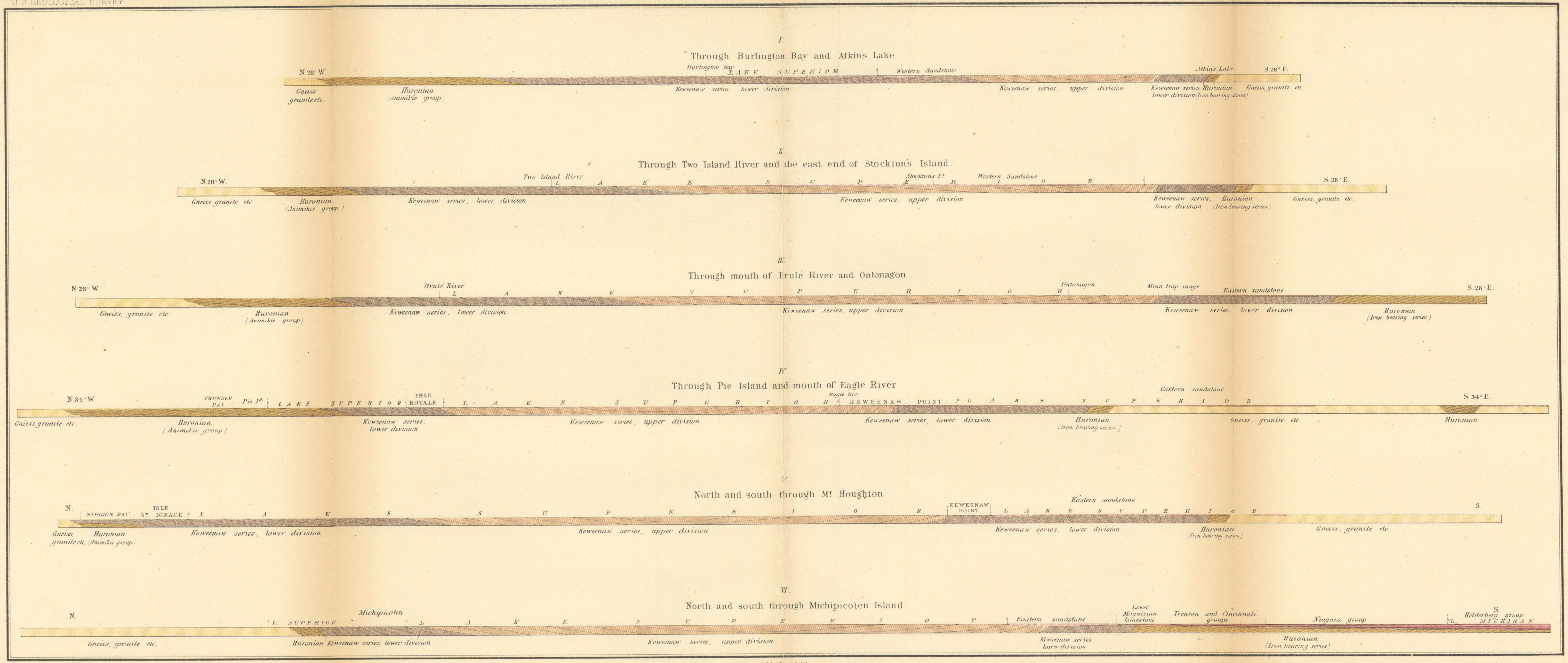
Beyond Copper Harbor to the eastward, on Keweenaw Point, the point and its strata begin to swing around to the south of east, and this direction is continued on Manitou Island and in Stannard's Rock, which is, as previously shown, a mass of quartzless porphyry. Parallel to this curving course is the coast line of the lake between Huron Bay and Marquette. Now on the North Shore, in the line of islands lying south of Nipigon Bay, and in the rock-belts composing them, a similar curvature to the south of east is begun. That this continues until it becomes nearly or quite a southerly course is shown by the trend of the northeast coast line of the lake—which is composed of the older rocks—between the Pic River and Michipicoten Island, where the Keweenawan rocks again appear. The parallelism of the northeast coast, of the line marked out by the eastern end of Keweenaw Point and Stannard's Rock, and of the south coast between Keweenaw Bay and Marquette, looks also the same way.

Still farther to the east the South Shore shows only rocks newer than the Keweenawan, but at the east end of the lake a continuous belt of the latter rocks is marked by Michipicoten Island, Capes Choyye and Gargantua, Pointe Aux Mines, the peninsula of Mamainse, the coast of Batchewanung Bay, and Gros Cap, the beds always dipping lakeward. The most striking thing about this belt is its parallelism to the lake coast behind it and the consequent abrupt turn, at more than right angles, in the Michipicoten bight.

In the map of Plate XVI, and the accompanying sections of Plate XVII, I have attempted to summarize the facts bearing upon the subject of this chapter, and to generalize from them to the structure of the synclinal. The spaces between the red lines of this map are supposed to represent each 2,500 feet of rock thickness, the spaces being narrow where the dip is high, and correspondingly broad where it is low. The lines were constructed by first platting out the spaces in those districts where actual measurements had been made of strike and dip, the width of each space being made to correspond to the width of the surface outcrop of a thickness of 2,500 feet at the measured angle of dip. Where actual thinning on a large scale had been proved by careful measurement to exist—*e. g.*, on Keweenaw Point—the lines are approached on this account also, to the determined amount. Then, taking into account the general lithological characters of different horizons—often recognized for over a hundred miles—the relations of the belts to the junction with the Huronian below and to the line between the upper and lower divisions of the Keweenawan above, and the angles of inclination and trends indicated by the nearest exposures, the broken connecting lines were sketched in.

The spaces between the lines do not, of course, represent single continuous beds, or even, in many cases, groups of beds, for, in the course around the lake, such beds must constantly thin out and be replaced by others. The spaces are, however, designed to cover the same general horizon as far as practicable. Of course there must be many imperfections in such a map, under the very best of circumstances; for not only do the courses of the belts under the lake have to be hypothetical, but from general similarity of the beds of the lower division at very different horizons, there must always be more or less doubt as to the correctness of the connecting lines, even on the land. Then, again, the map is very irregular as to accuracy in those places where the courses and inclinations of the beds can be marked out. On Keweenaw Point, for instance, the detailed measurements of Pumpelly and Marvine make it possible to locate the courses of the spaces of 2,500 feet with far greater minuteness of detail than it is possible to show on such a map as this. From this, downward, there is every degree of accuracy to cases where the lines must be put down as hypothetical.

Notwithstanding all these defects, the general correctness of the structure of the great synclinal indicated by the red lines appears to me unquestionable. One objection that I anticipate to this map is that it is an attempt to apply the methods used in studying sedimentary beds to a series largely formed of eruptive ones; to which I have to answer



GENERALIZED GEOLOGICAL SECTIONS OF THE LAKE SUPERIOR BASIN.

Scale $\frac{1}{500000}$ or 1 inch = 7.891 miles beforehand that this series is just as much made up of layers as any sedimentary one, and that, in a sedimentary series, beds thicken and thin and disappear just as here—in short, that the objection is no objection at all.

The map and sections do not show the nature of the bottom of the trough. I believe this bottom to be made up of Huronian slates below, resting upon the older gneiss, and of Keweenawan strata above, but both greatly thinned, since the eruptive rocks, which constitute so large a part of these groups around the edge of the basin, appear to me to have reached the surface there.

The simplicity of the synclinal has been further complicated by faulting. The fault to the south of the Keweenaw Point Range may probably have been connected with a sudden change in the dip of the strata from a flat to a steep lakeward inclination. It seems a plausible speculation that this fault is met at a large angle by another coming from the southeast, at a point behind the line from the end of Keweenaw Point to Stannard's Rock, the junction of the two being the lowest part of the dislocation. Behind the Porcupine Mountains, as previously shown, is again a fault of much smaller extent, which is again connected with a fold, though a subordinate one. I have also already indicated the probability of the existence of a fault on the north side of the Douglas County Copper Range of Wisconsin. The connection of the belts of this range with those of the north shore is to me one of the least satisfactory parts of the map of Plate XVI. It is evident, however, from the trends on the north shore, and in the Douglas County rock-belts, that some such connection must exist, though whether with so much of a fold as I have indicated is not so plain.

The relation of the Huronian to the synclinal is a point of great interest. Beyond question, in the western half of the Lake Superior basin, it bottoms the great trough, for its beds are found dipping inwards on both sides—on the North Shore at a low angle, and on the South at a high one. It appears highly probable that the eastern part of the trough is similarly bottomed by the Huronian. The Huronian beds are, however, here found just without the rim of the synclinal folded in a complicated manner; for instance, beyond the western end of the trough in Minnesota, in the iron regions of Michigan, on the east shore of Lake Superior, and about the head of Lake Huron. Other folded schists, which possibly belong with the Huronian, occur in Canada, north of Lake Superior, as shown in the preceding chapter. The connection of these folded beds with the unfolded is a structural problem which I am now engaged in investigating. So far as present knowledge will allow, it has been discussed in the previous chapter.

CHAPTER X.

THE COPPER DEPOSITS.

The plan of the work upon which this memoir is based did not embrace any special study of the copper deposits; nor could any important additions have been made, in the time at command, to our knowledge with regard to them. This chapter, then, embraces only a brief account of the more general geological relations of these deposits.

All the workable deposits of copper heretofore discovered in the Lake Superior region fall into one or other of two classes, which we may term belt, or bed, deposits, and transverse vein deposits. The first class includes the cupriferous conglomerates and sandstones, the cupriferous amygdaloids, and most, if not all, of the so-called veins carrying much epidote and coinciding with the bedding of the formation; the second class includes those veins which traverse the formation in a direction more or less nearly at right angles to the bedding. No copper has ever been observed in connection with the acid rocks, nor have any workable deposits been discovered in the massive non-vesicular diabase beds, except as distinctly subordinate to, and directly connected with, the amygdaloid deposits, and always accompanied with an extreme degree of alteration.

The conglomerate and sandstone deposits are simply portions of the beds of these rocks, in all respects of the ordinary character, save that they are impregnated with the native copper. Cupriferous deposits of this character are for the most part confined to the thin conglomerate beds which are interstratified with the ordinary diabase flows; but one cupriferous bed of sandstone is known within the upper or purely detrital division of the Keweenaw Series, and separated from the nearest trappean flow beneath it by a thickness of many hundred feet of sandstone layers. This is the belt of dark-colored sandstone and shale in which occurs the Nonesuch copper bed of the Porcupine Mountains. This belt has been traced from Keweenaw Point to Bad River, a distance of some 150 miles, and has been found to contain copper at a number of points in the vicinity of the Porcupine Mountains, and again on the Montreal River, the boundary line between Michigan and Wisconsin.

In the cupriferous conglomerates and sandstones, the copper occurs as a cementing material, and as a replacer of the constituent grains, being in all cases plainly of secondary origin and a result of deposition from an aqueous solution. Moreover, the cementing copper itself—*i. e.*, that which is to be seen in the thin section between the constituent grains molding itself sharply around their contours—is often really a replacer of still smaller constituent particles. In the case of the Nonesuch sandstone of the Porcupine Mountain region, a large proportion of the particles of cementing copper have within them a core of magnetite. It is, indeed, not improbable that in all cases the cementing copper is not a deposit in the original interspaces of the fragmental particles, but is always a replacer.

In the thin sections of these cupriferous conglomerates, the larger particles of porphyry matrix and fragments of the feldspars are found to be replaced by copper in varying degrees, the metal in the case of the feldspar fragments tending to follow the cleavage directions. In the famous conglomerate of the Calumet and Hecla mine, in the Portage Lake region, the copper has not only saturated the matrix, but has also entered into and more or less completely replaced large-sized pebbles, and even bowlders several inches to a foot or more in diameter. Hundreds of such bowlders are picked each day from the heaps of rock, before it is taken to the stamps. In these bowlders the copper has replaced both the matrix and porphyritic feldspars, occurring in the latter, when the replacement has not been carried very far, often along the cleavage lines only. Pumpelly has shown that the deposition of this copper has always followed other great changes in the condition of the porphyry fragments, and notably the replacement of both matrix and feldspars by chlorite and epidote—these minerals having in turn been replaced by the copper. This relation between copper, epidote and chlorite is one which exists also in the altered amygdaloids; and the source of the constituents of these minerals may be found either in the particles of amygdaloid matrix and other basic materials which not unfrequently occur in the conglomerates themselves—in the Nonesuch sandstone forming a predominating quantity—or in the overlying trappean beds, from which they may have descended along with the infiltrating carbonated waters.

The ordinary cupriferous amygdaloids, such as those which are so largely mined about Portage Lake, are, as Pumpelly was the first to show, simply the more or less completely altered and copper-saturated upper vesicular portions of the old lava flows, and are neither independent layers, nor "veins" parallel with the formation. The copper has been introduced into these amygdaloids during one of the later stages of a long chain of replacements, whose history has been worked out by Pumpelly. Several paragraphs of his descriptions may appropriately be quoted in this connection:

Considerable portions of the bed have lost every semblance of an amygdaloid, and consist now of chlorite, epidote, calcite, and quartz, more or less intimately associated, or forming larger masses of the most indefinite shapes, and merging into each other. Sometimes portions of partially altered prehnite occur. In places considerable masses of rich brown and green fresh prehnite filled with copper occur; but, as a rule, this mineral has given way to its products.

To this process the copper-bearing beds of Portage Lake—wrongly called lodes—owe their origin. Considerable portions of these beds are but partially altered amygdaloids, containing amygdules of prehnite, chlorite, calcite, or quartz, with more or less copper; other portions are in the condition described above.

In the still amygdaloidal portions the copper was deposited in the cavities and in cleavage planes of some minerals, and replaced calcite amygdules, &c. But in the confused and highly altered parts of the bed it crystallized free where it had a chance; more generally it replaced other minerals on a considerable scale. It formed, in calcite bodies, those irregular, solid, branching forms that are locally known as horn copper, often many hundred pounds in weight; in the epidote, quartz, and prehnite bodies, it occurs in thread and flake-like impregnations; in the foliaceous lenticular chloritic bodies it forms flakes between the cleavage planes and oblique joints, or in places—and this is more particularly true of the fissure veins, which we are not now considering—it replaces the chloritic, selvage-like substance till it forms literally pseudomorphs sometimes several hundred tons in weight.

The copper in these deposits is not restricted to that portion of the bed which was originally vesicular, but runs from it downward irregularly into the originally compact portions, following always a great alteration of the rock. The copper, however, tends always to be very irregular in distribution, and even in the longest worked and most remunerative amygdaloids, has frequently to be searched for through many feet of barren rock. In this search the diamond drill is now extensively used, the miners being guided in its use by the occurrence of seams of calcite and epidote, and other alteration-forms, which, when followed up with the drill, are often found to lead to pockets containing much copper.

In one class of amygdaloids—those of the ashbed type, which I regard as merely very highly scoriaceous and open lava flows, into the interstices of which the now intermingled detrital material has subsequently been washed—the distribution of the copper is sometimes more uniform than in the ordinary cupriferous amygdaloids, so that the whole of the bed may be broken down and taken to the stamps, as is done for instance at the Atlantic Mine.

The copper deposits of the Ontonagon region have not had the study given to them that has of late years been devoted to those of the Keweenaw Point and Portage Lake districts; so that it is not possible to be quite so positive in our statements in regard to them. The copper of this region does not occur in transverse fissures; but either lies in irregular accumulations—often solid masses many tons in weight—associated with much epidote and calcite, distributed along the courses of diabase beds; or else occurs with more persistent and vein-like aggregations of epidote and calcite. The latter coincide always with the bearing of the formation, and commonly also with its dip, but in some cases, as for instance in the once famous Minnesota Mine, dip at a higher angle than that of the formation, which they consequently slowly traverse in depth. According to Foster and Whitney, deposits like that of the Minnesota Mine show another indication of a vein-like character in the shape of slicken-sided and generally sharply-defined walls. It is evident, even with our present knowledge of the deposits of the Ontonagon district, that their history has been essentially the same as that of the Portage Lake deposits. In the case of that copper which occurs irregularly distributed, along with epidote and calcite, throughout certain of the trappean beds, the process of replacement has gone on irregularly, because of some irregularity of texture in the original rock. Deposits like that of the Minnesota mine may have resulted from the deflection of the altering waters along the course of a pre-existing but not open fissure; the "vein" being in this case, as before, a replacement, at least in large measure, of original rock substance.

The transverse veins have been mined for copper on Keweenaw Point only, where they are found varying in width from mere seams to 10 and even 20 and 30 feet. For the most part, however, they do not exceed one to three feet in width, the expanded portions being met with where they traverse the amygdaloidal or otherwise open-textured portions of the flows. The same veins which in the amygdaloid and looser-textured diabases are expanded and often rich in copper, will, when in the more compact and massive beds, such as the well-known "Greenstone," contract to mere seams without metallic contents; and the same is in large measure true of their intersections with sandstone belts. The veins lie always very nearly at right angles to the trend of the beds which they traverse, standing always very near the perpendicular. Quartz, calcite and prehnite, make up the common vein-stone; but they are mingled with more or less of the wall rock of the vein, which frequently predominates greatly over any true vein-stone. The veins are, in fact, for the most part not sharply defined from the surrounding rock, but consist in each case of a net work of smaller seams traversing the shattered wall rock. Veins composed almost wholly of calcite are not unknown, but they are never productive of copper. The copper in these veins occurs both in smaller fragments and minute particles, intimately mixed with veinstone, and again in masses many tons in weight. The larger masses frequently are found to contain within them portions of the wall rock.

Nearly all of the productive mines based on the transverse veins are working directly beneath "The Greenstone," the layer which is described in a previous chapter as constituting so prominent a feature in the geology and topography of Keweenaw Point. This position of the mines is not due to the non-occurrence of copper elsewhere on the courses of these veins, but results from the fact that farther south they become buried beneath a heavy coating of drift, while to the northward they pinch out and become barren in the broad "Greenstone" belt.

These veins, on account of their transverse position to the bedding of the formation, of their often slicken-sided walls, and from their carrying often a true veinstone, have commonly been regarded as "true fissures." That they are on the lines of pre-existing fissures or transverse cracks in the formation there can be no doubt; but that they are true fissure veins in the sense that the veinstone and metallic matter occupy, along with wall-rock fragments, original fissure space, I cannot admit. I see in them simply the results of a rock alteration entirely analogous to that which has brought about the deposition of copper and its associated veinstone minerals within the cupriferous amygdaloid. They are alteration-zones which traverse instead of following the bedding, simply because the drainage of the altering waters has been given this direction by the pre-existing fissures. All of the phenomena of these veins coincide completely with this view: the common occurrence of wall rock within the vein, or rather the embracing of the wall rock masses by the vein; the replacement of wall rock by copper masses; the occurrence of wall rock within these masses; the expansion of the veins and their greater richness where traversing the more readily alterable amygdaloids and looser-textured diabases; their contraction and barrenness within the compact and less readily changeable "Greenstone"; and the coincidence of the paragenesis of the vein minerals with that of those of the cupriferous amygdaloids—are all things better explicable on this view than on any other.

Thus the differences in origin of the several classes of copper deposits—conglomerate beds, cupriferous amygdaloids, epidote veins parallel to the bedding, and "fissure" veins transverse to it—which, at first sight, seem to be great, for the most part disappear on closer inspection. They are all the result of the percolation of carbonated waters, which, in the lines of fissure, the open-textured amygdaloids, and the nearly equally open conglomerates, found the least resistance to their passage, and at the same time the greatest susceptibility to their altering power. This susceptibility depended partly upon the very openness of these different rocks, but also, in the case of the amygdaloids, on the presence of a large proportion of glass basis, the most readily alterable substance among rock constituents.

The source and the cause of the arrest of the copper which was carried in with the altering waters, are other and more difficult questions. Its home has commonly been regarded as within the mass of the trappean flows themselves, with which it is supposed to have come to the surface. Another view is that it was originally deposited in a sulphuretted form along with the detrital members of the series, from which it was subsequently leached, partly in the shape of a sulphate, but principally as a carbonate and silicate. The latter is the view which Pumpelly has elaborated;[1] to whom also is due the credit of having advanced the only satisfactory view as to the cause of arrest of the copper in the places where it now is found. He has shown the existence of an intimate relation between the precipitation of the copper and the peroxidation of the ferrous oxide of the augitic constituent of the basic rocks; a relation so constant as to render irresistible the conclusion that in this ferrous oxide is to be found the precipitating agent of the copper. To this I would add that the ferrous oxide of the magnetite and of the unindividualized magma of the vesicular layers has also been concerned in this reaction.

[1] Geology of Michigan, Vol. I, Part III, p. 43.

While this explanation of the precipitation of the copper seems satisfactory, we have too little to go upon in deciding between the two views above referred to as to the source of the metal. Too few signs have been observed of the existence of copper in the upper sandstones of the series, such as would be expected were this its home, to allow of an easy acquiescence in Pumpelly's view. On the other hand the trappean rocks themselves are for the most part devoid of copper, except such as is plainly secondary. Copper in a sulphuretted form I have, however, observed in the coarse gabbros of Duluth, in the green uralitic gabbro of the Bohemian Mountains, and in the similar coarse rocks in one or two places on the north shore of Lake Superior. It is sometimes said that copper occurs in the conglomerates and sandstones only where it could have leached directly downwards from an overlying trappean mass; and with one exception the statement is undoubtedly correct. The exception—that of the Nonesuch cupriferous sandstone of the Porcupine Mountains—is, however, a very important one, since this rock not only has no overlying diabase, but is separated from the nearest trappean flow beneath it by many hundred feet of detrital material. As previously shown, this sandstone is unusual for its large proportion of basic detritus. Its copper can only be connected with a trappean source by supposing it to have formed part of this detritus in the sulphuretted condition, and afterwards to have been dissolved and redeposited in a native state. This is a supposition which would seem on the whole, however, to be much more violent than to regard the copper as having come from the overlying sandstones, and as having been arrested in its descent on meeting a layer so rich in basic detritus as to be able to furnish the requisite supply of precipitating agent.

From the facts and theoretical considerations thus given may be formulated a few simple rules to guide the explorer for copper in the regions traversed by the Keweenaw Series. Thus the explorer, should he be searching for transverse veins, should bear in mind that epidote, prehnite and chlorite are the favorite associates of the copper; that veins carrying a greatly predominating quantity of calcite are not likely to be cupriferous; that laumontitic veins have hitherto not proved to be sufficiently rich for exploitation; that a vein which may be very rich and wide in the amygdaloidal or other soft and easily decomposed rocks will pinch to a mere seam and become barren within the massive and more compact layers; that, hence, the intersection of a vein with such amygdaloidal or other soft beds should always be searched for; that the copper occurs in these veins with extreme irregularity; and, finally, that a vein found traversing decomposed amygdaloid beds with the favorable veinstone, even though it show only a little copper at surface, is worthy of examination.

Should our explorer be looking for cupriferous belts, he should see that they are well defined; that they present evidence of much alteration such as is above indicated; and that one or more of the favorite associate minerals of the copper is present. These favorable indications, along with a more or less well-preserved amygdaloidal character to the rock, and the presence of some copper at the surface, are sufficient to warrant further examination. In searching for these belts, care should be taken not to be misled by the occurrence of seams of native copper without veinstone along the joint cracks of an unaltered massive diabase, and of isolated pockets of epidotic and calcitic material carrying some copper.

In the case of sandstone and conglomerate deposits the explorer is to bear in mind that thus far they have been found only where a thin seam of conglomerate is directly overlaid by a trappean mass; or, if altogether away from the trappean beds, only in sandstone which is very rich in basic detritus. Beyond this there is nothing to guide him except the finding of the copper itself. Any one of the numerous conglomerate seams, which from Keweenaw Point to Minnesota are everywhere interbedded with the prevailing basic flows, might become cupriferous at any point along its course.

Large portions of the Keweenaw Series may be thrown out of the question in considering the possibilities of future discovery of copper in the Lake Superior region. Thus the whole extent of country occupied by the upper division of the series, with the one exception of the Nonesuch sandstone belt, is non-cupriferous. The extent of this upper division is indicated on the accompanying maps. Again, all of the belts and areas of acid rocks, such as the central area of the Porcupine Mountains, and the great spread of red rock in the Brulé Lake country in Minnesota, are without copper. The same is true also of all belts and areas of coarse-grained basic rocks, such as the great area of coarse gabbro in the Bad River region in Wisconsin and the similar area which occupies so large a belt of country between Duluth and Brulé Lake in Minnesota. The favorable phase of the formation for the existence of copper in any form of deposit is the thin and regularly bedded one, with well-developed amygdaloids.

Thus far native copper mining has proved profitable within the limits of Michigan only, and it seems to be true also that all or nearly all of the producing deposits have been opened on, and worked, by the ancient miners, whose attention was of course attracted by those deposits which by the accidents of erosion had been left prominently exposed. It is incredible that even in the long-settled districts of Michigan all of the workable deposits of copper have been discovered. Thus, on Keweenaw Point, the valley south of the Greenstone Range, in which lie buried beneath a surface coating of drift the equivalents of the Portage Lake cupriferous beds, has never been explored by trenching or mining operations. The same is, in a measure, true of the Bohemian Range of Keweenaw Point.

Without the boundaries of Michigan the attempts at copper mining have been but feeble, and utterly inadequate to prove or disprove the existence of workable copper deposits. In Wisconsin, native copper has been met with all along the course of the southern Keweenawan belt, from Montreal River to the Saint Croix. Running from the Montreal southwest and west is a belt of distinctly bedded and often amygdaloidal diabases, in which copper has been seen in greater or smaller quantity, both in crossing veins and in altered diabase belts at the crossing of each stream, the intervening areas being drift-covered. At the crossings of Montreal and Bad rivers this belt is worthy of further examination.[1] Beyond Bad River to the southwestward float copper is exceedingly common, and traces of it are here and there met with in the ledges themselves. Unfortunately the country is one covered with heavy drift accumulations, through which only the harder and more-enduring, and therefore non-cupriferous, beds ordinarily project. The indications are that, but for the overlying sheet of drift, this region would be as productive in copper as that of Keweenaw Point.

Rounding the turn at the western end of the great Keweenawan synclinal, in the Saint Croix Valley, we find the drift-covering lighter, and here, in the vicinity of Snake and Kettle rivers, and thence northeastward into Douglas County, in Wisconsin, are found plainly-bedded diabases and amygdaloids, carrying copper with interbedded cupriferous conglomerates. The region is one which in the early days of mining excitement on Lake Superior was so remote and inaccessible that the flood of copper hunters which at that time spread west from Keweenaw Point failed to reach it. It still lies almost wholly unexplored so far as mining exploration is concerned, while promising more to the copper miner than any other portion of the entire extent of the formation outside of Michigan.

Further south and east from the district last described lies the "Copper Range" of Douglas County, Wisconsin.[2] This range is fully described in chapter VI of the original memoir as to its position and structural characters. Copper has been found along its course in a number of places, chiefly in epidotic altered amygdaloids, and the general structural characters are such as to indicate the possibility of the occurrence of copper in quantity along this belt. Some little mining has been done at several points, but not enough to lead to any satisfactory conclusions.

On the Minnesota coast of Lake Superior copper has been met with at only two or three points. Of the five subordinate groups into which I have divided the rocks of this coast, only two, the Agate Bay and Temperance River Groups, are of such a nature as to encourage the expectation that copper might be found in them. The great thickness which makes up the other three groups—and the same is true of considerable portions of the two groups named—is for the most part composed of very massive compact beds, such as have never yielded copper on the South Shore. The beds of the Agate Bay and Temperance River

[1] See Geology of Wisconsin, Vol. III, pp. 205, 206.
[2] See Geology of Wisconsin, Vol. III, pp. 357-362.

Groups are often-thin, much altered, and highly amygdaloidal, and might very well be found to carry here and there workable deposits of copper. The distribution of the rocks of these two groups is approximately shown on Plate XIV of this volume, from which it will be seen that the extent of country within which there is any likelihood of the discovery of copper in this region, in the future, is a small one, lying for the most part in the immediate vicinity of the lake shore. It is also to be observed that the most probable mode of occurrence for copper within this restricted area is the amygdaloidal belt, the form in which occurs the copper of French River, where the metal is associated with much prehnite; that such amygdaloid belts will dip towards the lake at a very flat angle; and that cupriferous conglomerates are not to be looked for.

Isle Royale is the only remaining portion of the copper-bearing rocks within the territory of the United States. It has long been known to be cupriferous; the copper occurring here in the three forms of transverse veins, epidote courses, and amygdaloid belts. Thus far mining has not prospered on the island. It can, however, hardly be said that the ground has as yet been sufficiently tested.

SKETCH

OF THE

GEOLOGICAL HISTORY

OF

LAKE LAHONTAN,

A QUATERNARY LAKE OF NORTHWESTERN NEVADA.

BY

ISRAEL C. RUSSELL.

CONTENTS.

ILLUSTRATIONS.

SKETCH OF THE GEOLOGICAL HISTORY OF LAKE LAHONTAN.*

By I. C. Russell.

INTRODUCTION.

During the field season of 1881 the writer traveled through northwestern Nevada and some portions of California and Oregon for the purpose of studying the Quaternary geology. The journey was purely a geological reconnoissance, his companions including no scientific assistants, and all instrumental work being deferred until another season, when a more detailed study and survey of the points of special interest could be made. During the field season of seven months, about three thousand five hundred miles were traversed in the saddle, the route being planned with special reference to the investigation of the more recent geological changes, or of those most directly concerned with the present surface features of the country.

The most interesting results of the reconnoissance were, the discovery of a number of fossil lakes of Quaternary age in a land that is now extremely arid, and the acquisition of many new facts in regard to other extinct lakes that had previously been reported. Of the lakes that occupied many of the valleys of northern Nevada during Quaternary times, by far the most interesting, as well as the largest, was Lake Lahontan; and as this affords the most complete record of Quaternary climatic oscillations, we have chosen it as the subject of our present sketch, leaving the consideration of the smaller lakes, many of which have interesting histories, for a more extended report.

Before studying the geology of any region it is always desirable to know something of its present condition, and especially of the peculiar features of climate and geography that characterize it. For this reason we shall preface the description of the Quaternary lakes by a brief sketch of the Great Basin as the explorer finds it to-day.

*This paper was written by Mr. Russell in camp, while continuing the study of the same subject. Having no access to books he was unable to make the references he desired to the work of others, and lack of time compelled him to leave the manuscript in a somewhat unfinished condition. It was moreover impracticable for him to correct proof-sheets. At his request the paper was revised and edited by me, so that I share with him the responsibility for many of the details.—G. K. Gilbert.

THE GREAT BASIN.

In crossing fromthe Atlantic to the Pacific, between the Mexican boundary and the central portion of Oregon, one finds a region, bounded by the Sierra Nevada on the west and the Rocky Mountain system on the east, that stands in marked contrast in nearly all its scenic features with the remaining portions of the United States. The traveler in this region is no longer surrounded by the open, grassy parks and heavily timbered mountains of the Pacific slope, nor by the round and flowing outlines of the forest-crowned Appalachians. Neither does the scenery suggest aught of the boundless plains east of the Rocky Mountains, or of the rich savannas of the Gulf States. He must compare it rather to the parched and desert areas of Arabia and the shores of the Dead Sea and the Caspian.

To the geographer the most striking characteristic of the country along the eastern base of the Sierra Nevada is the fact that it is a region of interior drainage. For this reason it is known as the "Great Basin." No streams that rise within it carry their contributions to the ocean, but all the rain that falls inside the rim of the basin is returned again to the atmosphere, either by direct evaporation from the soil, or after finding its way into some of the lakes that occupy the depressions of the irregular surface. The climate is dry and arid in the extreme, the average yearly rainfall probably not exceeding 12 or 15 inches.

The area thus isolated from the water systems of the world is 800 miles in length from north to south, and nearly 500 miles broad in the widest part, and contains not far from 208,500 square miles—an area somewhat greater than that of France. The southern part of the region includes the Colorado Desert, Death Valley, and much of the arid country in southern California and Nevada. In northern Nevada the Carson and Black Rock deserts exhibit the extreme of desolation. The most northerly part of the Great Basin, occupying the central portion of Oregon, is less barren, its rugged surface abounding in volcanic table lands and isolated mesas, weathering as they grow old into rounded buttes that are covered with luxuriant bunch grass and bear a scattered growth of cedars and pines. At the south the valleys of the Great Basin are low-lying, Death and Coahuila valleys being depressed below the level of the sea; but at the north the valleys have a general elevation of from 4,000 to 5,000 feet, while the intervening mountain ranges rise from 5,000 to 7,000 feet above them.

Diversifying this region are many mountain ranges and broad desert valleys, together with rivers, lakes, cañons, etc.—topographic elements to be found in all quarters of the world, but here characterized by features peculiar to the Great Basin. The mountains exhibit a type of structure not described before this region was explored, but now recognized by geologists as the "Basin Range structure." They are long, narrow ridges, usually bearing nearly north and south, steep upon one side, where the broken edges of the composing beds are exposed, but sloping on the other with a gentle angle conformable to the dip of the strata. They have been formed by the orographic tilting of blocks that are separated by profound faults, and they do not exhibit the anticlinal and synclinal structures commonly observed in mountains, but are monoclinal instead.

The valleys or plains separating the mountain ranges, far from being fruitful, shady vales, with meandering streams, are often absolute deserts, totally destitute of water, and treeless for many days' journey, the grayish-green *Artemisia* or "sage bush" giving character to the landscape. Many of them have playas in their lowest depressions—simple mud plains left by the evaporation of former lakes; and sometimes these playas are of vast extent. In the desert bordering Great Salt Lake on the west, and in the Black Rock Desert of northern Nevada, are tracts hundreds of square miles in area, showing scarcely a trace of vegetation. In the summer months portions of them become so baked and hardened as scarcely to receive an impression from a horse's hoof, and so suncracked as to resemble tessellated pavements of cream-colored marble. Other portions of the valleys become incrusted to the depth of several inches with alkaline salts, which rise to the surface as an efflorescence and give the appearance of drifting snow. The dry surface material of the deserts is sometimes blown about by the wind, saturating the air, or is caught up by whirlwinds and carried to a great height, forming hollow columns of dust. These swaying and bending columns, often two or three thousand feet high, rising from the plains like pillars of smoke, are a characteristic feature.

The rivers of the Great Basin are not all perennial; some of them disappear before the heat of summer. In the streams that are perennial a high percentage of the annual discharge is crowded into a brief space toward the end of the rainy season. Thus the arteries of this parched and heated country make but one feverish pulsation in a year. The streams usually diminish in volume as they descend into the valleys, and in many instances their waters are lost on the thirsty deserts and their channels run dry. In general they are larger near their sources than at their mouths. Commonly, too, instead of being pure, sparkling waters, refreshing to the lips as well as the eye, they are heavy with sediment and bitter and alkaline to the taste.

The lakes into which much of the surface drainage finds its way are commonly saline and alkaline—their shores a desert waste, shunned by animals and by all but salt-loving plants. Of the salt lakes the typical example is furnished by Great Salt Lake in Utah, an inland sea whose features call to mind the familiar descriptions of the Dead Sea in Palestine. Mono Lake in California, and Abert and Summer lakes in Oregon, are also highly charged with saline matter, and are remarkable for the amount of carbonate of soda they contain. Pyramid, Walker, Winnemucca, and Carson lakes, in Nevada, as well as many smaller lakes throughout the Great Basin, are also without outlet, yet hold comparatively small percentages of saline matter in solution.

Other lakes, which indicate still more pointedly the contrast between an arid and a humid climate, we may call *playa lakes*. These are broad sheets of shallow water, covering many square miles in the winter season, but evaporating to dryness during the summer, their beds becoming hard, smooth mud plains or playas. In many instances a lake is formed over a playa during a single stormy night, only to disappear beneath the next noonday sun. When the weather is unsettled these lakes are scarcely more permanent than the delusions of the mirage, but come and go with every shower that passes over the land. Other playa lakes are more persistent, and only become dry during excessively arid seasons. Examples of these are furnished by Honey Lake in California, North Carson Lake ("Carson and Humboldt Sink") in Nevada, and Sevier Lake in Utah, all of which have been known to become dry during the past few years. The water of playa lakes has a greenish yellow color, due to the extremely fine silt which is held in suspension and not allowed to settle, because every breeze stirs the shallow water to the bottom. A remarkable lake of this class is sometimes formed on the northern part of the Black Rock Desert during extremely wet seasons. Its water is furnished by Quinn River, and it has been known to have a length of 50 or 60 miles, with a breadth of 20. During the summer it disappears entirely, leaving an absolutely barren plain of mud, Quinn River at the same time shrinking back a hundred miles toward its source.

A few lakes situated on the borders of the Great Basin have outlets, and discharge their surplus waters into reservoirs at lower levels within the area of interior drainage. These lakes are of the same type as the ordinary lakes of humid climates, with waters as pure and fresh as springs and melting snow can furnish. Their finest example, Lake Tahoe, lies just within the western rim of the Great Basin, at an elevation of 6,247 feet, amid the peaks of the Sierra Nevada. Its outlet, the Truckee River, flows downward with a descent of 2,400 feet to Pyramid and Winnemucca lakes, where the water is evaporated, leaving the lower lakes charged with soda salts. Just within the eastern border of the Great Basin lie Bear Lake and Utah Lake, the former discharging its water through the Bear River and the latter through the Jordan River into Great Salt Lake. These streams carry down from the mountain their small percentages of saline matter, as a contribution to the already saturated solution of the inland sea where their waters are evaporated.

It may be taken as a rule, that all lakes which overflow are fresh, and all lakes that do not find outlet become in time charged with mineral salts. The explanation of the salinity lies in the fact that river water is never absolutely pure, but always contains a small percentage of mineral matter, which is left behind when the water is evaporated.

Should this process continue long enough it is evident that a lake without an outlet would in time become a saturated solution, from which the less soluble mineral salts would begin to crystallize.

The examination of those inclosed lakes of the Great Basin that are comparatively fresh, and especially of the lakes occupying the Lahonton Basin, shows that salt lakes may become fresh without overflowing; and it has been suggested by Mr. Gilbert, in explanation, that a lake may evaporate to dryness and its salts become buried beneath the deposits of playa lakes, so that on the return of humid conditions the water that re-occupies the old basin may be comparatively if not absolutely fresh.

To the artist the scenery of the arid lands of the Far West is contrasted with that of more humid regions by the russet brown desolation of the valleys, the brilliant colors of the naked rocks, and the sharp, angular outlines of the mountains. A country without rain is necessarily a desert, while with abundant moisture, at least in tropical and temperate latitudes, it becomes a garden of luxuriant vegetation. In the most desert portions of the Great Basin the annual precipitation probably does not exceed 4 inches, while in the valleys on the borders of the basin it reaches 20 or 30 inches. Throughout this region the only fruitful areas are along the margins of streams or where springs come to the surface. In such places, water being available for irrigation, one finds oases of delicious shade, with green fields and orchards, yielding an unusually abundant harvest. Thus in nearly all its physical features the Great Basin stands in marked contrast with those favored lands where rain is more abundant and more evenly distributed.

The rainfall that a region receives is a potent though silent factor, controlling an almost infinite series of results in its physical history and topography. In a humid region vegetation is usually luxuriant; the rock forms are masked by forests, erosion is rapid, and the rocks are commonly buried beneath the accumulations of their own *débris* or concealed by layers of vegetable and animal mold that in turn are clothed with vegetation; the hills have flowing outlines and are dark with foliage; the valleys have gently sloping sides that conduct the drainage into streams meandering through broad plains, and the whole scene has the softness and beauty of a garden. In an arid land like the Great Basin all this is changed. The mountains are rugged and angular, are for the most part unclothed by vegetation, and receive their color from the rocks of which they are composed. From the gorges and cañons sculptured in the mountain side alluvial cones descend to the plain. These sometimes have an extent of several miles, and they are steep or gentle in slope according to the grade of the streams that formed them. The valleys, even more dreary than the mountains, are without arboreal vegetation and without streams, and form a picture of desolation and solitude. In traveling through the Great Basin one sometimes rides a hundred miles without sight of a tree, and many times that distance without finding shade enough to protect him from the intense summer sun.

The bare mountains reveal their structure almost at a glance, and show distinctly the many varying tints of their naked rocks. Their richness of color is sometimes marvelous, especially when they are composed of the purple trachytes, the deep-colored rhyolites, or the many-hued volcanic tuffs so common in western Nevada. Not unfrequently a range of volcanic mountains will exhibit as many brilliant dyes as are assumed by the New England hills in autumn. On the desert valleys the scenery is monotonous in the extreme, yet has a desolate grandeur of its own, and at times, especially at sunrise and sunset, great richness of color. At midday in summer the heat becomes intense, and the mirage gives strange delusive shapes to the landscape and offers promises of water and shade where the experienced traveler knows there is nothing but the glaring plain. When the sun is high in the cloudless heavens and one is far out on the desert at a distance from rocks and trees, there is a lack of shadow and an absence of relief in the landscape that make the distance deceptive—the mountains appearing near at hand instead of leagues away—and cause one to fancy that there is no single source of light, but that the distant ranges are self-luminous. The glare of the noonday sun conceals rather than reveals the grandeur of this rugged land, but in the early morning and near sunset the slanting light brings out mountain range after mountain range in bold relief and reveals a world of sublimity. As the sun sinks behind the western peaks and the shades of evening grow deeper and deeper on the mountains, every ravine and cañon becomes a fathomless abyss of purple haze, shrouding the bases of gorgeous towers and battlements that seem incrusted with a mosaic more brilliant and intricate than the work of the Venetian artists. As the light fades and the twilight deepens, the mountains lose every detail and become sharply outlined silhouettes, drawn in the deepest and richest of purple against a brilliant sky.

The succession of seasons is less plainly marked on the deserts of the Great Basin than on the forest-covered hills of the Atlantic slope. As autumn advances, but little change appears in the color of the landscape, excepting, perhaps, a spot here and there of vermilion or carmine high up on the mountains, where a clump of aspens or dwarfed cedars marks the site of a spring that trickles down and loses itself among the rocks. The valleys with their scanty growth of sage remain unchanged, as do the dusky bands of pines and cedars on the higher mountains. As the autumn passes away the skies lose their intense blue, and become softer and more watery—more like the skies of Italy. The hues of sunset appear richer and more varied, and during the day cloud masses trace moving lines of shadow on the surface of the desert. By and by storm clouds gather in black, gloomy masses that envelop the ranges from base to summit. These early storm clouds cling close to the mountains and yield to the parched deserts but a few scattered drops of rain. The observer from below hears the raging tempest amid the veiled peaks, while all about him is sunshine. The mountains wrapped in impenetrable clouds, the glare of lightning, and the deep roll of thunder as it echoes from cliff to cliff and from range to range, bring to mind the scriptural account of the storms of Sinai. And when the black clouds at last roll back from the mountains, and the sun with a wand of light dispels the storm, behold what a transfiguration! The peaks are no longer dark and somber, but glitter with the silvery sheen of freshly fallen snow.

As winter approaches, the storms amid the uplands become more frequent, until every range is white as snow can make it, and the tent-like mountains gleam like the encampment of some mighty host. Long after they are covered the valleys between are bare as in midsummer, and the snow seldom lies in them for more than a few days at a time. The highlands retain their snow far into the summer, but on none of the ranges can it be said to be perpetual. In the valleys there are flowers beneath the sage-brush by the middle of April, and from that time until November scarely a drop of rain falls. For many days together the skies are without a cloud.

The agriculture of this arid region is restricted to those scanty areas of land that can be irrigated. Of more importance is the grazing of sheep and cattle on the bunch-grass that frequently abounds in the mountains and sometimes grows luxuriantly beneath the sage-brush. The mines of the precious metals, however, are the principal source of wealth, and to that must now be added a growing industry in salt, borax, sulphur, and carbonate of soda.

Although the Great Basin is not attractive to the pleasure-seeker, yet to the geologist it is peculiarly fascinating, both because the absence of vegetation gives such unusual facilities for investigation and because of the interesting character of the problems to be solved. In this inhospitable region, so arid that many a lost traveler has perished from thirst, there existed in recent geological times a system of great lakes, comparable in number and magnitude with the lakes of the Saint Lawrence basin. At the time New England and a number of the Northern States were covered with an immense *mer de glace*, and the lofty peaks of the Rocky Mountains, the Sierra Nevada, and a few of the intermediate ranges, gave birth to local glaciers, the ratio of precipitation to evaporation throughout the Great Basin was so great as to give rise to a great number of lakes, whose combined surface must have formed a large percentage of the total area of the region. Twenty-one of these ancient lakes, of which Lake Bonneville and Lake Lahontan are the most interesting, have already been explored in the northern part of the basin, and at least three of some magnitude are known to have existed at the south.

Although the Great Basin is an extensive area of interior drainage, it is far from being a simple basin-shaped depression in form. It is broken and diversified by many mountain ranges, which divide the surface into numerous separate drainage areas or hydrographic basins. These subsidiary basins held the Quaternary lakes. They owe their origin almost invariably to orographic displacements, and, like the intervening mountains, exhibit a type of structure that is peculiar to the region. In many instances, one edge of a long and narrow orographic block is upraised along a fault line so as to form a lofty mountain range, while the depressed edge underlies a valley that constitutes an inclosed lake basin. Like the Basin ranges, the Basin valleys have faults along their edges, one or both, and are commonly monoclinal.

The Basin Range structure, as it appears along a large number of east and west sections, is rudely shown in the accompanying diagram, in which the upraised edges of the orographic blocks form mountain ranges, and the depressions are represented as occupied by lakes or as deeply filled with lake sediments and alluvium from the mountains.

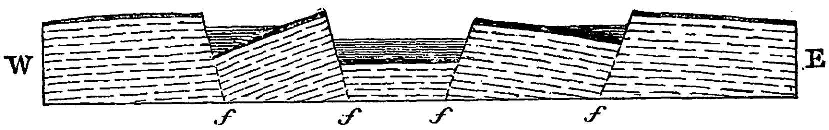


FIG. 44.—Ideal section illustrating Basin Range structure.

At *f*, *f*, *f*, *f*, are represented faults that have divided the country into long, narrow blocks, with a north and south trend, and these blocks are represented as displaced and tilted at various angles. The depression formed by the fault at the left may be taken as a rude generalized expression of Surprise Valley, California, which once held a lake nearly a hundred miles long, and is now deeply filled with lake-beds. The central depression represents rudely the structure of Christmas Lake Valley, Oregon, with its great fault scarps from 1,500 to 2,000 feet high on either side. Instances could be multiplied almost without number from all parts of the Great Basin, of valleys once occupied by Quaternary lakes and having this same type of structure.

Lake Bonneville and Lake Lahontan each occupied many valleys of this type. The former extended along the western base of the Wasatch Range for 300 miles, its northern extremity reaching a few miles into Idaho, its surface covering 19,750 square miles, and its hydrographic basin having an area of 52,000 square miles. The latter, named by Mr. King in honor of the French explorer,* lay on the western side of the Great Basin, and was of nearly as great extent. The hydrographic basins of these two great Quaternary lakes occupied the whole breadth of the Great Basin in the latitude of the 41st parallel.

*Reports of the Fortieth Parallel Survey, vol. I, p. 504.

LAKE LAHONTAN.

GEOGRAPHIC EXTENT.

The principal body of Lake Lahontan lay in what is now northwestern Nevada, but a small arm occupied Honey Lake Valley in California. From a point a few miles north of the Oregon boundary it extended southward 260 miles to latitude 38° 30′, and it had its greatest width a little north of the 40th parallel. As may be seen in the accompanying map it was extremely irregular in outline, more irregular in fact than any other lake, recent or fossil, that has been mapped. Perhaps the most peculiar feature of its geography is the irregular island it inclosed, 126 miles long from north to south by 50 miles broad. This bore a number of lofty and rugged mountain ranges, and held in its interior two small lakes, neither of which outflowed into the surrounding lake. Of the subordinate bodies of water which united to form Lake Lahontan the two largest covered the Carson and Black Rock deserts respectively, being connected with each other by narrow straits. One connecting arm occupied the valley of Pyramid Lake, and extending through the cañon now traversed in part by the Truckee River joined the Carson area through the Ragtown Pass; the other stretched from the Carson Desert northward up the Humboldt Valley, and then ran to the west of the Eugene Mountains until it joined the northern end of the Black Rock area in Quinn River Valley.

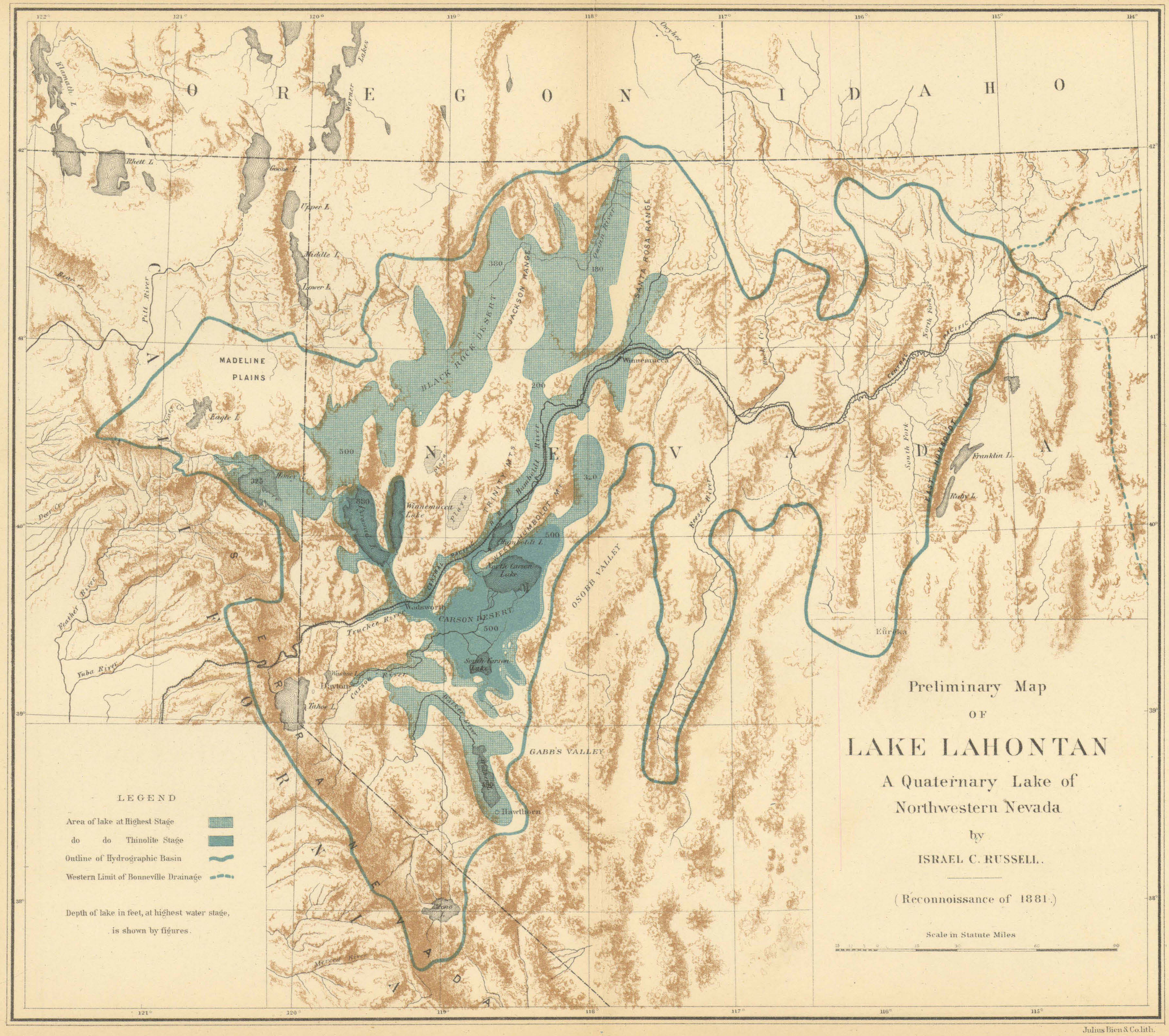
The evaporation of its water has left the old lake basin divided into a number of comparatively small hydrographic areas, of which the principal ones are now occupied by lakes. The modern lakes are Pyramid, Winnemucca, Humboldt, North Carson, South Carson, and Walker, all of Nevada, together with Honey Lake in California. All of these are more or less saline or alkaline, but in no instance are they concentrated brines, as would be the case were they the remnants left by the incomplete evaporation of Lake Lahontan.

The Central Pacific Railroad passes for 165 miles through the desiccated bed of the extinct lake, entering it a few miles east of Golconda by the cañon through which the Humboldt River traverses the Sonoma Mountains, and leaving it on the west in the cañon of the Truckee River about 15 miles west of Wadsworth. While passing down the valley of the Humboldt from Golconda to Humboldt Lake, one may see from the train the sedimentary beds deposited by the waters of the former lake. They are exposed in the cliffs of clay and marl that border the river, and the height of these cliffs, which in places amounts to 150 or 200 feet, exhibits the amount of erosion performed by the river since the evaporation of the lake. The horizontal lines carved by the waves of the lake on the steep shores that confined it, may likewise be traced by the passenger all along the bases of the mountains on either hand. Between Humboldt Lake and Mirage Station the traveler has a glimpse out onto the broad Carson Desert to the southward, at one time covered by the waters of Lake Lahontan to a depth of 500 feet, but now an absolute desert. At Wadsworth the train descends into the cañon excavated by the Truckee River through the old delta that was formed by the same stream when Lahontan filled this portion of the valley and received the *débris* brought down from the Sierra. Sections of the Truckee delta and of Lahontan lake-beds are well exposed in the river bluffs north of Wadsworth, and synchronous strata may also be seen clinging in fragmental masses to the rugged sides of the cañon for a distance of 15 miles west of the station. The lake-beds are here easily distinguished, by their light color and horizontal stratification, from the dark volcanic rocks against which they rest.

The rim of the hydrographic basin of which Lake Lahontan received the drainage, scarcely more regular in outline than the lake itself, is indicated on the accompanying map by a heavy blue line. On the west it coincides with the rim of the Great Basin, and is formed by the crest of the Sierra Nevada. Along this high divide, at the time Lahontan had its greatest extent of surface, there were four lakes of considerable size that overflowed into it. Beginning at the south we have, first, Mono Lake, in regard to whose outlet, however, there is some doubt; second, Lake Tahoe, at that time surrounded by glaciers; third, the little lake filling Washoe Valley; and fourth, a lake, since drained dry, that covered the Madeline Plains, in Lassen County, California. The extent of the hydrographic basin is shown by the river systems compassing it. These were Walker, Carson, and Truckee rivers on the west, Quinn River on the north, and the Humboldt and Reese rivers on the east. All of these streams at that time flowed with somewhat greater volume than at present. From the desert region at the southeast no tributaries were received. The area of the drainage basin was about 45,400 square miles, and the ratio of lake surface to drainage area was nearly as 1 to 5.

TOPOGRAPHY OF THE LAHONTAN SHORES.

We have said that a number of valleys of northwestern Nevada were at one time occupied by the waters of a large lake. It is natural for the reader to ask how we know this, and what kind of evidence we have to prove our statement. In reply we would say that the evidence by


Preliminary Map
OF
LAKE LAHONTAN
A Quaternary Lake of
Northwestern Nevada
by
ISRAEL C. RUSSELL.
(Reconnoissance of 1881.)
Scale in Statute Miles
LEGEND
Area of lake at Highest Stage
do do Thinolite Stage
Outline of Hydrographic Basin
Western Limit of Bonneville Drainage
Depth of lake in feet, at highest water stage, is shown by figures.
O R E G O N
I D A H O
N E V A D A
MADELINE PLAINS
BLACK ROCK DESERT
JACKSON RANGE
SANTA ROSA RANGE
CARSON DESERT
OSOBB VALLEY
GABB'S VALLEY
Winnemucca
Wadsworth
Hawthorne
Eureka
Winnemucca Lake
North Carson Lake
South Carson Lake
Humboldt L.
Franklin L.
Ruby L.
Eagle L.
Goose L.
Upper L.
Middle L.
Lower L.
Rhett L.
Warner Lakes
Klamath L.
Tahoe L.
Washoe L.
Mono L.
Truckee River
Carson River
Humboldt River
Reese River
Pitt River
Feather River
Yuba River
Merced River
Owyhee R.
Quinn River
Deer Cr.
South Fork
North Fork
PACIFIC
Dayton
300
180
200
500
325
830
500
500

which we determine that a valley was at one time occupied by a lake is of the same nature as that which leads us to conclude when we walk along an ocean shore that the tide is high or that it is low.

Again, if a mill-pond be drained by the opening of its gates we have no difficulty in determining how deep the pond was when its waters filled it. We find a little terrace or ridge of sand and gravel all about the horizontal line where the surface of the lake met its shores. This terrace and this ridge are shore records. Throughout the little basin once filled by the pond we find a deposit of mud, which is simply the dirt and silt brought in by the inflowing rills and rivulets. To the geologist this deposit is a lake-bed. In the layers of mud at the bottom of the pond we usually find the shells of fresh-water mollusks, and perhaps also a few bones of fishes or of land animals, or maybe a buried branch or twig. These are fossils, and illustrate the character of the animals and plants that lived in and about the pond. And finally, at the point where each rill and rivulet from the hills entered the pond we find a fan-shaped accumulation of sand and gravel, constituting a delta with all the essential features of the delta of the Nile or of the Mississippi.

Turning now to the valleys of northwestern Nevada, if our conclusion that they were once filled by a lake is correct, it is clear that we should find terraces, lake-beds, fossils, and deltas—the same records, in fact, that may be seen to-day in every mill-pond, but on a grander scale. In the case of Lake Lahontan all of these proofs, and more besides, have come under our observation. The entire shore line, intricate and tortuous as it is, has been followed and mapped in the field, and it is to the character of this shore line that we now invite attention.

As has been remarked by Mr. Gilbert, "there is a topography of the land and a topography of the sea." The topography of the land is due to the beating of the rain, the expansive action of frost, the flow of rills and rivers, and so forth. The slopes of the valleys and ridges that these agencies carve on the mountain side are controlled by the flow of water in response to gravity, and the lines thus formed are therefore more or less inclined. The topography of the shores of oceans and lakes exhibits the lines carved by waves where they beat against the land; these lines conform to the water surface, and are horizontal.

Throughout the boundaries of Lake Lahontan its ancient shore line is clearly defined. The sloping sculpture of rain and rills above, and the horizontal lines due to wave action along the base of the mountains, afford a contrast that is noticeable at a glance. The fact that these shore lines are continuous all about the borders of the former lake, and are not cut by a channel of overflow, proves that the lake never found an outlet. The multitude of beach lines scoring the mountain bases also indicate that the lake underwent many fluctuations of level—rising and falling, as do all inclosed lakes. Each individual shore line marks a pause in the fluctuations of level of the surface, and the relative duration of the various pauses is indicated to some extent by the width of the wave-cut terraces, the magnitude of the embankments built at different horizons, and the thickness of the contemporaneous sediments accumulated at the bottom of the basin. By the state of these various phenomena we are enabled to decipher at least a portion of the Lahontan history, and learn something of the climatic changes on which that history depended.

THE FORMATION OF TERRACES AND EMBANKMENTS.

The tendency of waves washing against a shore is to cut away the rocks so as to form a terrace or gently sloping shelf, bounded on the landward side by a steep escarpment or sea cliff. The accompanying diagram shows the profile of a shore against which the waves break, and will illustrate the character of the notch the waves carve.

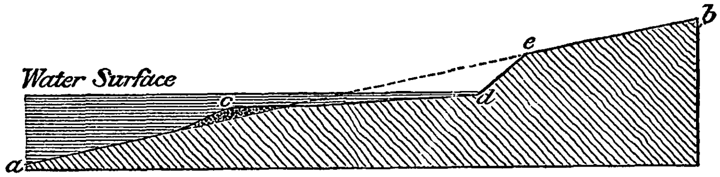


FIG. 45. Profile of Terrace and Sea Cliff.

In the diagram the line *a b* represents the original slope of the shore (it may be of alluvium or of solid rock), in which the waves have excavated the terrace *c d*, forming at the same time the steep sea cliff *e d*. The outer portion of the terrace at *c* is commonly formed of *débris* from the cutting of the terrace. The steepness of the sea cliff, and to a less degree the slope of the surface of the terrace, depend on the nature of the material composing the shore.

When the wind acting on the water of a lake causes the waves to advance at right angles to the shore, the water rushes up the gently inclined surface of the terrace, carrying with it a load of the sand and loose pebbles that come within its reach, and thus freighted it dashes against the shore and grinds away the base of the sea cliff. As the water returns to the lake, forming an undertow, the stones roll back down the terrace and the finer material is carried to the outer edge of the slope, or perhaps into deep water. This sapping of the sea cliff goes on until portions are undermined and fall away, their *débris* adding to the supply of tools with which the water works. When the waves break against a shore at any angle except a right angle a shore current is established, and the action of waves and currents combined proves still more efficient in carving away the land. In some instances, as on the eastern coast of Australia, the wave-cut terraces are nearly a mile broad. In the Quaternary lakes of the Great Basin they were frequently several hundred feet wide, with sea cliffs rising above them several hundred or even a thousand feet.

If we stand on a gently sloping lake shore when a strong wind is blowing against the beach at any angle, say 30° for illustration, we find that a current is soon established along the shore which moves a quantity of loose material with it, the waves lifting the pebbles and stones and the current carrying them along. This sheet of sand and gravel traveling along a shore has been designated *shore drift*. To the transportation of shore drift, and to its eventual deposition, we owe the most striking and interesting of shore phenomena, namely, shore embankments. The cutting of a terrace with its overhanging sea cliff is a work of excavation—the *carving* of a new form on a pre-existing surface; the topographical features produced by the accumulation of shore drift are works of construction, consisting of embankments of various forms *superimposed* on the pre-existing topography.

A current sweeping along a shore carries with it, as we have described, a narrow sheet of shore drift. On shores of moderate inclination this material forms a terrace of gravel that is not infrequently adjoined to a cut terrace, forming a sort of platform—the highway for the transportation of the shore drift. On a low shore of alluvium the tendency is to form a bar or embankment with rounded crest, parallel to the shore, and at some distance from the actual water margin. Such an accumulation is known as a *barrier*. When the current comes to an angle of the coast,

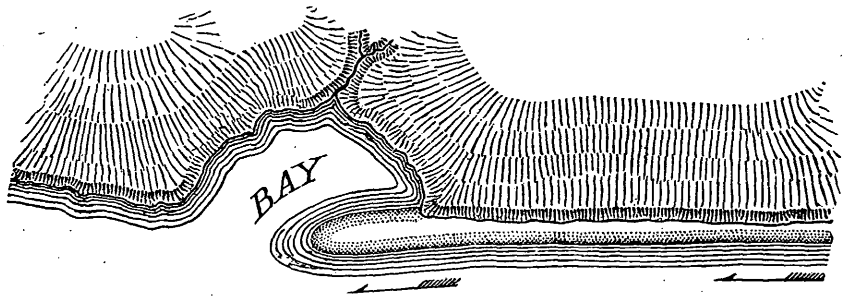


FIG. 46.—Ideal plat illustrating the formation of a Shore Embankment.

as, for example, the mouth of a bay, it does not follow the sinuosities of the water line, but holds the trend previously established, and sweeps its load of shore drift forward into deeper water, where the force of the current is soon lost and the *débris* deposited at the bottom. Other material is piled upon that first deposited until an accumulation or embankment is formed that reaches nearly to the surface, and constitutes a continuation of the shore terrace along which the drift had previously been carried. This accumulation of *débris* has the form of a railroad embankment, and forms a path for the transportation of fresh material. This, in its turn, is carried to the end of the embankment and serves to prolong the structure.

The action of shore currents in building out embankments is illustrated by the accompanying topographical diagram. The dotted surface represents the limit of the shore drift, and the arrows show the direction of the current as it follows the shore. On arriving at the entrance to the bay, where the shore makes an abrupt turn, the current continues directly onward, carrying the shore drift with it and building out the embankment. In a simple instance like that of the illustration the embankment is straight, with a rounded extremity. This extremity is bounded beneath the water surface by a steep escarpment, the angle of the slope being the angle of stability in water of the material of which the structure is composed. At times the distal end of such an embankment is curved, and forms a hook bending into the bay. Again it may be carried completely across the bay, thus shutting it off from the lake and forming a lagoon. Being constructed chiefly during storms, embankments have their crests a little above the surface of the lake at its ordinary stage.

The action of waves and currents that conspire to form embankments like that shown in the sketch is subject to a multitude of variations, depending on the topography of the shore, on changes in the direction of the wind, and on the nature of the material moved; and, as may be imagined, the resultant forms are extremely diverse. When the lake is likewise subject to great fluctuations of level the embankments are superimposed one upon another and frequently form complicated structures of great size. Sometimes, too, an embankment that has been built during a high-water stage is cut away by subsequent wave action at lower levels, and its material remodeled.

It is to be remembered that the ability of waves and currents to modify shores depends largely on the sand and pebbles forming the shore drift. Where the shore is steep it is evident that the cutting power of the water is small, since nearly all the sand and pebbles fall into deep water beyond the reach of the waves and cannot be used as cutting tools. In such places we find narrow terraces with high sea cliffs. Where the water stands against a perpendicular wall its cutting power is at zero. Again, where the shores are only moderately steep the cutting of a terrace goes on rapidly, the *débris* being carried forward to form embankments where the shore becomes less steeply inclined or where the material is thrown into deep water. The alternation of these two conditions along the margin of a lake seems most favorable for the production of a conspicuous shore topography. Where we find heavy embankments of gravel formed by an accumulation of shore drift, we may look for the quarry from which the material was derived along the terraced slopes near at hand.

In Lake Lahontan the coasts were moderately steep, and the most common of the surviving shore records are cut terraces. From the highest water line down to the bottom of the basin, as it now exists, the surface is scored by a large number of horizontal terraces. Examples of embankments of gravel formed in the manner just described may also be seen at many places along the ancient borders of the lake; but all these phenomena are less finely displayed than in the Bonneville basin, where the water was deeper and the stretches of open water were broader.

The features in the shore records of Lake Lahontan that are most strongly accented are, first, the highest water line of all, showing the maximum depth of the old lake; second, a broad, sharply cut terrace about 30 feet below the highest water line; and third, a broad terrace about 400 feet lower than the last, or 100 feet above the present (1881) level of Pyramid Lake. For reasons which will appear in the sequel the second of these has been named the *Lithoid*, and the third the *Thinolite* terrace. The highest terrace of all, the *Lahontan*, is an inconspicuous feature in itself, but is important as forming the boundary between subaerial and subaqueous sculpture in the sides of the valleys. It usually appears as a terrace of construction a few feet wide, resting on the broad Lithoid terrace 30 feet below. Where the shore records are unusually well preserved, as along the western margin of Pyramid Lake and on the south side of the Carson Desert, the Lithoid terrace sometimes has a width of 200 or 300 feet. Resting on it we sometimes find two built terraces of gravel and rolled stones, the water line of the one being the highest of all the shore records, while the second is intermediate between that and the Lithoid terrace. This arrangement is illustrated in the accompanying diagram, which exhibits a profile of the shore.

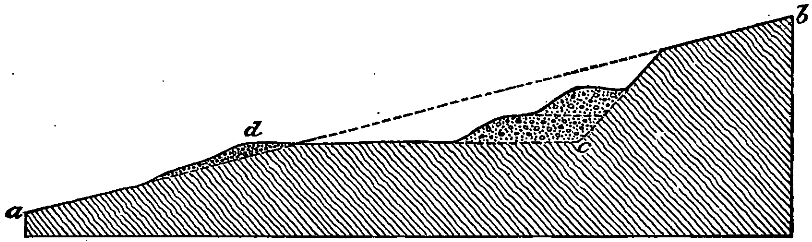


FIG. 47.—Profile of the Lithoid Terrace.

The line *a b* represents the original slope of the mountain side before it was modified by the waves of the lake. The Lithoid terrace *c d* was first formed, the outer edge being built of *detritus*. The magnitude and persistence of this terrace indicate that the water stood for a long time at a nearly constant level, allowing the waves to carve out a broad shelf from the solid rock. As we shall see farther on, the terrace became coated with calcareous tufa, and its gravel was cemented into a conglomerate. At some later period in the history of the lake the water rose and built the two small embankments or terraces that rest upon it, but it remained at those horizons only a comparatively short time.

The Thinolite terrace, 100 feet above the present level of Pyramid

Lake, can be followed all about the shore of that lake and about Winnemucca Lake, and appears again on the borders of the Carson Desert. This evidently marks the outline of Lahontan when its waters were greatly reduced by evaporation. As we shall find when examining the tufa deposits, the date of its formation is subsequent to that of the high, broad terrace just described.

Besides the terraces, there are bars and embankments of gravel, that are not only interesting as examples of wave action but also render much assistance in deciphering the history of the ancient lake.

At a locality about two miles west of Allen Spring, on the south side of the Carson Desert, there is a series of gravel embankments built one upon another and extending from the highest water line some distance down the mountain side. These structures were formed by currents from the westward bringing great quantities of gravel from a high sea cliff and depositing it in a series of embankments that are curved or hooked at the free extremity. A somewhat hasty examination of these gave the impression that they were built in ascending order, the lower ones being older than the upper, as though formed by the waves of a rising lake. The higher members of the series rest upon the broad, tufa-covered terrace thirty feet below the maximum water line, and prove by their position that they are records of a high water period subsequent to the first rise of the lake. This interesting group of embankments will be mapped and more fully studied during the coming field season, and will without doubt prove an instructive page of Lahontan history.

Another series of wave records, which for various reasons we regard as equivalent to the looped bars at Allen Spring, may be seen at the north end of Pyramid Lake. They consist of horizontal terraces built of rolled stones and masses of rounded tufa, and they cross the face of a steep bluff at nearly equal intervals from the highest water line down to the present water surface. They form a conspicuous topographic feature even at a distance of ten miles, and the marked contrast between the angular volcanic rocks above the ancient water line and the horizontal wave sculpture at the base of the cliff shows that the highest embankment of the series is the highest of all the shore records. We have christened the locality Terrace Point. As these terraces contain rolled fragments of tufa of a particular kind, their connection with Lahontan history cannot be fully set forth until the tufa deposits of the lake have been described. They will receive further consideration in another place.

At the southern end of Humboldt Lake a large gravel bar of Lahontan age sweeps in a gentle curve across the valley and forms a natural dam to confine the waters of the modern lake. This is a typical wave structure, constituted of well-worn gravel, and was built out from either shore until it was completed. It now stands like a huge railroad embankment, from fifty to sixty feet high, sweeping completely across the valley.

This bar received additions at various stages of the lake, and has a complicated structure. One of the latest events in its history occurred when the waters finally fell below its level. The body of water to the northward, receiving the tribute of Humboldt River, rose and overflowed across the lowest point of the bar and commenced the erosion of a channel, which was continued as the water of the main lake fell until the gravel dam was breached nearly to the bottom.

A barrier similar to the one which confines Humboldt Lake, but of greater height and with a more complicated history, was formed at the southern end of Winnemucca Lake, and at one time appears to have acted as a dam to the waters north of it. This structure, also, has been cut by drainage to its foundations.

A study of the bars fringing the ancient shores of Lahontan indicates that there were a number of periods of bar building; that is, separate dates when the lake was sufficiently deep, and remained long enough at one horizon, to allow its waters to construct heavy embankments of gravel.

CHEMICAL DEPOSITS.

An ordinary fresh-water lake, as is well known, is but the enlargement of a river, or else of several confluent rivers. To the geologist it is only a transient feature, for the time soon comes in its geological history when it is completely filled with sediment, being thus replaced by a plain through which the stream or streams meander. The water of such a lake has the normal composition of the streams that supply it, and remains fresh, for the reason that the mineral substances delivered to it in solution are discharged wite equal rapidity by the outflowing water. The solid substances, however, as sand and mud, which are carried into a lake by its tributaries, remain there; as is clearly seen when one contrasts the turbid and muddy waters of the inflowing streams with the free and pellucid waters that leave the lake to start afresh on their journey.

A lake without an outlet has a more complicated history than this, for it retains not only all of the solid substances delivered to it in suspension, but all of the material that the tributary waters have dissolved from the rocks with which they have come in contact. As the water of an inclosed lake escapes slowly by evaporation, leaving all dissolved mineral substances behind, the lake becomes more and more highly charged with various salts, until at length the point of saturation for some of them is reached and precipitation commences. Thus the density of lake water is frequently a rough index to the length of time that has elapsed since the formation of an inclosed basin, or since the date that the lake was last filled so full as to overflow and thus flood out the salts previously accumulated.

Of lakes that do not overflow the examples best known are the Dead Sea and Great Salt Lake. The former contains from 21 to 28 per cent. of saline matter in solution, the amount varying in different places and at different depths. An analysis of the water of Great Salt Lake, collected in 1850, when the lake was unusually low and therefore much concentrated by evaporation, gave 22.282 per cent. of solid matter*; another analysis, from a sample collected in 1869, when the lake contained more water, gave 14.994 per cent.† Many of the lakes in the Great Basin contain large percentages of saline matter, but none so large as to rival Great Salt Lake.

The source of the saline matter held in solution by lakes without outlet is found in the inflowing streams. These, although fresh in the ordinary meaning of the word, are never absolutely pure, but on analysis show a small amount of mineral matter in solution. Forty-eight analyses of river water given by Bischof in his Chemical Geology show an average of 11 parts of carbonate of lime to 100,000 of water, and exhibit many other salts, but in less quantity. Moreover, carbonate of lime is a substance but sparingly soluble in water, and the amount actually contained by rivers frequently approximates the limit of saturation. When, therefore, a body of river water is concentrated by evaporation carbonate of lime is usually the first mineral to be precipitated. Considering that Lake Lahontan was a body of water deriving its supply from rivers, and that its basin exhibits a vast amount of calcareous tufa, restricted in its distribution to the limit marked out by the shores, the conclusion is inevitable that the tufa was produced by precipitation from the water of the lake. When the point of saturation was once reached and the deposition was initiated every additional portion brought by the tributary streams would produce an excess and lead to an additional precipitation. The deposition was thus continuous for long periods.

The basin exhibits three distinct deposits, each characterized by a separate variety of tufa. For convenience we shall designate these varieties, in the order of their age, *lithoid*, *thinolitic*, and *dendritic*. As the three deposits are superimposed one upon another their relative age is at once apparent. Each variety is found in great abundance, and they are especially well exposed on steep rocky shores and on outstanding buttes, where they could not be overplaced by alluvium or lake-beds.

LITHOID TUFA.

This, the first formed tufa deposit, is found on the rocky slopes of the basin from the level of the Lithoid terrace downward as far as any sections are now exposed. Its upper limit, wherever it could be determined, is the outer edge of the Lithoid terrace. It is well exhibited on the steep bluffs of basalt on the southern border of the Carson Desert

* Stansbury's Expedition to the Great Salt Lake, p. 419.
† Geological Exploration of the Fortieth Parallel, vol. I, p. 502.

Thinolite.

Heliotype Printing Co., 211 Tremont St., Boston.

and on the equally rugged limestone bluffs, known as Marble Buttes, at the south end of Pyramid Lake.

About one mile west of Allen Spring a small conical butte rises nearly to the level of the Lithoid terrace near at hand. Owing to its isolated position it could not be covered by shore drift, and it also escaped erosion to a great extent, so that it now remains almost completely sheathed with compact, gray, lithoid tufa. Here, as at many other localities, the deposit appears to consist of imbricated masses thatching the tops and sides of the butte. Or one can imagine it had been poured upon the butte from above and congealed as it flowed down the sides. This latter semblance, however, is due in great measure to weathering.

Near its upper limit this tufa is seldom more than a few inches thick, at least as it remains at the present time, but it increases as we follow it down the slopes. In many places it forms a cement for the gravel embankments and for the material constituting the surface of the Lahontan alluvial slopes. On the butte near Allen Spring, as well as at many other localities, and especially at the southern end of Pyramid Lake, its sheet shows many horizontal lines or bands, where it has been more or less completely removed by shore action, thus recording fluctuations of lake level subsequent to its deposition. In other places, where the shore is less steep, the tufa has been completely removed, or else buried beneath shore drift. At a number of localities the shells of fresh water gasteropods have been found in great abundance imbedded in the solid tufa, thus indicating that the lake when it first rose consisted of fresh water. As compared with the other varieties, this first formed tufa is usually gray in color and compact in structure. It sometimes shows irregular concentric bands and open spaces, but is far more dense and stone-like than the varieties subsequently deposited. Between its layer and the one that was formed over it we sometimes find layers of cemented sand and gravel. The surface of the lithoid tufa also shows the effects of a weathering before it was covered by the second deposit. From this we learn that the surface of the lake fell in the interspace between the deposition of the first and second tufas. How nearly it approached complete desiccation we are unable to state, but it certainly reached a lower level than the present surface of Pyramid Lake.

THINOLITIC TUFA.

The second layer of tufa was deposited at a lower water stage than the first, and is of a very different nature. The upper limit of its deposit on the sides of the basin is the Thinolite terrace, 100 feet above the present (1881) level of Pyramid Lake. Its geographic extent is shown on the accompanying map. It occurs about Pyramid and Winnemucca lakes and at a few localities on the borders of the Carson Desert. These two areas were possibly connected, at the time the thinolitic tufa was formed, by a strait extending through the cañon north of Wadsworth, as indicated on the map. This valley or cañon is now occupied by the lower portion of the Truckee River, and has been deeply filled with gravel and lake-beds, whose relation to the thinolitic tufa it is difficult to determine.

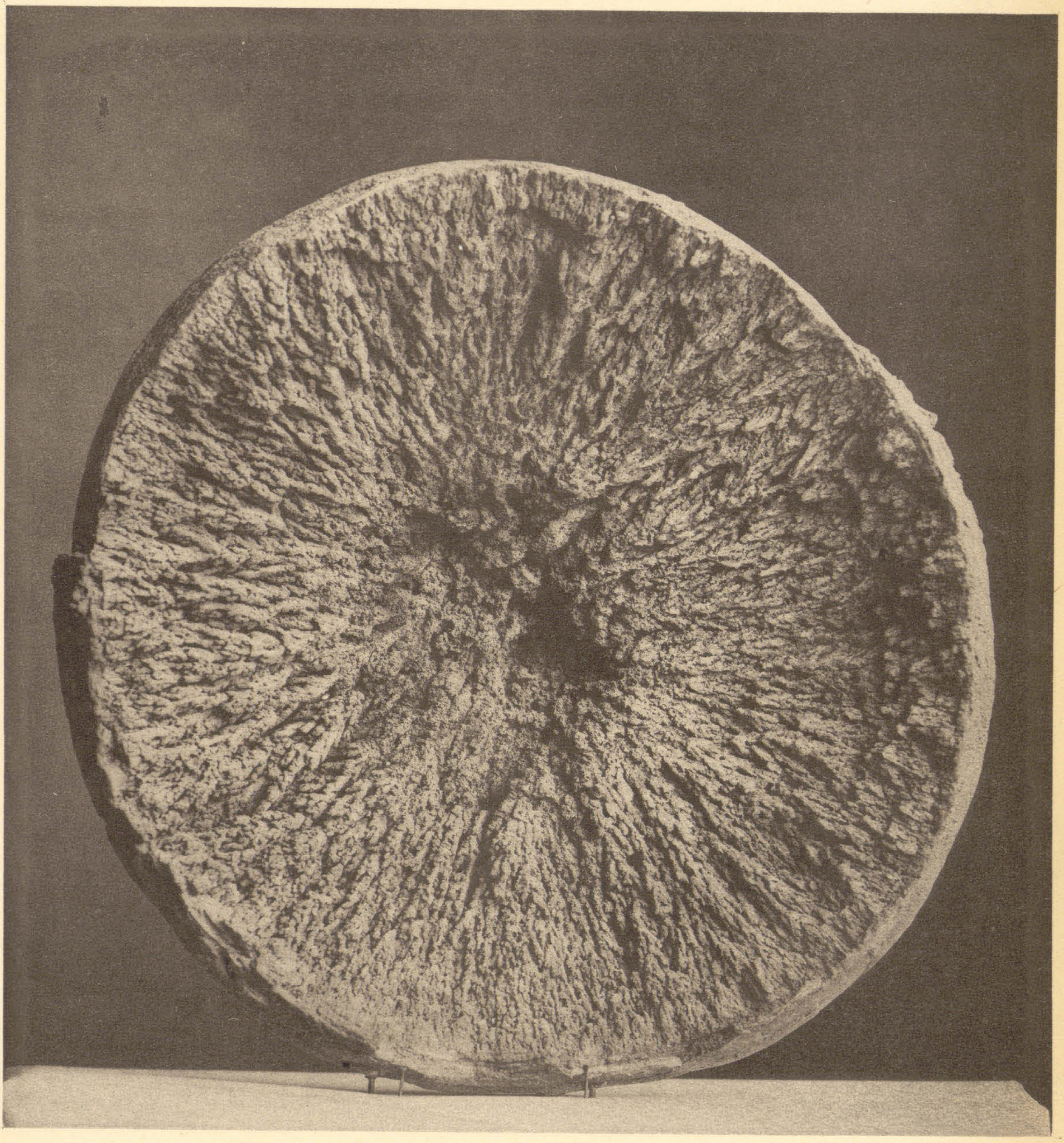
The external character of this tufa is shown in the right-hand upper figure of Plate XXV in Volume I of the Fortieth Parallel Survey. It is the variety that led Mr. King to give the name "thinolite" to the tufa deposits throughout the Lahontan Basin. But since we have been able to discriminate three distinct deposits, and since only one of these exhibits the characters described by Mr. King, we have preferred to restrict the name to this second deposit and apply other titles to the overlying and underlying layers.

The thinolite differs from the other tufa of the basin, and from calcareous tufa in general, in that it is constituted of crystals. These crystals are orthorhombic prisms, with faces and angles somewhat obscure and rough, and without well-defined terminations. They are often 6 or 8 inches in length, with a thickness of half an inch. They are light gray in color, and are seldom solid throughout, but contain flattish cavities more or less parallel with their sides. Weathered specimens frequently exhibit an imbricated structure, as if formed of thin pyramids or hoppers set one within another. The edges of these hoppers when broken across appear as lines parallel with the sides of the prisms. These crystals are announced in the Reports of the Fortieth Parallel Survey as pseudomorphs after gaylussite, and as they are intimately connected with the chemical history of Lake Lahontan they will necessarily receive great attention as the study of that history is pursued. It is interesting in this connection to note that identical crystals were also formed on a large scale in the Quaternary lake that occupied Mono Valley, California.

Where best exposed the layer of interlaced crystals has a thickness of from 6 to 8 feet, and exhibits concentric zones of larger and smaller crystals. (See Plate XIX.)

DENDRITIC TUFA.

We have given this name to the third variety of tufa—that deposited after the formation of the thinolitic crystals. This is the most abundant of the chemically formed rocks in the Lahontan Basin, and in places attains a great thickness. Its greatest depth is not less than 20 feet and may be as much as 50. The upper limit of the deposit is not definitely determined, but is about 200 feet below the highest water line, and from this level downward it coats the sides of the basin wherever the conditions are favorable. Like the previously formed varieties it was deposited on rocky slopes and outstanding buttes, where the action of the shore drift was least and where a solid nucleus could be found for the commencement of crystallization. The finest displays examined by the writer are to be seen on the high rocky buttes, once a Lahontan island, that rise just south of Carson Lake, and on the steep rocky shores



Dendritic Tufa.

Heliotype Printing Co., 211 Tremont St. Boston.

of Pyramid and Winnemucca lakes. The islands in Pyramid Lake are thickly coated.

Dendritic tufa occurs also over large portions of the bottom of the old lake, especially on the surface of the plain through which the Truckee River has cut a recent channel between Wadsworth and Pyramid Lake. In this region it is found in dome-shaped bodies, starting from small nuclei and spreading out to form mushroom-shaped masses of all sizes up to 5 or 6 feet in diameter. These completely cover the surface of the lake-beds over an area several square miles in extent. Another fine locality for tufa domes of this nature is on the surface of lake-beds in the cañon of the Carson River about 20 miles west of Ragtown. The mushroom-shaped masses occur here in great profusion, and are commonly polygonal in outline, owing to their having interfered with each other's growth. In places they are hexagonal and form a complete pavement on the surface of the lake-beds, each block being about 2 feet in diameter. Not infrequently one of these mushroom-shaped masses has weathered away at the top so as to form a vase-shaped cup that exhibits within the dendritic structure of the tufa—branching twigs of stone radiating on all sides from the small nucleus about which they first commenced to crystallize. This structure is shown in the accompanying plate, which represents a section of a dome after the top, to the depth perhaps of a foot, had been removed by weathering.

The dendritic tufa sheathing the steep cliffs exhibits similar mushroom forms, but far less perfect than those growing from isolated nuclei on the surface of the desert. The swelling bosses of tufa that cover the rocks in imbricated masses are usually weathered at top into shallow cups, and these have often a striking resemblance to swallows' nests coating the face of the cliff. The characteristic dendritic structure of this variety of tufa, exhibited in the plate, is so pronounced that even small weathered fragments can be identified with certainty. The appearance of the Lahontan shores when coated with this tufa is well shown in Plate XXIV of Volume I of the Reports of the Fortieth Parallel, and also in Plates XXI and XXII of this volume.

SUCCESSION OF TUFA DEPOSITS.

The accompanying diagram, Fig. 48, gives a generalized expression of the relation of the three successive tufas to each other and to the sides of the basin. The first formed deposit, the lithoid tufa, represented in the notation of the diagram by vertical lines, extends upward about 500 feet above the horizontal lake-beds occupying the bottom of the basin. The second deposit, the thinolitic tufa, finds its upper limit 100 feet above the present level of Pyramid Lake. The third and last, the dendritic tufa, which is far more abundant than either of the others, extends upward to within about 200 feet of the highest shore line. The lower limits of these deposits cannot be determined with certainty, as they are concealed by lake-beds.

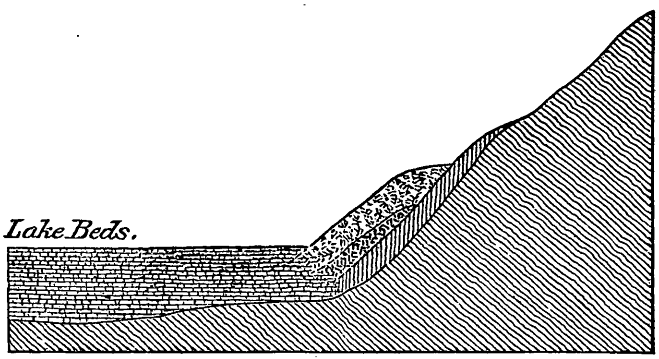


FIG. 48.—Diagrammatic section illustrating the Relations of the Tufas.

Chemical analyses were made by Prof. O. D. Allen of samples of each of these varieties of tufa, and the results, given below, show that their constituents are practically identical. The insoluble residue exhibited in each case may be due in part to foreign matter imprisoned in the tufa at the time of its formation, and is certainly due in a measure to foreign matter carried by atmospheric agencies into open cavities of the rôck after the desiccation of the lake.

	Lithoid tufa.	Thinolitic tufa.	Dendritic tufa.
Insoluble residue	1.70	3.88	5.06
Lime (CaO)	50.48	50.45	49.14
Magnesia (MgO)	2.88	1.37	1.99
Oxide of iron and alumina	.25	.71	1.29
Carbonic acid (CO_2)	41.85	40.90	40.31
Water (H_2O)	2.07	1.50	2.01
Phosphoric acid (PO_5)	.30	Trace.	Trace.
Chlorine and sulphuric acid	Trace.	Trace.	Trace.
	99.53	98.81	99.80

Not only do these tufa deposits still sheathe the slopes of the Lahontan Basin, but they appear also in isolated, castellated masses and rugged crags about the shores of Pyramid and Winnemucca lakes and on the borders of the Carson Desert. These outstanding masses occur characteristically as upright cylinders, or groups of cylinders, with rounded, dome-shaped tops, and are of all sizes, from a few inches up to a hundred feet or more in height. The larger masses are composed of groups of many tower-like, cylindric bodies of unequal height, and bear a striking resemblance to rugged mediæval castles with rounded towers and castellated battlements. A fine example of such a water-built castle stands about the middle of the western shore of Pyramid Lake, and rises 100 feet above the waves that wash its base. The domes between the eastern shore of the lake and Pyramid Island are the tops of similar towers, the foundations of which are deeply submerged. Other masses of the same nature, but smaller in size and usually broken and weathered, occur in abundance. Frequently these outstanding cylinders and castles of tufa are broken across, or split from base to summit, so as to reveal every desired section of their interiors. An examination of a large number of these dissected masses brought to light the interesting fact that all the tufa crags below the broad terrace 100 feet above Pyramid Lake—the Thinolite terrace—have a tripartite structure, and all above that horizon have a bipartite structure.

Each of the tufa towers below the Thinolite terrace has a core of compact gray tufa in all respects identical with the first-formed sheath of tufa on the rocky sides of the basin. This core of lithoid tufa is commonly from 2 to 6 feet in diameter, and sometimes shows a tubular structure. When the base is exposed it is occasionally seen to spring from a small nucleus of rock.

Outside the core of gray tufa is a coating of thinolite crystals, from 2 to 6 or 8 feet thick, that completely envelops its sides and top. These crystals are interlaced in every direction, but show a radial grouping, and also a concentric banded structure—zones of elongated prisms alternating with narrow bands of smaller crystals. The largest crystals are from 6 to 10 inches in length and an inch or more in diameter. This layer of thinolite is best displayed in the masses of tufa that occur low down near the surface of Pyramid Lake. The deposit is there thickest and the crystals are largest.

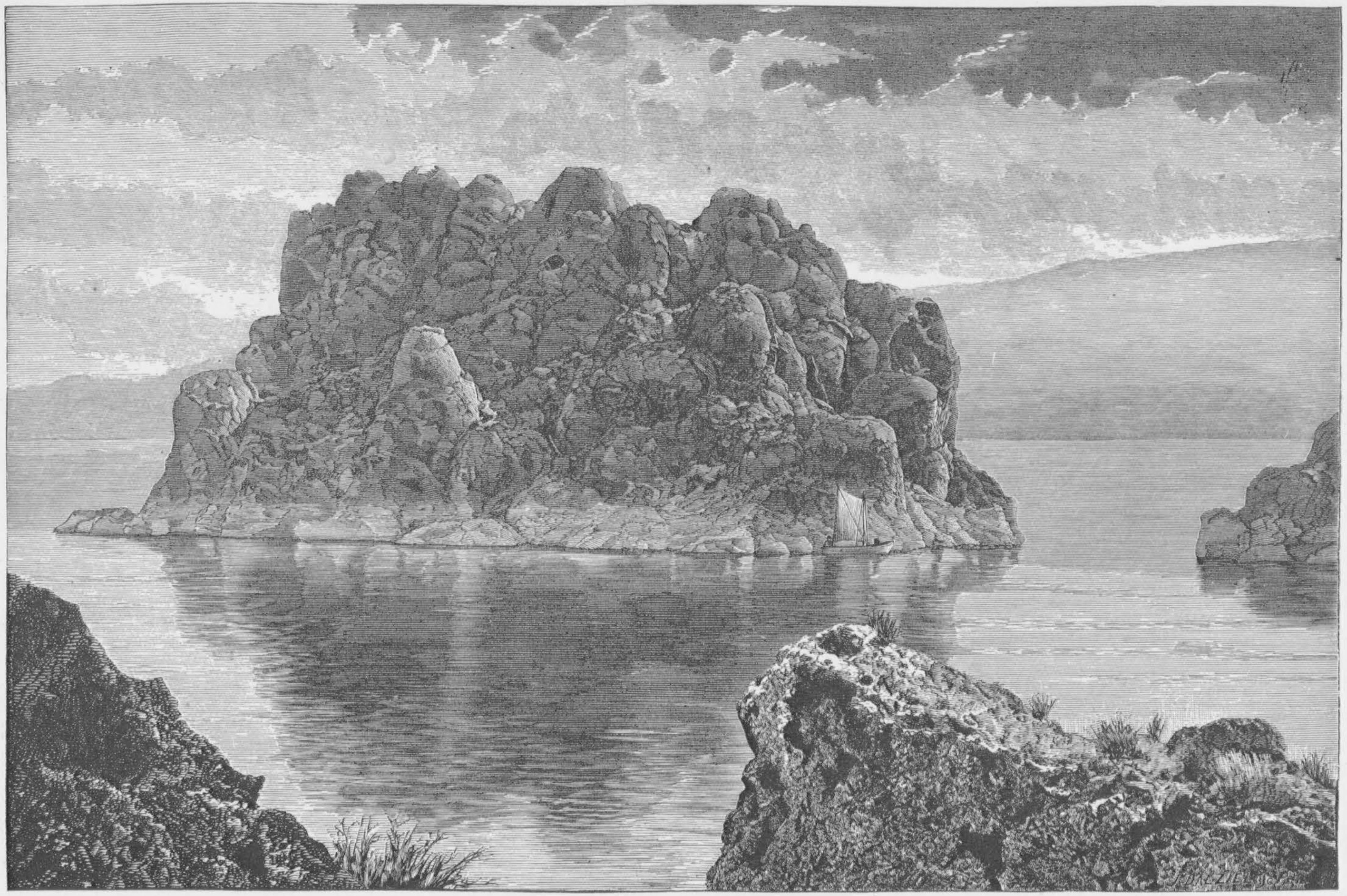
About the layer of thinolite, and in turn completely covering it, is a third tufa deposit, equal to or even exceeding in thickness either of the previous layers. It usually arches over the top of the column in a low dome. This third layer is of dendritic tufa and always shows the characteristic branching structure, resembling a group of cedar boughs changed to stone.

Frequently the dome-shaped summits of these tufa towers are weathered into holes, and sometimes the entire top is dissolved away down to the layer of thinolite crystals, or even deeper. In the hollows thus formed, which are frequently 10 or 12 feet in diameter, a person can stand as on the top of a wide tower, with a parapet of dendritic tufa 3 or 4 feet high all about him. On the west side of Winnemucca Lake, near the southern end, there stands a tufa tower, fully 40 feet high, that has been split from base to summit into three sections, the open fractures being wide enough for a person to pass through. In remembrance of Heidelberg I have called this the "Rent Tower." The whole of this tower is composed of tufa, the nucleus from which it started being some distance below the surface of the surrounding lake-beds and gravels. It stands just above the level of the Thinolite terrace and is composed entirely of lithoid and dendritic tufa, the middle or thinolitic member being wanting. Near at hand and a few feet below the horizon of the Thinolite terrace are other dome-shaped masses showing the intermediate thinolite also.

While the isolated tufa towers having thinolite as a middle member are confined to the shores of Pyramid and Winnemucca lakes and to the borders of the Carson Desert, the similar masses in which the thinolite is wanting occur over a much wider area, especially along the borders of the Black Rock Desert. Examples may also be seen along the line of the Central Pacific Railroad southeast of Humboldt Lake.

In some cases where the lake-beds and gravel have been washed away from the base of a tufa tower, we find the outer layer of dendritic tufa projecting as an irregular shoulder about the lower part of the column, thus showing how much of the column projected above the bottom of the lake at the time the dendritic layer was added. In one instance, where the entire mass has been uprooted, the layer of thinolitic crystals extends about 2 feet lower down than the coating of dendritic tufa, and then terminates in the same abrupt manner. In this case the central core of lithoid tufa ends in a tapering, irregular base, the nucleus of which is a group of small pebbles.

One of the physical conditions favorable, if not absolutely necessary, for the formation of tufa seems to be the presence of a solid nucleus about which the carbonate of lime can commence to crystallize. This nucleus may be a pebble resting at the bottom of the lake or it may be the solid cliff that forms the shore. It plays the same role here as it does in the crystallization of alum or rock candy in a laboratory experiment, or as may be seen in the structure of oolitic sand. The crystallization once started, the process was continued until hundreds and even thousands of tons had formed in a single isolated mass. Where the shores are too steep and solid for the ready formation of terraces and embankments of gravel they favor the deposition of tufa. In such places the chemical deposit cannot be disturbed or carried away by the shore drift. The most favorable places of all for the accumulation of calcareous deposits are rocky islands. Tufa frequently cements the gravel and sand of which embankments are constructed, and sometimes forms a complete pavement on their surfaces. This happens when by a rise of the lake the surface of the embankment is so far submerged as to escape the action of the shore drift. Tufa has never been observed by the writer resting on beds of fine clay or silt unless there were pebbles for nuclei. In many instances every pebble on a surface of fine lake-beds has its upper surface coated with tufa, or perhaps supports a mushroom-shaped growth some inches in height, while the surrounding plain of fine mud is entirely free from calcareous deposit.



TUFA DOMES—SHORE OF PYRAMID LAKE.

It has been suggested that these isolated tufa masses may have been formed by springs rising in the bottom of Lake Lahontan. That this is not the explanation of the origin of all the structures is shown by the frequently observed presence of a nucleus; the structure of the different varieties of tufa; their occurrence on rocky slopes; the correspondence of the three members composing the isolated masses below the Thinolite terrace with the three coatings of tufa sheathing the interior of the basin below that terrace; and the further correspondence of the two members composing the masses above the Thinolite terrace with the two coatings of tufa sheathing the rocky slopes above that terrace. The mounds of calcareous tufa deposited about hot springs have a structure, at least when formed on land, like that represented in cross section by the diagram, Fig. 49. If the spring has a single orifice the tufa is dedeposited on both the inner and outer edges of the rim in irregular, imbricated layers that build up a more or less perfect cone about it. Such a cone is broad in proportion to its height, and is irregular in structure.

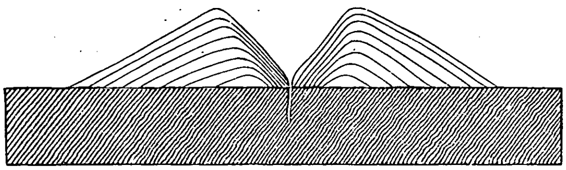


FIG. 49.—Ideal section of a Spring Deposit.

In the tufa domes of Lake Lahontan the height is usually much greater than the diameter, and the structure is always exogenous, as indicated in Fig. 50, which is a rude representation of a section of one of these domes observed near the shore of Pyramid Lake.

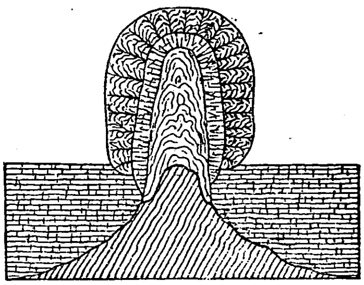


FIG. 50.—Generalized section of Tufa Dome.

On the other hand, the tubular structure of the inner core of lithoid tufa—in some instances branching irregularly and spreading out as it rises—certainly indicates that the formation of some of the isolated domes or crags has been initiated by the action of subaqueous springs. The deposition of carbonate of lime from springs rising under water has not been observed in any of the present lakes of the Lahontan Basin. It is possible, however, that the waters of these lakes are not sufficiently charged with mineral substances to cause the springs to deposit their lime when they come in contact with it. In Mono Lake, where the waters are strongly alkaline and saline, there are a large number of sub-lacustrine springs that are now depositing carbonate of lime and building tufa towers. In many instances these deposits are formed of porous and tubular tufa, closely resembling some of the lithoid tufa that forms the cores of the towers about Pyramid Lake.

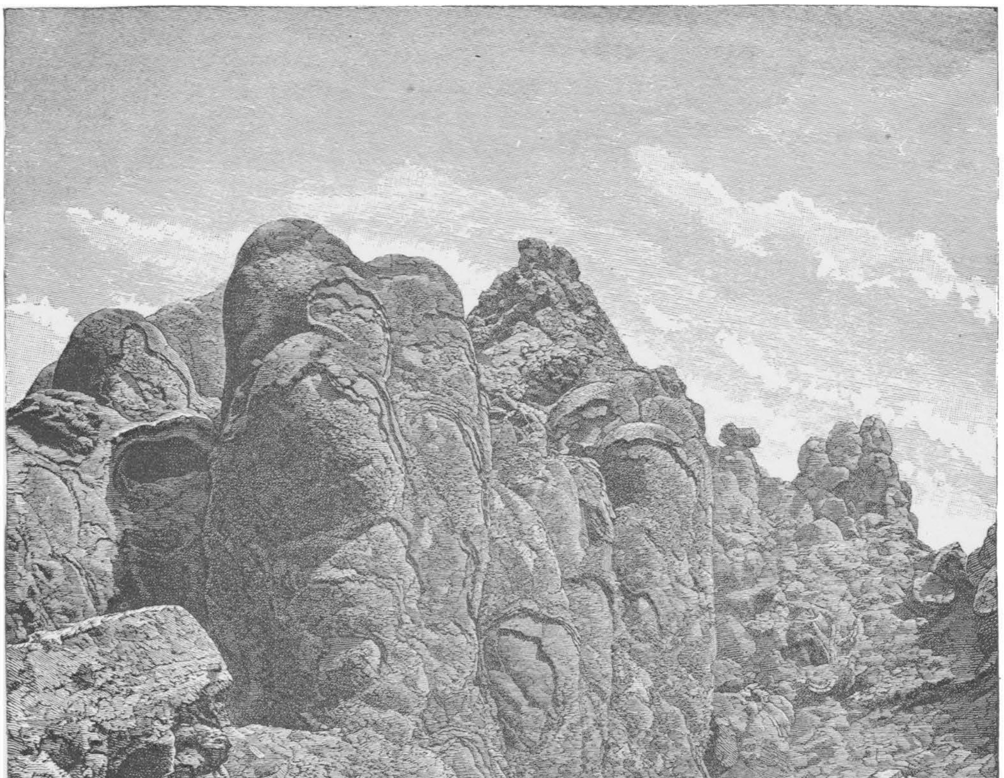
It is evident, then, that the formation of isolated tufa towers commences in two ways. In some instances the carbonate of lime begins to crystallize about a solid nucleus; in others the beginning is made by a deposition from springs that rise in lakes already highly charged with mineral salts. In the case of the towers about Pyramid and Winnemucca lakes, which have a core of tubular lithoid tufa completely enveloped by subsequently formed layers of the thinolitic and dendritic varieties, we must conclude that the lithoid tufa owes its formation to the action of submerged springs, while the outer layers were precipitated directly from the waters of the lake.

As the different varieties of tufa were deposited at separate periods, we should expect to find, in favorable localities, a succession of lake-beds or gravel deposits with intervening layers of tufa. This is also suggested by the unequal distances to which the different layers of tufa extend downward on the sides of the tufa domes. In our search for exposures of this nature we were only partially successful. In the sides of a deep cañon the Truckee River has excavated through Lahontan beds near its entrance into Pyramid Lake we found a layer of dendritic tufa, from 4 inches to 2 feet thick, exposed for some miles along the walls of the cañon, with well stratified lake-beds both above and below. A similar exposure has also been observed at Mill City, where the Humboldt River has excavated a deep channel through Lahontan sediments. No interstratification of thinolitic or lithoid tufa with beds of sedimentation has yet been observed.

We learn from the tufa deposits that there have been at least three well-defined periods in the history of Lake Lahontan. When the first tufa was formed the lake filled its basin to within 30 feet of the highest water line now scoring its sides. This tufa contains the shells of fresh-water gasteropods, showing that the lake was then fresh.

At a later date, when the volume of water was much less and the surface of the lake marked a shore line 400 feet below its former level, the broad Thinolite terrace was carved, and the chief deposit of thinolite crystals was formed. If the thinolite is a pseudomorph after gaylussite, then we can safely say that the waters of Lahontan were highly charged with soda and must have had a chemical composition resembling that of the waters of the Ragtown Ponds, in the Carson Desert, where beautiful crystals of gaylussite are now forming. At present we are unable to determine at what date after the formation of the gaylussite crystals the pseudomorphism took place, or what became of the soda once contained in the gaylussite and now replaced by lime. As Lake Lahontan never overflowed, the escape of this immense amount of soda from the basin is impossible. The question thus arising is one of the most interesting subjects for future investigation in connection with the history of the lake.

In the epoch of the dendritic tufa the water rose 200 or 250 feet above the Thinolite terrace, and the heaviest of all the tufa deposits was precipitated. No broad and well-defined terrace marks the upper limit of



TUFA DOMES—SHORE OF PYRAMID LAKE.

this deposit, and it is probable that the lake underwent many fluctuations of level during its formation. We find fragments of dendritic tufa built into the embankments that were formed at a later date, and also lake-beds resting on its layers. The final rise of the lake recorded by these phenomena was the highest rise of all. In the lagoons confined by the last formed bars we find gasteropod shells in abundance, and in the contemporaneous lake-beds resting on the dendritic tufa are hundreds of shells of *Anodonta*, indicating that the lake was fresh at this period.

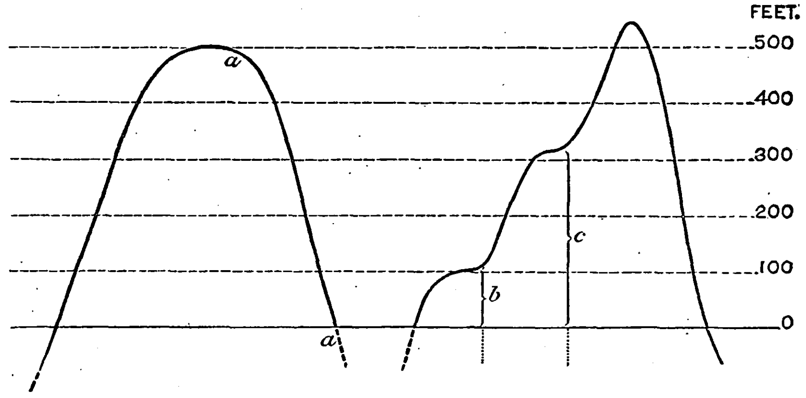


FIG. 51.—Curve exhibiting the Rise and Fall of Lake Lahontan; *a a*, deposition of lithoid tufa; *b*, deposition of thinolitic tufa; *c*, deposition of dendritic tufa. The zero of heights is the level of Pyramid Lake.

If we project the fluctuations of Lake Lahontan in a curve (Fig. 51), the ordinates representing depths of the lake at various stages, and the abscissas succession in time, we find there are two maxima and two minima. We have two moist periods when the lake was deep, separated by a time of desiccation, and followed by the present period of aridity. We know that the first of the two high water periods was the longer continued, for the terraces the waves then cut in the rocks are broader and more strongly marked than the terraces recording the second rise. The second high water period was of short duration, but the lake rose to a higher level than at the first filling.

SEDIMENTARY DEPOSITS.

The various streams which entered Lake Lahontan deposited at their mouths a large portion of the material brought down in suspension and formed delta accumulations. Owing to the many fluctuations of the lake level, however, these deposits have been mostly destroyed, or have been so modified and buried beneath lake gravels and lake-beds that no well-defined deltas now remain. The splendid preservation of the deltas of Lake Bonneville, as compared with those of Lake Lahontan, appears to be due to the fact that they were built at horizons determined by overflow, and were never afterward submerged or brought within the action of shore currents.

The rivers that entered Lake Lahontan fell at moderately low grades, and consequently carried mostly finely comminuted sediments and well-worn gravel. When they reached the lake the gravel and coarser material were deposited, while the impalpable mud was carried far out from shore and served to form lake-beds. The suspended material brought down by the Humboldt River was deposited largely in the long, narrow arm extending from the river mouth in the Sonoma Range to the present Humboldt Lake. These beds now form the nearly level floor of the valley, and may be seen in section in the sides of the deep cañon recently carved by the Humboldt River. The beds thus exposed are variable in composition, and seldom show identical sections at points half a mile apart. At many localities, as for example at Mill City, they are grouped in three divisions, thus:

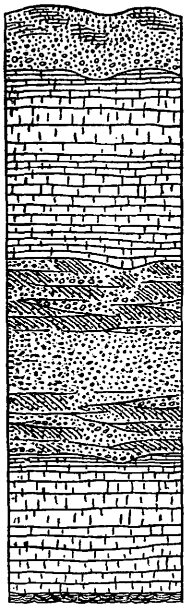
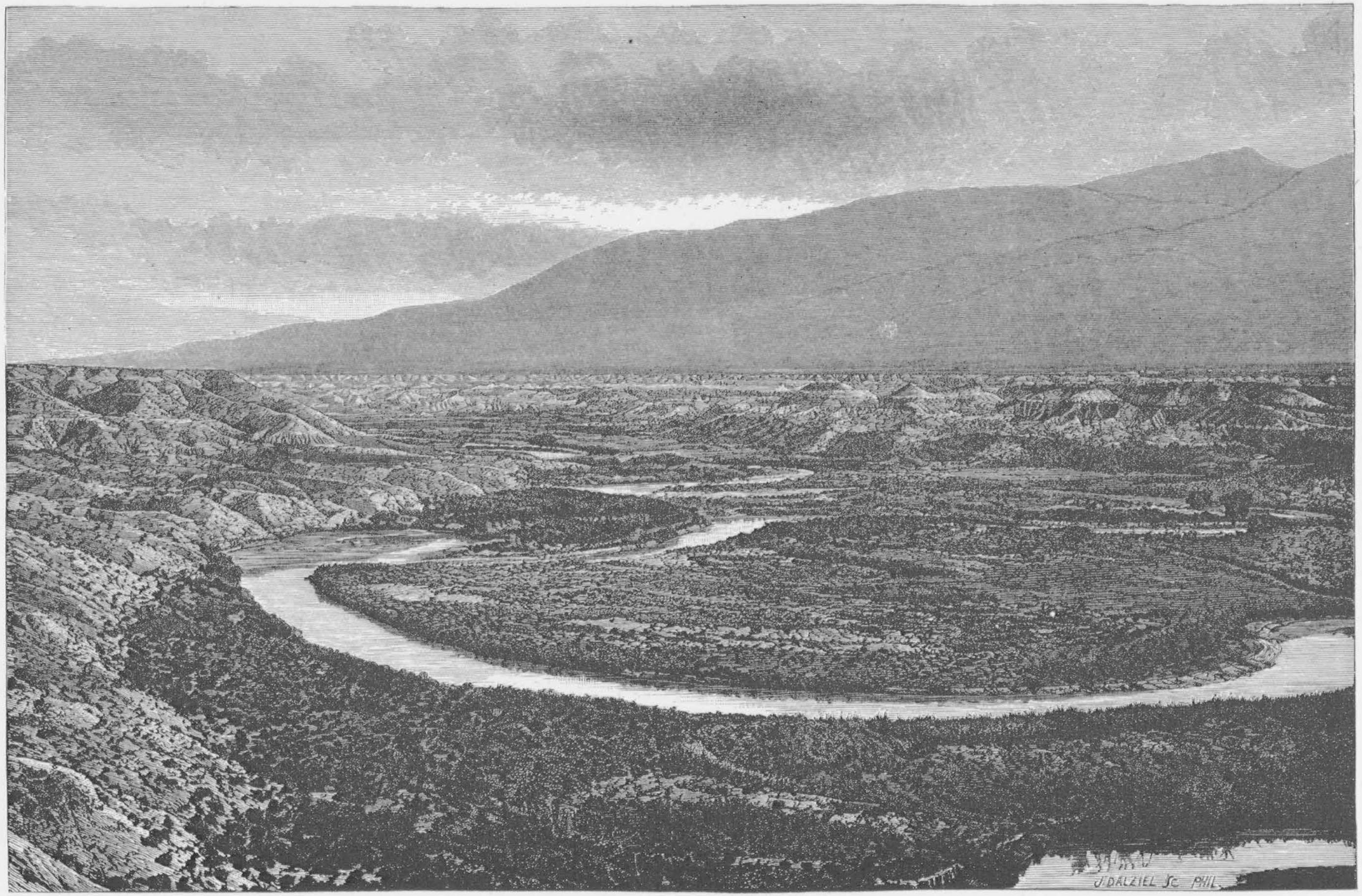


Fig. 52.—Section of Quaternary strata at Mill City, Nevada.

Lake-beds. Fine, evenly stratified, drab clays, weathering into cubical blocks, and containing *Anodonta;* partly covered by Æolian sand.	10 to 20 feet.
Layer of *Dendritic Tufa.*	
River gravels. Cross-stratified sand and gravel, with *Limnæa,* etc.	12 to 18 feet.
Lake-beds. Fine, evenly stratified, drab clays	8 to 12 feet.

This sequence of strata gives evidence of two periods when lake sediments were deposited in quiet waters, separated by a low-water period, when stream-borne, current-bedded gravels were spread out over the lower lake-beds. The middle member of the section is unconformable with the beds of clay, both below and above it, as indicated in the diagram.

This section, with various modifications of its middle member, may be followed for some miles along the cañon walls of the Humboldt, in the



LAHONTAN LAKE-BEDS IN HUMBOLDT VALLEY.

neighborhood of Winnemucca and Mill City. The shells found abundantly in the gravels have not yet been determined specifically, but they are identical with those occurring in the Lahontan tufas, and would point to the identity in age of these deposits, even if other evidence were lacking.

As we follow southward the section of lake-beds exposed by the Humboldt we find them more and more marly, with less and less gravel, until finally it is difficult to determine with accuracy the three members so conspicuous at Mill City. The cañon walls near Rye Patch are fully 200 feet high, and are cut by side drainage into typical bad-land forms, as illustrated by Plate XXIII.

At the highest stage of Lahontan the water extended up the cañon of the Truckee River to a point 15 miles west of Wadsworth. While it stood there it checked the flow of the water, and received from the river only fine material; but when the lake afterward fell, the grade of the stream was increased, and coarse material was carried out over the lake-beds. Still later, when the waters of the lake finally subsided, the *débris* that filled the cañon west of Wadsworth was mostly removed by the river, and at present only fragments of the lake-beds remain clinging to the sides of the cañon in sheltered places.

During the final desiccation there must have been a time when the Truckee flowed out over the nearly horizontal lake-beds filling the narrow strait about Wadsworth, and was free to turn either to the north or to the south. Without any apparent reason for the choice it turned northward, and it has cut a deep cañon through delta material and lake-beds to the depressed area now occupied by Pyramid Lake. The sections displayed by the vertical walls of this cañon show many variations, just as in the Humboldt River sections, but in many places there are two deposits of lacustrine clays, separated by a broad band of current-bedded gravel. Here also we find, as shown below, a continuous stratum of dendritic tufa, with evenly-bedded, fine-grained lake-beds both above and below it.

GENERALIZED SECTION ON EAST BANK OF TRUCKEE RIVER TWO MILES ABOVE THE INDIAN AGENCY.

	Feet.	
Æolian sands	0 to 20	
Fine yellow sands in contorted strata	20	Lake-beds.
Evenly stratified, drab clays, jointed	4	
Dendritic tufa	0.3 to 2	
Evenly stratified, drab clays, jointed	12	
Current-bedded gravels and sand in irregular strata, with partings of clay.	80	Shallow water deposits.
Evenly stratified clays, to river	20	Lake-beds.

In the cañon of Carson River the history given by the Humboldt and Truckee rivers is again repeated. This was a deeply eroded cañon before the formation of Lake Lahontan. The lake occupied it as far up as Dayton, and below that point the sediments brought by the river were deposited, partially filling the ancient valley. When the lake receded the river flowed over the soft lake-beds and cut them away, forming a cañon within an older cañon, the older and larger cañon being carved out of solid volcanic rock, and the newer one eroded from soft lake-beds, as indicated in the diagram.

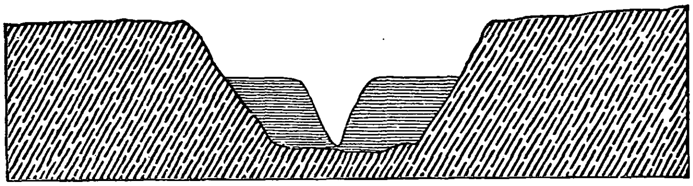


FIG. 53.—Ideal section illustrating the relation of the Ancient and Modern Cañons of Carson River.

In the cañon of Walker River, between Mason Valley and Walker Lake, these conditions are again shown.

In each of these cases the delta accumulations and lake-beds filling the old cañon extend up the river to a point where the contour marked by the horizon of the former lake crosses the valley. In each case, also, the strata contain fossil shells that are identical with those found in the tufa deposits of the old lake.

All the deposits occurring near the mouths of the tributaries of Lake Lahontan are similar in general character, varying from fine drab clays and white marls to coarse gravel. At a distance from the Lahontan shores, however, and forming the level floors of the broad deserts, are sediments of a different character. Over the most of the Carson and Black Rock deserts the material, to a considerable depth at least, is of fine, greenish, tenacious clay, having a remarkably uniform appearance over wide areas. This sediment, being deposited far from the mouths of the rivers, could only be formed of the finest silt, such as might be transported long distances and at the same time resist the solvent action of the water. It is composed mainly of the silicate of alumina, but contains also some soluble salts that appear to have been absorbed from the brine of the lake as the latter was evaporated to dryness.

DESICCATION PRODUCTS.

If Lake Lahontan had overflowed, the most of the salts carried into it by tributary streams would have been flooded out, but as it never found outlet it is evident that all the material delivered to it in solution must still remain in the basin. It is to the saline deposits left by the evaporation of the ancient lake that the term "desiccation products" is applied.

The study of the saline residua of the fossil lakes of the Great Basin is perhaps the most puzzling of the problems they present, the difficulty in arriving at the facts being due to the burial of the precipitated salts beneath the level and unbroken surfaces of the deserts, and also to the changes the chemical compounds have undergone since their first deposition.

A lake which disappears by evaporation may leave a stratum of salt upon its bed, as in the case of Sevier Lake, Utah, and the lake which once occupied Osobb Valley, Nevada. In each of these instances the bed of the extinct lake is now a dazzling field of salt many square miles in area. In other cases lakes have evaporated to dryness without leaving a layer of salt, but have left the lacustrine beds beneath saturated with a strong brine. An instance may be seen in Diamond Valley, Nevada, and there are a number of others in dry valleys of the Great Basin where playas occupy the sites of ancient lakes. The North Carson Lake, otherwise known as the Carson and Humboldt Sink, affords an example of the evaporation of a large lake of alkaline and somewhat saline water without the formation of a field of salt. It is a shallow lake, and has usually a length of more than 20 miles and a breadth of 12 miles, but in consequence of a series of unusually dry seasons it has been known to disappear by evaporation, leaving a plain of saline mud. Over the surface of this mud there is a profuse efflorescence of salt, testifying to the presence of that mineral in large quantities in the lake-beds beneath.

In the Lahontan Basin the salt once held in solution by the water nowhere exists as a surface deposit, but impregnates, or else is buried beneath, the fine clay sediments with which the plain is floored.

The presence of saline substances whitening the surface of the deserts during the drier portions of the year is due to the formation of a crust by efflorescence and not to the precipitation of salt on the evaporation of a lake. Areas many miles in extent are thus covered with impure layers of various salts, varying from a fraction of an inch up to five or six inches in thickness, the soluble minerals which impregnate the clays beneath being brought to the surface in solution by capillary action and there deposited as the water is evaporated. These incrustations are usually composed chiefly of the chloride of sodium and the sulphate of soda, with smaller quantities of carbonate and borate of soda, and with still smaller percentages of the sulphates of calcium and magnesium.

The best idea of the nature of the salts impregnating the Lahontan sediments can be obtained by an examination of the various salt works located within the lake basin.

BUFFALO SALT WORKS.

At the Buffalo Salt Works, situated on the west side of Smoky Creek Desert, the brine from beneath the desert is allowed to collect in wells, and is then pumped into vats at the surface and left to evaporate. The crust of salt that remains is then gathered, and is found sufficiently pure for all domestic uses. About 250 tons are annually collected, the total amount produced since the works were started being not far from 1,500 tons. When fresh water is caused to flow over the surface of lake-beds in the vicinity it soon becomes strongly saline, and when it gathers in hollows and evaporates it leaves a crust of salt that is sometimes several inches in thickness. This method is employed to some extent for obtaining the less pure grades used principally for chloridizing silver ores.

Two miles east of the works there are level, pond-like areas on the surface of the desert that are usually covered with a white efflorescence some inches in thickness. Other depressions are soft and completely saturated with bitter brine. In some there are deposits of sulphate of soda at least several feet in thickness, but never probed to the bottom. When examined by the writer these sulphate beds were covered to the depth of several inches with mother-liquor or soft mud that rendered the surface unsafe to walk upon. The whole desert region on the edge of which the Buffalo Salt Works are situated is one vast stretch of yellowish mud, without vegetation, impassable except during the dry season, and locally known as the "Mud Lakes." The salt obtained from the wells of the salt works, and the sulphate of soda and other minerals found on the surface near at hand, are all derived from the salts impregnating the Lahontan lake-beds.

The brine from the wells has been analyzed by Mr. F. W. Taylor, of the National Museum, with the following result:

Specific gravity, 1.1330.

Silica in solution	Trace.
Calcium sulphate	0.1467
Magnesium sulphate	.8833
Potassium sulphate	.3111
Sodium sulphate	.5306
Sodium chloride	14.8383
Water	83.2900
	100.0000

EAGLE SALT WORKS.

Another locality favorable for the study of the desiccation products of Lake Lahontan is at the Eagle Salt Works, situated near the Central Pacific Railroad, about 18 miles east of Wadsworth. The long valley in which they lie was a strait during the higher stage of Lake Lahontan. When the water fell about 100 feet the region where the salt is now found became a bay, connected with the Carson division of the lake through the Ragtown Pass. The country about the works is a desert mud plain, much of which is covered during the summer by a white saline efflorescence. The method here employed for obtaining the salt is to dissolve the crust that is formed on the surface of the desert and allow the saturated water to gather in shallow vats and evaporate. The water from springs on the eastern edge of the plain is conducted over the surface of the lake-beds, and made to flood small areas inclosed by low dams or ridges of clay. From the flooded areas it soaks through the clay ridges and enters shallow vats dug in the lake-beds on either side, where it evaporates and deposits its salts. The areas inclosed by clay ridges and flooded by the fresh water are called "reservoirs" by the workmen, and the long troughs between them where the brine evaporates are known as "vats." These are arranged alternately and may be multiplied to any extent. A profile through a reservoir and the vats on either hand is shown in the diagram.

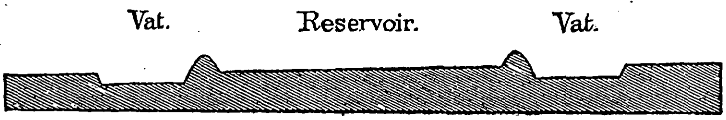


FIG. 54.—Section of Reservoir and Vats at Eagle Salt Works, Nevada.

The lake deposit here is a fine, greenish mud or clay, and is so completely saturated with brine that a thick crust is formed on the surface by efflorescence every dry season. The salt, being supplied from the beds below the surface, is renewed every summer, thus allowing a series of crops to be gathered from the same ground.

A sample of brine from a vat in which the salt had begun to crystallize was analyzed by Mr. Taylor, with the following result:

Specific gravity, 1.2115.

Silica (insoluble)	.0028
Iron and alumina (insoluble)	.0004
Calcium sulphate	.2897
Calcium chloride	.3578
Magnesium chloride	.3787
Potassium chloride	.0023
Sodium chloride	25.3793
Water	73.5890
	100.0000

The annual yield of salt during the past ten years is reported to have been about 2,500 tons. The production has been determined solely by the demand. The amount that could be collected by the simple process of leaching the saline lake-beds and evaporating the saturated waters is practically without limit.

SAND SPRING SALT WORKS.

The most interesting salt field in the Lahontan Basin is situated at the eastern end of a long, barren valley, joined to the Carson Desert on the southeast by a narrow pass, and known as Alkali Valley. The floor of this valley when left dry by the evaporation of Lake Lahontan had the same general level as the Carson Desert, and the lake-beds may be traced through the pass from one desert to the other. In riding from the Carson Desert eastward into Alkali Valley one comes to a line crossing Alkali Valley from north to south beyond which the surface of the desert has a gentle inclination eastward. The surface of the lake-beds when first deposited was horizontal, and the present inclination is due to a fault crossing the valley with a north and south strike, and to the tilting of the orographic block on which the eastern portion of the valley is situated. The tilting of the floor of the valley resulted in the establishment of a drainage to the eastward for the surface waters, and the formation of a small lake at the eastern end of the valley near Sand Springs. During the winter the water collects there, forming a sheet of brine of variable size, sometimes covering 10 or 15 square miles of surface, but with a depth of only a few inches. In the summer the water evaporates and adds to the layers of salt previously deposited.

The deposit of salt thus accumulated is from 3 to 5 inches thick near the margins, and is said to have a depth in the central portion of the basin of not less than 3 feet. It is gathered by simply shoveling it into barrows and wheeling it out onto firm ground, where it is piled in huge heaps ready for transportation.

The surface of the inclined lake-beds draining to the salt field is absolutely destitute of vegetation, and usually exhibits no saline efflorescence, since this is dissolved away to supply the salt field. Its soil, like that beneath the accumulated salt, is a fine, greenish, saline clay, and may be readily examined in the sides of drainage channels, which score the sloping surface to the depth of 3 or 4 feet.

The method here arranged by nature for dissolving the efflorescent salts from the surface of the lake-beds and evaporating the saline waters in the restricted basin, is practically the same as that employed by man on a smaller scale at the Eagle and Desert Crystal Works.

Associated with the salt obtained at the various salt works are greater or less quantities of the borate of soda and the borate of lime, and in some cases, as at the borax works in Alkali Valley, they attain such importance as to afford a considerable quantity of borax. There are many other localities in the Lahontan Basin where the chloride, the borate, the sulphate, and the carbonate of soda exist, sometimes in large quantities, in the incrustations that form on the deserts, but at present the demand is not sufficient to warrant the working of these deposits for economic purposes.

The chemical study of the desiccation products of Lake Lahontan is far from being completed, but it is safe to say that the vast amount of carbonate of lime sheathing the sides of the basin, and the great quantity of salt impregnating the sediments of the ancient lake, could only have been accumulated by a long process of concentration.

The character of the modern lakes occupying portions of the basin serves to indicate one other element of the physical history of the lake. It is well known, both from laboratory experiments and from the examination of deposits left by the natural evaporation of mineral waters, that the various salts are deposited upon evaporation substantially in the inverse order of their solubility. Their order of deposition is also controlled in part by their relative abundance in the original brine, or, in the case of a lake, by their relative abundance in the waters of the rivers tributary to it. In a lake that is concentrating by evaporation at the same time that tributaries are bringing in fresh supplies of mineral salts, the first deposit formed is carbonate of lime, this being the least soluble as well as the most abundant of the substances contained in river water; next follows the sulphate of lime; while common salt, which is alike highly soluble and slowly supplied, is stored up for a long time before precipitation commences. Eventually, however, its point of saturation is reached and it begins to crystallize out. The chlorides of magnesium and calcium, and a number of other substances which are more soluble than common salt but less abundant, still continue to increase after the accumulation of salt has reached its limit, and attain their points of saturation only after immense periods of time. These laws are of such wide application that the chemical composition of an inclosed lake gives some basis for the estimation of the time during which concentration has gone on, or at least it affords the means of judging which of two lakes that are without outlet is the older.

Turning now to the Lahontan Basin, and knowing that the old lake underwent a long period of evaporation, while it never filled its basin sufficiently to overflow and thus discharge its saline matter, we should expect to find in the modern lakes of the region, saturated solutions of common salt, with a considerable percentage of the more soluble but rarer minerals. The fact is, however, that none of the present lakes of the Lahontan Basin are highly charged with saline substances, and the proper conclusion appears to be that they are not remnants left by the evaporation of the ancient great lake. The analyses of the waters of the modern lakes have not been completed, but our reconnoissance has shown that the most of them are sufficiently pure to be drunk by horses and cattle, and even, in case of emergency, by man.

Since Lake Lahontan never rose so as to find outlet, the present freshness of the lakes of its basin cannot be ascribed to a discharge of the saline minerals by overflow, and we seem driven to the conclusion, first suggested by Mr. Gilbert, that the basin has been recently desiccated to dryness and its precipitated salts buried beneath strata of clay and gravel. The chemical history of the lakes thus indicates that the climate of the region, in one of its latest oscillations, was more arid than it is at present.

From the study of the terraces and tufa deposits of Lake Lahontan we learn that the lake had two periods of high water, separated by a time when its basin was even more thoroughly desiccated than it is now, and followed by the present period of aridity. But this evidence fails to show whether the basin ever attained complete desiccation. The unweathered character of the surface of the thinolitic tufa, unlike that of the older lithoid variety, indicates that it was not exposed to subaerial erosion before the dendritic tufa was deposited over it. When the lake reached its second high-water stage it was inhabited by fresh-water gasteropods and conchifers, and it must have attained a certain degree of freshness. However, since modern lakes, such as Pyramid and Walker, with a degree of salinity distinctly perceptible to the taste, are now inhabited by similar gasteropods, it is not necessary to assign to Lahontan at that stage a high degree of freshness, and it may even have contained in its total volume an amount of saline matter sufficient to produce a highly charged condition when dried away to the relatively small volume corresponding to the deposition of thinolitic tufa. But the discussion of these changes is premature, for there remain many observations not yet thoroughly correlated, and there are many questions to be asked of the lake records during the coming season, the answers to which it is hoped will shed much light on what are now the dark passages of Lahontan history.

LAHONTAN CLIMATE.

Regarding the Lahontan record as a history of climatic oscillations, we learn, first, that there was a time previous to the first flooding of the plains when the basin was at least as arid as at present, and when the alluvial slopes that were afterwards scored by lake terraces were built far into the valleys. The first knowledge we have of the lake is when it formed a gravel embankment across the Humboldt Valley at what is now the southern border of Humboldt Lake, and then, rising higher, cut terraces on the sides of the basin until it reached the Lithoid terrace and stood 500 feet deep over the Carson Desert. This is the record of a moist period. Following it came a time of desiccation, when the lake fell to some point below the present level of Pyramid Lake. Then it rose to the level of the Thinolite terrace and deposited the second sheathing of tufa. This was a time of small precipitation or of moderate aridity. Then followed the period of dendritic tufa, when the lake may be said to have been half filled; and this was succeeded by a brief epoch of still greater precipitation, when the water line was carried to its highest point. Last of all came the evaporation of the water down to its present level, and probably much lower—the final period of aridity.

Thus we find record of three periods of dryness in the history of the basin—a pre-Lahontan, an inter-Lahontan, and a post-Lahontan. There were also two periods of more abundant precipitation, the earlier being longer continued than the later, but the later producing the greater flood.

The curve drawn on page 221 to represent the oscillations of the lake surface may therefore also be used to represent the oscillations of the moisture element in the climate of the basin, and it is here repeated with a different notation as a curve of climate.

The great number of lakes that diversified the surface of the Great Basin during the Quaternary, and even the broad extent of Lakes

Bonneville and Lahontan, does not prove that the climate of that period was excessively humid. When we consider that a great number of the

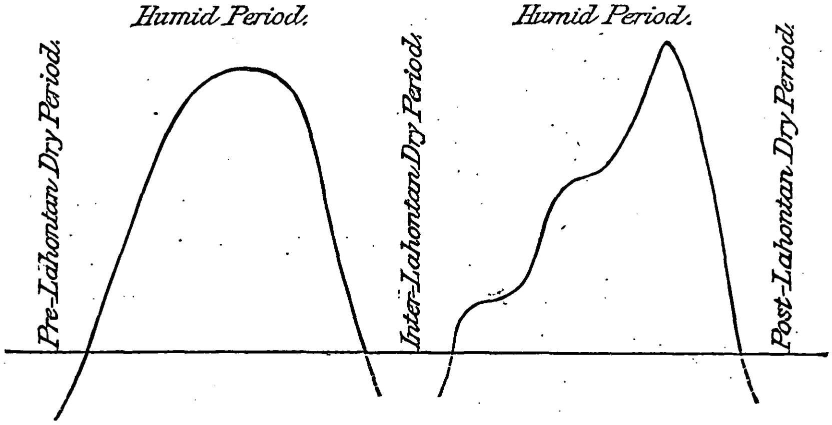


FIG. 55. Curve of Lahontan Climate—Wet *versus* Dry.

inclosed lakes did not overflow, and that this list includes Lahontan, which received the drainage from one flank of the great Sierra, we are forced to admit that the climate could not have approached in humidity that of the basin of the Laurentian lakes, where every lake and almost every pond has its outlet, and where the total discharge constitutes a perennial river of great magnitude. In all probability the ancient climate of Nevada differed less in moisture from its modern climate than from the modern climate of Minnesota.

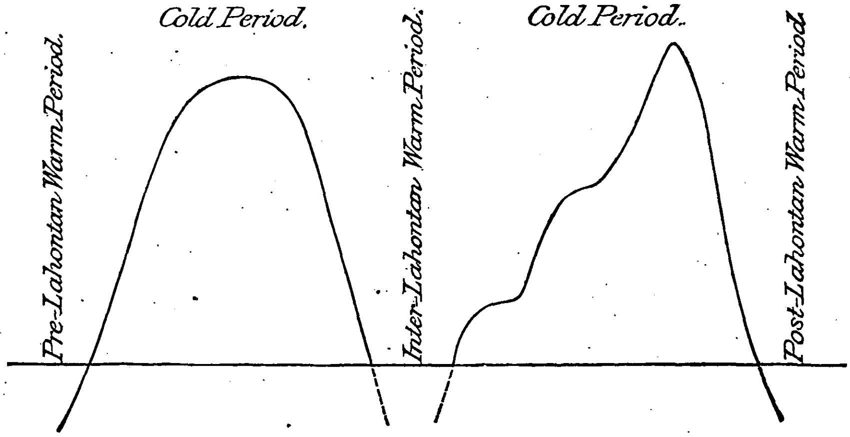


FIG. 56. Curve of Lahontan Climate—Cold *versus* Warm.

Moreover, we have independent evidence in the existence of local glaciers that the Quaternary temperature of the Great Basin was lower than its modern temperature, and since lowering of temperature diminishes evaporation and thus promotes the growth of lakes, it is not even certain that there was in Quaternary time any greater precipitation than now. The discussion of this question in a quantitative way has not yet been undertaken, but with the facts in hand it seems safe to advance the qualitative hypothesis that the ancient climate of the Great Basin was characterized by very moderate humidity coupled with a low mean temperature and a consequent slow rate of evaporation.

If this view is correct the fluctuations of the lake surface may be interpreted as oscillations of temperature, a low lake corresponding to a high temperature and *vice versa*. Thus construed our curve represents a succession of alternating warm and cold periods, the earlier of the cold periods being of longer duration than the later, and the later being characterized by the lower temperature.

POST-LAHONTAN OROGRAPHIC MOVEMENTS.

Nearly all the valleys that combine to form the basin of Lake Lahontan owe their origin to profound fractures, on the opposite sides of which the rocks have been either raised or lowered to different levels. The displacements in numerous instances have a magnitude of 4,000 or 5,000 feet. Not only did these differential movements produce the lake basin, but their continuance has modified it alike during the existence of the lake, during the inter-Lahontan dry period, and since the final desiccation. There is little doubt that these movements are still in progress, and that the mountains throughout the Great Basin are still slowly rising or being depressed. As a matter of observation we find the evidence of recent faulting best defined along the bases of the highest of the ranges, indicating that these owe their distinction to the fact that they are still growing.

In numerous instances the lines of recent faulting are marked by the presence of hot springs, and so constant is this association that it may be taken as the rule throughout the Great Basin that wherever we find thermal springs we may expect other evidence of recent displacement. The persistence of this relation gives rise to the suggestion that the heat of the hot springs is due to the friction of the rocks along the plane of faulting, or, in other words, to the conversion of motion into heat.

In nearly all cases the recent faults follow old lines of displacement, and they are usually confined to the immediate bases of the mountains, but occasionally, as on the Smoke Creek Desert, one is seen to cross the open plain. The recent fault-scarps divide the alluvial cones that stream down from the mountain valleys, and in numerous instances cut the bars and terraces formed by Lake Lahontan. They range in height from ten feet to fifty or sixty, and sometimes one hundred.

A fault-scarp more recent than the withdrawal of the waters of Lake Lahontan may be traced for more than fifty miles along the western border of the Smoke Creek and Black Rock deserts. Its course is irregular, varying from a little west of north to northeast, its height seldom exceeds twenty feet, and its line is marked by numerous springs that are either warm or else give evidence of having been thermal during an earlier stage of their existence. The fault at the south end of the Smoke Creek Desert is marked for a long distance by a line of verdure traversing an absolute desert.

Another line of recent displacement occurs on the northeast side of Honey Lake Valley, its course being marked by boiling springs. A third can be traced for fully a hundred miles along the western base of the West Humboldt Range, its scarp in the Lahontan gravels on the eastern border of Humboldt Lake being fully fifty feet in height.

Many other illustrations might be given to show that orographic movements have taken place in very recent times throughout the whole breadth of the Great Basin, and no geologist who examines them can fail to believe that these profound movements of the earth's crust are in progress at the present time.

THE SMALLER FOSSIL LAKES OF THE GREAT BASIN.

The explorations thus far made in the Great Basin, by the geologists of the Fortieth Parallel Survey and by our own corps, have brought to our knowledge fifteen basins (besides those of the great lakes Bonneville and Lahontan) that were occupied by lakes during the Quaternary period. At the present time these valleys are either dry or hold small saline or alkaline lakes. Some of these smaller lakes had outlets and overflowed into lower basins, carving channels of discharge; others were always contained by the barriers that now surround their basins. The valleys that held these minor Quaternary lakes are given in the following list:

Gosiute Valley	Nevada.
Clover and Independence Valleys	Do.
Ruby Valley	Do.
White Pine Valley	Do.
Grass Valley	Do.
Osobb Valley	Do.
Diamond Valley	Do.
Washoe Valley	Do.
Granite Spring Valley	Do.
Mono Valley	California.
Horse Valley	Do.
Madeline Plains	Do.
Pueblo Valley	Do.
Surprise Valley	Do.
Long Valley	Do.

In some of these the evaporating lakes left fields of salt; others, including Surprise, Pueblo, Ruby, and Osobb, still contain shallow lakes. The basins of others are now broad, sage brush valleys, with beach lines about their margins, and with playas in their lowest depressions, which are converted into shallow lakes during wet seasons.

The features that distinguish these valleys from those of the Great Basin that had free drainage during Quaternary times, are marginal lines of sea-cliffs, wave-cut terraces, and wave-built embankments. Usually, too, they are flat-bottomed, the lakes having deposited their sediments in horizontal sheets; and in some instances their sides bear deposits of tufa. In the tufa and the lake-beds the shells of fresh water mollusks are commonly found.

In a valley that has had free drainage for a considerable time the bottom is more or less irregular, sometimes becoming distinctly V-shaped, and it is usually cut by strongly marked lines of drainage. The rim of such a valley is incomplete, and all phenomena due to the action of waves and currents are absent.

Besides the valleys indicated in the preceding list there are others that without doubt held lakes of greater or less size during Quaternary times, the shore records of which have either been effaced or are too indefinite to be distinguished. These valleys are inclosed basins, and usually have playas at bottom, and in some instances they exhibit incrustations of soda salts. In this class we may group:

Gabbs Valley	Nevada.
Soda Springs Valley	Do.
Fairview Valley	Do.
Virginia Salt Marsh	Do.
Great Salt Basin	Do.
Adobe Meadows	California,

and probably also a large number of the small valleys so numerous throughout central and southern Nevada.

ABSTRACT OF REPORT

ON

GEOLOGY OF THE EUREKA DISTRICT, NEVADA.

BY

ARNOLD HAGUE.

CONTENTS.

ILLUSTRATIONS.

ABSTRACT OF REPORT ON THE GEOLOGY OF THE EUREKA DISTRICT.

BY ARNOLD HAGUE.

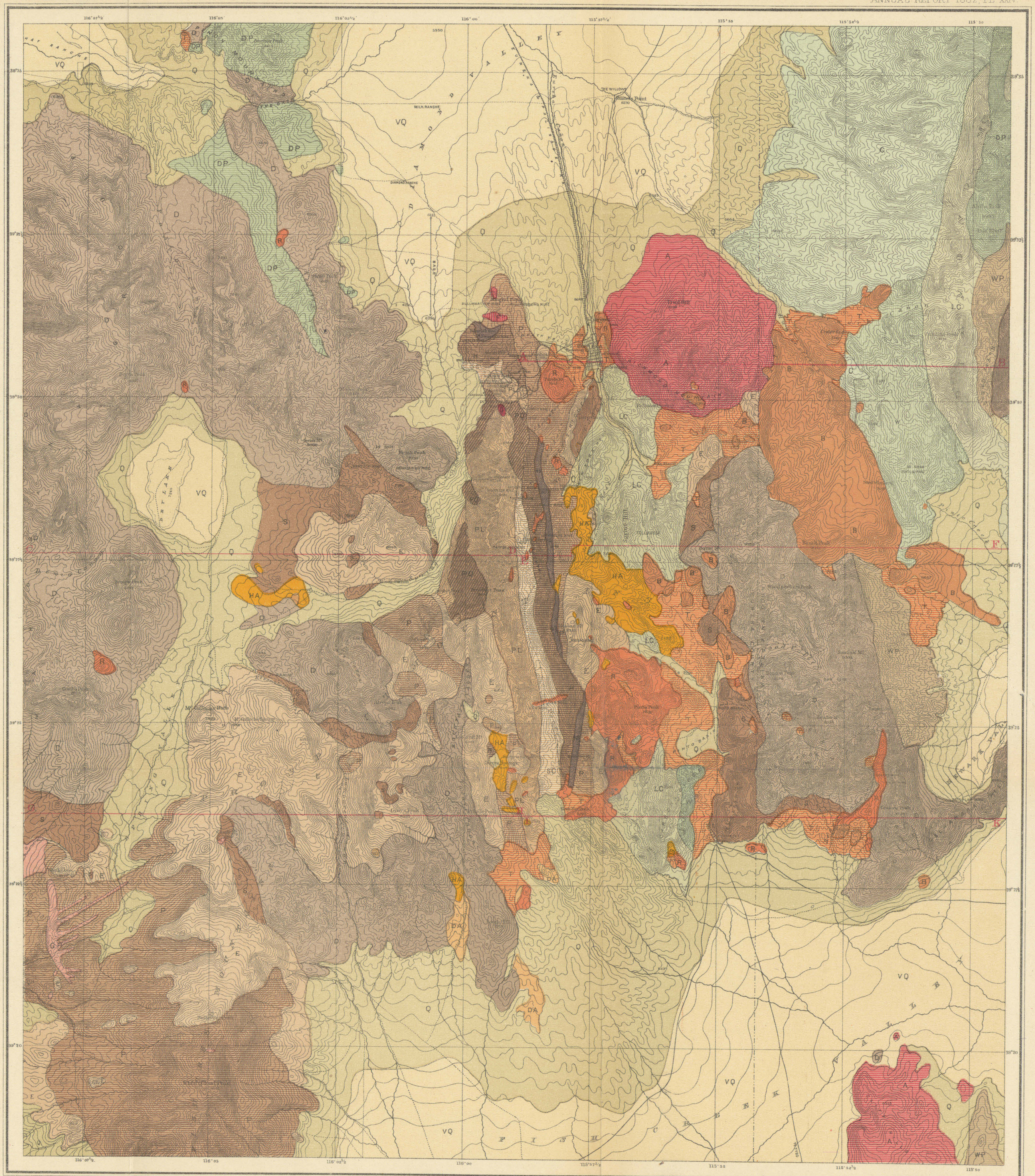
INTRODUCTION.

It is doubtful if within the province of the Great Basin there is any region of equally restricted area which surpasses the Eureka District in its grand exposures of Paleozoic formations, especially of the lower and middle portions of the series.

As the district, moreover, is one of great economic interest as the seat of an active mining industry, and has been, as well, the center of intense volcanic action, it was judiciously selected for a more careful survey and study than had heretofore been given to any region of sedimentary rocks in Nevada. Unmapped and only occasionally visited by geologists, but little had been accomplished, except for the immediate purposes of mining, towards investigating its structure or solving its many geological problems. It was known to be an exceptionally broad expanse of mountains, affording fine geological sections if properly worked out, and of special interest for the purposes of comparative study in other regions of the Cordillera. In this direction almost nothing had been done.

The monograph upon the Eureka District is purely geological in its scope and is mainly a careful study and survey of a comparatively small block of mountains, which may be designated as the Eureka Mountains, but which should not be confounded with the Eureka mining district, as several other well-known mining districts also lie wholly within this mountain area. This report upon the district appears in two parts; one a volume of text, the other an atlas of topographical and geological maps and cross-sections, and as the text is, in great measure, explanatory of the atlas, the two should be considered as parts of the same work.

The text presents as concisely as is consistent with clearness and completeness the principal geological facts observed and such general deductions as have been drawn from their study. Accompanying the report are two special monographs, prepared by Mr. Charles D. Walcott and Mr. Joseph P. Iddings, the able assistants in the geological field-work of the survey. Mr. Walcott's paper upon the Paleon-



F. A. Clark, Topographer

Julius Bien & Co. lith.

Arnold Hague, Geologist-in-Charge.

GEOLOGICAL MAP OF THE EUREKA DISTRICT, NEV.

QUATERNARY.
- Mountain Quaternary. — Q
- Valley Quaternary. — VQ

CARBONIFEROUS.
- Upper Coal Measures. — C
- Weber Conglomerate. — W
- Lower Coal Measures. — LC
- Diamond Pk. Quartzite. — DP

DEVONIAN.
- White Pine Shale. — WP
- Nevada Limestone — D

SILURIAN.
- Lone Mt. Limestone — S
- Eureka Quartzite. — E
- Pogonip Limestone. — P

CAMBRIAN.
- Hamburg Shale. — HS
- Hamburg Limestone. — H
- Secret Cñ. Shale. — SC
- Prospect Mt. Limestone. — PL
- Prospect Mt. Quartzite. — PQ

IGNEOUS.
- Basalt. — B
- Rhyolite. — R
- Pumice and Tufa. — T
- Dacite. — DA
- Augite Andesite. — A
- Hornblende Andesite. — HA
- Quartz Porphyry. — F
- Granite Porphyry. — GP
- Granite. — G

tology of the Eureka District gives the results of a detailed study of the organic forms obtained throughout a wide range of geological formations, the region having proved an exceptionally rich one in paleontological material from Cambrian, Devonian, and Carboniferous rocks. In addition to the descriptions of many forms new to science and the identification of nearly three hundred species, the report contains notes, more or less full, upon many species which presented in their characters or geographical distribution information not heretofore published. It will be illustrated by over three hundred accurate drawings of fossils, arranged on twelve plates. Four plates represent the fauna of the Cambrian, five that of the Devonian, and three that of the Carboniferous. All specific identifications of the organic forms from the Eureka District referred to in this paper were made by Mr. Walcott.

The special paper by Mr. Iddings upon the microscopic petrography of the eruptive rocks of the Eureka District presents the results of a careful examination of thin sections prepared from a large number of rocks, representing every type known to occur in the region. It is a concise statement of a systematic study of the material, and is of great interest, bearing directly upon many geological questions connected with eruptive masses. Mr. Iddings's report will be illustrated by six plates, four of which are reproductions of photo-micrographs, showing some interesting characteristics in structure of fine groundmass, and two of drawings of minute crystals and microscopic objects found in the rocks. All references to the purely microscopical details of the rocks have the advantage of having undergone Mr. Iddings's searching scrutiny.

The atlas accompanying the text will consist of thirteen sheets—

Sheet I.—Title.

Sheet II.—Legend.

Sheet III.—Topographical map of Eureka District; a single atlas sheet, scale 7,200 feet to the inch. This is a general map, covering the entire field surveyed. On the map will be shown the locations of all the more important mines, wagon-roads, and elevations above sea-level of prominent peaks, ridges, and well-known landmarks.

Sheet IV.—Geological map of Eureka District, a single atlas sheet. This is the same as Sheet III. geologically colored, and the boundaries of the large geological sheets laid down.

Sheets V. to XII., inclusive.—Eight double atlas sheets. The scale is 1,600 feet to the inch. The area covered by these maps is precisely the same as that of Sheet IV. They are numbered consecutively from left to right, No. V. being in the upper left-hand corner of the general map. Two maps cover the area from west to east. They are printed in color, and, in addition to the boundaries of geological formations, all the principal lines of displacement are laid down and the structure of the country brought out as clearly as possible by conventional signs indicating the strike of the rocks and, within certain limits, the dip of the beds. All the principal localities are marked which have yielded important groups of organic remains, and lines are drawn indicating where cross-sections have been constructed.

Sheet XIII.—Geological cross-sections drawn to a natural scale across the map from west to east, showing the structure of the different sedimentary uplifts, and their relations to the igneous outbursts.

The preparation of the topographical map was intrusted to Mr. F. A. Clark, who employed three able assistants in the field—

Mr. G. H. Wilson, assistant topographer, with the plane table;

Mr. G. Olivio Newman, in charge of triangulation;

Mr. Morris Bien, assistant topographer.

The original sheets from which the present map was constructed were drawn on a scale of 1:10,000, with 50 feet contours. In Spring Valley, northwest of Ruby Hill, a base line was measured 9,000 feet in length, from which a triangulation with average sides of one mile was developed.

The writer's acknowledgments are due to many gentlemen, superintendents of mines and others, who rendered valuable assistance in obtaining information in regard to the country, and who generously afforded every facility in the prosecution of the work. Special thanks are due to Mr. R. Rickard, formerly superintendent of the Richmond Mining Company, and to Mr. Thomas J. Read, superintendent of the Eureka Consolidated Mining Company.

GENERAL DESCRIPTION.

The area covered by the geological and topographical survey of the Eureka District embraces a region of country twenty miles square. It is situated on the Nevada Plateau, in Central Nevada, midway between the basin of Lake Lahontan to the westward and the basin of Lake Bonneville to the eastward. It lies partly in the county of Eureka and partly in the county of White Pine.

The meridian of 116° west from Greenwich passes just to the westward of the center of the examined area, and the 39°30′ parallel of north latitude crosses Ruby Hill, the seat of the present activity in precious-metal mining.

On the Nevada Plateau the broad central north and south valleys, lying between meridional mountain ranges, reach an average altitude of 6,000 feet above sea-level, the country falling away gradually on both sides till at Salt Lake, in Utah, the altitude is 4,250 feet, and at Carson and Humboldt Lakes, in Nevada, 3,800 feet above sea-level. In general the broader physical features of the Great Basin ranges are much the same all the way from the bold escarpment of the Sierra Nevada of California to the precipitous wall of the Wahsatch Mountains of Utah, the distance in an east and west line being about 425 miles. They form long, narrow mountain uplifts with sharply-defined limits, rising with more or less abruptness above broad intervals of desert. In width they seldom measure more than eight miles, but frequently extend for more than 100 miles in length, with serrated peaks and ridges rising from 2,000 to 6,000 feet above adjacent valleys. For the most part they possess a simple topographical structure and a simple drainage system. They are characterized, more especially the lower ranges, by absence of trees, and in many cases are nearly bare of all vegetation, presenting rough, rugged slopes of naked rock.

On the higher parts of the plateau the ranges, reaching a greater altitude, partake more of an Alpine or sub-Alpine character. Precipitation of moisture is more abundant, as seen both in the more frequent rains of summer and snows of winter. A greater precipitation produces larger and more frequent streams, and a continued moisture favors a varied vegetation—the spurs and ridges being more or less covered with a dwarfed and stunted forest growth.

These characteristic features distinguish the ranges of the Nevada Plateau from those of Lake Lahontan and Lake Bonneville Basins, which present a more arid and weird aspect. A striking feature of nearly all these ranges is their isolated position, only a few of them presenting outlying spurs or low lines of rolling foot-hills. Occasionally inferior ridges stretch diagonally across valleys connecting distant ranges, and still more frequently outbursts of volcanic rocks in irregular flows serve to unite in confused masses bodies of sedimentary formations otherwise distinct.

The East Humboldt Mountains, midway between the Sierra and the Wahsatch, form the most prominent range in the Great Basin. They present not only by reason of the greater number of rugged and commanding peaks, many of them attaining an elevation over 11,000 feet above sea-level, but by their broad, massive proportions, long, unbroken ridges, and Alpine character, the boldest uplift on the Nevada Plateau. Next west from the Humboldt occurs the Diamond Range, followed by the Piñon Range, with the broad Diamond Valley lying between them. Southward the southern extremities of these two ranges enter the Eureka District and form a part of its mountainous region.

On the plateau, among the more marked exceptions to the long narrow ranges which rib the surface of the country may be mentioned the Roberts Peak Group, connecting the Wahweah with the Piñon Range, the White Pine Mountains, and the subject of the present report, the Mountains of the Eureka District.

The Eureka District forms a rough mountain block standing out by itself, except for its narrow connections with the Piñon and Diamond Ranges, almost as completely isolated from its neighbors as the longer parallel ranges. As a mountain mass, however, it has never received any distinct appellation which would include all its members, it being made up of portions of several ranges and short uplifted blocks so intimately connected and inosculated as to form both topographically and geologically a single group, hemmed in on all sides by the characteristic detrital valleys. To the north Diamond Valley extends for over 40 miles in an unbroken plain, the lowest part of the depression being covered in winter by a broad sheet of water, which, upon evaporation, presents during the greater part of the year a hard level floor, strongly impregnated with salt. To the south of the district lies the broad basin of Fish Creek Valley, connecting with Newark Valley on the east side of Diamond Range, while Antelope Valley cuts off the Eureka District on the west side from the neighboring mountains.

It is doubtful if any area of equal extent in Nevada possesses more varied physical features with such strongly marked contrasts. In close proximity may be seen long serrated ridges, broad summits, gently inclined tables of nearly horizontal sedimentary beds, with abrupt escarpments along cañon-walls, and highly tilted strata in rough irregular spurs. And as might be expected in a country made up of individual blocks and parts of ranges and so interlocked as to form one broad mass, the region is characterized by broad shallow basins, long narrow ravines and winding valleys, presenting a more than ordinarily accidented surface with an intricate structure. Above the broad base of the surrounding sage-brush valleys, which have an altitude of 6,000 feet above sea-level, rise many prominent peaks from 2,500 to 4,500 feet. Diamond Peak in the northeast corner of the district, at the southern extremity of Diamond Range, is the culminating point, measuring 10,637 feet above sea-level, and, with the exception of the high summits in the East Humboldt Range, is one of the loftiest peaks on the Nevada Plateau. Prospect Peak on the central ridge, and the second point in the district, measures 9,604 feet, while Atrypa Peak, to the southwest on the same ridge, has an altitude of 9,063 feet above sea-level. Other points are White Cloud Peak, the highest point on a broad plateau-like ridge, 8,950 feet, Alpha Peak 8,985 feet, and Woodpecker's Peak 8,598 feet, all of them being formed of sedimentary rocks. Among volcanic mountains may be mentioned Richmond Mountain just east of the town of Eureka, which rises to a height of 8,392 feet; and Pinto Peak, an isolated cone to the southward, which reaches an altitude of 7,880 feet above sea-level.

Up to the time of the rapid development of the mining interests upon Ruby Hill and Prospect Mountain, the slopes and ridges about Eureka were exceptionally well supplied with an arborescent growth, a condition which was due partly to the number of high peaks but in great part to broad masses of mountains acting as condensers of desert moisture. To-day, so great has been the demand for wood and charcoal in the reduction of lead ores, that the mountains are as bare of trees as any part of the Great Basin. Several species of pines, dwarfed junipers (*Juniperus occidentalis*), and mountain mahogany (*Cercocarpus lædifolius*), which attains a height of over 20 feet, are, or rather were, the prevailing trees, but are now only found in a few areas preserved by their owners for future use, at no distant day.

Nature presents a barren, arid appearance. Vegetation is everywhere limited, and is mainly confined to bunch grasses on the mountain slopes, and sage-brush in the open valleys.

As the valleys are mainly filled with coarse detrital material from mountain slopes, soils suitable for agricultural purposes occupy very small areas, and are only found in the broader basins. In the favored spots where water for irrigation purposes can be readily obtained, all the more hardy vegetables grow well, and are of excellent quality, but nearly all crops suffer from early frosts. In no sense can the country be regarded as an agricultural one, and cultivation of the soil is only remunerative to the farmer by reason of the very high prices received for his produce.

A rigorous winter, a long, hot summer, a dry atmosphere, with a light precipitation of moisture, are characteristic climatic features of the Eureka District. In summer rain-falls are limited to showers, frequently very severe, but of short duration, and what are popularly known as cloud-bursts are by no means uncommon during late July and early August. The clouds, late in the afternoon, centering over Prospect Peak, break with such force that many people caught without warning have been drowned. In July, 1874, a severe storm and flood carried off seventeen lives, and destroyed property to the value of many thousands of dollars.

During the season of our field operations snow fell in the month of May no less than eight times, and again on June 10 and 11. In summer the days are warm, the nights cool. The daily variation between the maximum and minimum thermometers was always very considerable, frequently showing a difference of 50° Fahrenheit. As early as August 30 the thermometer fell below 32° Fahrenheit, and on October 9 a light fall of snow covered both mountain and valley.

In the summer of 1864 the first locations of mining property were made in New York Cañon, on the eastern side of Prospect Mountain. This property was known as the Eureka Mine, and although it never fulfilled the expectations of its original owners, it gave a name to the town, to the mining district, to the county, and finally to the neighboring group of mountains. In mining operations very little was accomplished until the season of 1869, when important discoveries were made on Ruby Hill, and active, intelligent work was undertaken. From that time forward mining operations on Ruby Hill have gone on steadily, and to-day the Eureka District is the most successful mining region in the State of Nevada.

Recent estimates of the value of the ore production of the district since the first shipment of crude bullion in 1869, are as follows:

From 1869 to 1873	$10,000,000
From 1873 to January, 1882	40,000,000
Total	50,000,000

Around this industry has grown up the town of Eureka, which is the center of population and trade for this part of the State. It is a long narrow settlement, lying in the main northern drainage channel of the mountains, and sheltered on the east side by Richmond Mountain.

The Eureka and Palisade Railway, 88 miles in length, connects the town with the Central Pacific road at Palisade. Branch tracks connect with the Eureka Consolidated and Richmond furnaces, the former at the lower, and the latter at the upper end of the town, and these again by a somewhat sinuous course with the principal mines, which are situated about two and one-half miles southwest of Eureka. There are an imposing well-built court house, three or four churches, and several blocks of brick stores and warehouses in the town. It supports two daily papers, which have a considerable influence and a wide circulation throughout the State.

Ruby Hill, the only other town of any importance in the district, is a flourishing place, nearly the entire population being actively engaged in mining in the immediate neighborhood. It is built on the north and east sides of an isolated hill which bears the same name, and on which are located all the more prominent mines, including the Albion, Richmond, Eureka Consolidated, Phœnix, and Jackson properties.

PALEOZOIC FORMATIONS.

Sedimentary rocks cover by far the greater part of the area of the Eureka District and belong exclusively to Paleozoic and Quaternary ages. The beds of the Quaternary, however, are of slight geological interest, and although they extend over wide areas are in most cases quite superficial, formed of detrital material brought down from the mountains and deposited along their flanks, where it serves to conceal the underlying rocks along the foot-hills. Igneous rocks play a most interesting part in the geology of the area, but nevertheless do not form an important feature of the individual mountain uplifts, appearing either as narrow dikes and small intrusive masses penetrating the older rocks, or as larger bodies encircling and lying outside the main blocks of sedimentary formations.

The Paleozoic rocks present a great development of limestones, quartzites, and shales, extending through many thousands of feet of Cambrian, Silurian, Devonian, and Carboniferous beds. Nowhere within the limits of the district is there any one exposure which shows these beds without a break in their continuity, the longest continuous section representing about one-third the entire sequence of formations. Yet the region offers in so many instances such long exposures of beds, and so many in which the formations overlap each other, that the reconstruction of an entire section is easily made out when the parts are carefully compared and studied. The reason there is no one unbroken section, is easily understood by a glance at the structural features of the country. The orographic movements which brought about the elevation of the mountains produced an intricate structure with profound faults, flexures, and folds, and broke up the immense thickness of sediments into individual masses. Although so intimately related to each other that it is frequently difficult to draw sharp topographical boundary lines between them, the Eureka Mountains may be divided into six blocks with well-marked structural and geological differences (Plate XXIV). In most instances the blocks are separated from each other by profound displacements. The blocks may be classed as follows:

Prospect Ridge.
Fish Creek Mountains.
Silverado and County Peak Group.
Mahogany Hills.
Diamond Mountains.
Carbon Ridge and Spring Hill Group.

Prospect Ridge.—This ridge forms the most prominent orographic feature of the district. It is centrally situated, and presents a bold serrated outline extending, with an approximately north and south trend, from Diamond Valley to the Quaternary of Fish Creek Basin. Topographically, the structure is quite simple—a single narrow ridge rising abruptly on the west side, but falling away gradually to the east. On Prospect Peak, the central point of the ridge, the western side descends for 2,500 feet toward Spring Valley, with an average slope of 30° with the horizon. Here at Prospect Peak, where the main cross-section was constructed, the anticlinal structure of the range is clearly shown, the axis of the fold being situated midway down the western slope. To the southward the western side of the anticlinal has been carried down by a fault, and the structure presents a simple monoclinal ridge, with the beds all dipping to the east. Along its eastern base the boundary of Prospect Ridge is sharply defined by the Hoosac fault, which extends the entire length of the range, approximately parallel with its trend. To the northwest the range is equally as well defined by a profound fault along Spring Valley, which separates the ridge from the Mahogany Hills. To the southwest, however, Prospect Ridge is closely connected with Fish Creek Mountains; and a sharp boundary between them, from a topographical point of view, except for a slight change in the trend of the ridges, would be difficult to establish.

Geologically, Prospect Mountain Ridge presents a conformable series of sedimentary beds standing at highly inclined angles. They extend from the axis of the anticlinal on the west side of Prospect Peak, which occurs in the oldest formation exposed, through 11,000 feet of strata, to the eastern base of the ridge, where they are abruptly cut off by the Hoosac fault. It is wholly composed of Cambrian and Silurian rocks.

Fish Creek Mountains.—To the southward of Prospect Peak the character of the mountains changes, Prospect Ridge taking a course a little to the east of south, and a new set of ridges come in with an approximately northeast and southwest trend. At the same time the geological structure undergoes a complete change, and the appearance of the country is wholly altered. From a single ridge it becomes a broad rough mass four to five miles in width, irregular in outline, with a very diversified and broken surface. It is in the region of Atrypa Peak and Lookout Mountain that any classification of the mountain masses becomes difficult, the present orographic structure being the resultant of quite different dynamic forces, which elevated respectively the Fish Creek Mountains and Prospect Ridge. Southward, however, from Castle Peak the Fish Creek Mountains become more clearly defined, and, with a north and south trend, stretch for several miles beyond the limits of the map. They are about five miles in width, and rise over 2,000 feet above the adjoining Quaternary valleys. In structure they are a broad table-topped mass of limestone, nearly horizontal on the summit, but inclining toward the four points of the compass with a quaquaversal dip from White Cloud Peak. On the west the beds fall away, with low angles, toward Antelope Valley, the outlying spurs being capped with quartzite. In strong contrast with the west slope the east side presents an abrupt declivity, produced by a north and south fault, which has dropped the limestone about six hundred feet. From the Reese and Berry Cañon, southward, the Fish Creek Mountains may be considered essentially as a Silurian formation, although along the outer edges and foot-hills Devonian rocks occupy considerable areas.

Silverado and County Peak group.—This group stands by itself, almost completely isolated from the other mountain blocks, separated from them by profound faults, along which igneous rocks have poured out in large masses. In this way it is completely cut off from its immediate neighbors, the Diamond Range, and in great part from the Carbon Ridge and Spring Hill Group. It is roughly broken up into three minor groups —a northern, southern, and southeastern. The two former are separated by Wood Valley, opening to the west, and a narrow cañon south of Sentinel Peak on the east, while the latter is somewhat isolated by the deep valley of Rescue Cañon and an arm of Newark Valley. The northern part may be designated as County Peak Group, the southern as Silverado, and the ridges to the southeast as Alhambra Hills. Taken together the group has a northwest and southeast trend extending from Richmond Mountain to Fish Creek Valley, and in an east and west line stretching from the Pinto fault to the Quaternary plain. The mountains are almost wholly made up of Silurian and Devonian beds, the many long ridges offering excellent continuous sections through 6,000 feet of strata.

Mahogany Hills.—Upon the west side of the district, remote from the last-named group, lie the Mahogany Hills. They occupy by far the largest area of any mountain block, and at the same time are sharply defined in their topographical outlines by Spring Valley, which separates them from Prospect Ridge and Fish Creek Mountains. With the Piñon Range to the north, however, they are both structurally and geologically intimately connected. This latter range from "The Gate" northward presents a long narrow uplift, for the greater part of the distance, a single well-defined ridge extending nearly to the Humboldt River. At "The Gate" the range may be said to terminate, as it loses its distinctive character, although the same formations in northwest and southeast ridges continue to Brush Peak, where they are abruptly cut off by a fault at Spring Valley.

The Mahogany Hills rise abruptly above Dry Lake and Spring Valley, and slope gradually westward toward the broad plain of Antelope Valley, just beyond the limits of the map. Silurian limestones occur in one or two localities at the base of the sedimentary series passing up into Devonian beds. At the top of the series directly overlying upper members of the Devonian rests a long highly inclined ridge of Carboniferous quartzite. But all the prominent ridges and long gentle slopes are formed of Devonian limestone, which in the neighborhood of Modoc Peak is shown in a continuous section for 5,400 feet, neighboring localities furnishing other exposures nearly as complete.

Diamond Mountains.—This range is one of the best defined uplifts on the Nevada Plateau, extending for 40 miles along the east side of Diamond Valley. Only a small portion, however, in the northeast corner of the map, comes within the limits of this survey, as the range properly terminates with the outlying ridges of Newark Mountain. Diamond Peak, the highest and broadest peak in the range, lies within this limit, and the structure and development of beds exposed upon the flanks of the two mountains add greatly to the interest in the Paleozoic section. For the greater part of the distance Carboniferous rocks form the range, and, as is so often the case throughout Nevada, no lower beds immediately underlying them have been recognized. Here, however, Newark Mountain is made up exclusively of Devonian rocks, dipping to the westward, which pass under the east base of Diamond Peak and are overlaid by an immense thickness of Carboniferous beds, which, with the exception of the Devonian beds mentioned, constitute its entire mass. In its structure, Diamond Peak presents a synclinal fold, the same beds as are found upon its east slope dipping into the peak coming up again on the opposite side with a reverse dip. The Devonian beds, however, are not brought up to the surface, as a longitudinal fault extends along the west base, completely cutting them off and bringing up still higher Carboniferous formations than are found on the peak. These higher beds belong to the Upper Coal-measure Group, and form the long gentle slopes which extend westward from the peak to the Quaternary plain and the igneous rocks of Richmond Mountain.

Carbon Ridge and Spring Hill group.—This block occupies a far less conspicuous position than any of the others, and upon a superficial examination would command hardly any attention as a prominent physical feature of the country. Unlike the neighboring uplifted blocks, which rise grandly out of the plain, this one has rather the appearance of a depressed region, without any special character, lying between two prominent groups of mountains. Moreover, as it is formed of two distinct parts, separated by flows of igneous rocks, its continuity is broken, and their true relations, at first sight, difficult to make out. Geologically, however, the two parts are intimately connected, and their east and west boundaries, approximately the same, sharply defined by two longitudinal faults—the Hoosac and the Pinto—which extend the entire length of the district from Richmond Mountain southward until concealed beneath the superficial deposits of Fish Creek Valley.

Prospect Ridge rises immediately to the westward of the Hoosac fault, and the Silverado and County Peak Group to the eastward of the Pinto fault. This depressed region, which presents many most interesting geological features, is wholly made up of Carboniferous rocks.

Paleozoic section.—It will be seen that each of these six blocks exposes several thousand feet of strata, and, while they frequently overlap each other, no two of them represent precisely the same horizons, although the Diamond Range includes within its strata the bed exposed by the Carbon Ridge and Spring Hill Group. The six blocks essentially correspond to the following horizons:

Prospect Ridge: Cambrian and Silurian.

Fish Creek Mountains: Silurian.

Silverado and County Peak: Silurian and Devonian.

Mahogany Hills: Devonian.

Diamond Mountains: Devonian and Carboniferous.

Carbon Ridge and Spring Hills: Carboniferous.

From the lowest exposed members of Cambrian strata to the overlying beds of the Coal-measures they represent a series of sedimentary deposits 30,000 feet in thickness. In the subjoined tables the relative thickness and general lithological characters are given of all the geological divisions which have been made of the sedimentary rocks.

In the four great periods of Paleozoic time fourteen groups have been recognized; five in the Cambrian, three in the Silurian, two in the Devonian, and four in the Carboniferous. With one exception local names have been given to designate the different groups into which the Cambrian, Silurian, and Devonian periods have been divided, as heretofore throughout the Great Basin the division of the larger periods into epochs has not been necessary, the horizons not having been sufficiently studied. The exception is made in favor of the Pogonip limestone of the Silurian, a name first applied by the Geological Exploration of the Fortieth Parallel. In the Carboniferous period a large quartzite body at the base of the series has been designated the Diamond Peak quartzite, but for the remaining epochs the well known names Lower Coal-measures, Weber conglomerate, and Upper Coal-measures are retained. In the section a plane of non-conformity in the Silurian is indicated by double dividing lines between the Eureka quartzite and Lone Mountain limestone.

Eureka Section, Nevada, 30,000 feet.

CARBONIFEROUS, 9,300 feet.	Upper Coal-measures	500	Light-colored blue and drab limestones.
	Weber conglomerate	2,000	Coarse and fine conglomerates, with angular fragments of chert; layers of reddish yellow sandstone.
	Lower Coal-measures	3,800	Heavy-bedded dark blue and gray limestone, with intercalated bands of chert; argillaceous beds near the base.
	Diamond Peak quartzite	3,000	Massive gray and brown quartzite, with brown and green shales at the summit.
DEVONIAN, 8,000 feet.	White pine shale	2,000	Black argillaceous shales, more or less arenaceous, with intercalations of red, and reddish brown friable sandstone, changing rapidly with the locality; plant impressions.
	Nevada limestone	6,000	Lower horizons indistinctly bedded, saccharoidal texture, gray color, passing up into strata distinctly bedded, brown, reddish-brown and gray in color, frequently finely striped, producing a variegated appearance. The upper horizons are massive, well-bedded, and bluish-black in color; highly fossiliferous.
SILURIAN, 5,000 feet.	Lone Mountain limestone	1,800	Black, gritty beds at the base, passing into a light gray siliceous rock, with all traces of bedding obliterated; Trenton fossils at the base; Halysites in the upper portion.
	Eureka quartzite	500	Compact, vitreous quartzite, white, blue, passing into reddish tints near the base; indistinct bedding.
	Pogonip limestone	2,700	Interstratified limestone, argillites, and arenaceous beds at the base, passing into purer, fine-grained limestone of a bluish gray color, distinctly bedded; highly fossiliferous.
CAMBRIAN, 7,700.	Hamburg shale	350	Yellow argillaceous shale, layers of chert nodules throughout the bed, but more abundant near the top.
	Hamburg limestone	1,200	Dark gray and granular limestone; surface weathering, rough and ragged; only slight traces of bedding.
	Secret Cañon shale	1,600	Yellow and gray argillaceous shales, passing into shaly limestone; near the top, interstratified layers of shale and thinly bedded limestones.
	Prospect Mountain limestone	3,050	Gray, compact limestone; lighter in color than the Hamburg limestone, traversed with thin seams of calcite; bedding planes very imperfect.
	Prospect Mountain quartzite	1,500	Bedded brownish white quartzites, weathering dark brown; ferruginous near the base; intercalated thin layers of arenaceous shales; beds whiter near the summit.

NOTE.—Plane of unconformity indicated by double dividing line.

CAMBRIAN ROCKS.

Rocks of this period are almost exclusively confined to Prospect Ridge, forming all the more elevated portions, while the Silurian rocks although perfectly comformable with the lower beds only come in along the outlying spurs and foot-hills. All along the east slope of the ridge the beds have a nearly uniform thickness, but attain their greatest development opposite Prospect Peak, where the lower strata are best exposed. Here they measure about 7,700 feet from base to summit. They have been divided into five epochs, as follows: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Cañon shale, Hamburg limestone, Hamburg shale. So far as known, nowhere within the State of Nevada do the Cambrian rocks afford as fine geological sections as at Eureka.

Prospect Mountain quartzite.—This group lies at the base of the series, and is consequently the oldest sedimentary rock exposed. It takes its name from the peak where it reaches its broadest development and forms its entire western slope. With one or two slight breaks in the continuity, the quartzite may be traced along the base of the ridge northward to Ruby Hill, where as the foot-wall of the Richmond and Eureka Consolidated Mines it becomes of considerable economic interest. There can be no question but that the quartzite of Prospect Peak and that of Ruby Hill are identical. On Prospect Peak the strata have a thickness of 1,500 feet and occur distinctly bedded, but in some localities all lines of stratification appear to be wanting. At the base of the series the beds are largely composed of conglomerates and brecciated masses firmly cemented together with ferruginous material, and the weathered surfaces deeply stained by iron. In the conglomerate quartz pebbles may occasionally be seen showing compression and flattening on their broader sides, arranged in the beds parallel with the planes of stratification. Interstratified in the lower beds of the quartzite are occasional bands of fine-grained arenaceous and micaceous shales only a few feet in thickness. No organic remains have been found in this group, although diligent search was made in the interstratified shales, as if they occur they would be of the highest paleontological interest.

Prospect Mountain limestone.—Directly overlying the Prospect Mountain quartzite occurs the Prospect Mountain limestone, which forms the greater part of the ridge extending from Ruby Hill southward to the entrance of Secret Cañon. Along the east side it presents a bold clifflike front, erosion having worn away the overlying shales. In general, it possesses a light bluish-gray tint, although nearly all colors are found in the limestone, which is characterized by thin seams of calcite crossing it in all directions.

In texture the limestone is crystalline and granular, and over wide areas is so highly altered as to obliterate all traces of fossils; and while in places planes of bedding may be seen distinctly from Ruby Hill southward, they are, over the greater part of the ridge, wholly wanting. Numerous analyses of the rock from Ruby Hill and the Prospect Mountain tunnel show the beds to be a magnesian limestone throughout the formation, but the amount of magnesia, in most instances, is far too low to permit the rock, as a whole, to be classed as a dolomite. Interstratified in the limestone are irregular beds of shale, lenticular or wedge-shaped bodies, varying greatly in width. Indeed they form a characteristic feature in the limestone, which passes readily from massive to shaly beds. Two of the shale bands are quite prominent to the north, but are lost to the southward. The thickness of the beds may be taken at 3,050 feet.

Secret Cañon shale.—The Prospect Mountain limestone passes, by gradual transition, from shaly limestone into brown and yellow argillaceous shales, which, with the exception of one or two thin calcareous layers, present a very uniform character from the extreme southern end of Secret Cañon northward till cut off by a fault a short distance northwest of the Dunderburg mine. In their broadest development they measure 1,600 feet, although in places where they are encroached upon by the Hamburg limestone they occur considerably thinner. The topographical features of the mountains are largely modified by this shale body, which, eroding more readily than either the overlying or underlying limestone, has been largely instrumental in determining the drainage channels of the ridge. There are few finer examples of the wearing away of a soft, easily eroded body lying between two harder rock masses than can be seen in Secret Cañon, where the Prospect Mountain limestone rises like a wall on one side and the Hamburg limestone nearly as abruptly on the other, while the cañon for over three miles is carved out of the shale.

Hamburg limestone.—Transition beds of shaly limestone, varying in thickness from 25 to 200 feet, pass gradually into the overlying Hamburg limestone, which forms a prominent, bold ridge between the overlying and underlying shales, and, as it is cut through at regular intervals by east and west drainage channels, presents one of the most striking topographical features of the region, and a geological horizon most easily traced in the field. In general, this limestone is sharply contrasted in its lithological habit with the Prospect Mountain body, as it is darker in color, carries more siliceous material, and possesses a characteristic rough and ragged surface produced by weathering. The thickness of the limestone may be taken at 1,200 feet, and along the east slope of the ridge, except in the shaly beds at the top and bottom of the series, no planes of bedding are traceable. At Adams Hill, however, where the beds lie inclined at a much lower angle, stratification may be occasionally observed.

Hamburg shale.—This shale body in general resembles the one underlying the Hamburg limestone, except that it is by no means as uniform in composition, showing very rapid changes in conditions of deposition, becoming more or less arenaceous and calcareous throughout its development as well as in its lateral extension. It is characterized by cherty nodules, and near the top by more or less persistent layers of chert and sand. Across its broadest development it measures 350 feet, yet it rarely maintains for any long distance a uniform thickness. The best exposures are seen opposite the Hamburg and Dunderburg mines, and again in the ravine north of Adams Hill, where it attains as great a thickness as on the eastern slope.

Paleontological evidences.—As has already been mentioned, no organic remains have been found in the beds which have been assigned to the Prospect Mountain quartzite. Directly overlying them, however, in strata which may be regarded as transition beds between them and the overlying group, occur the lowest forms obtained in the district. Along the east side of Prospect Peak may be traced for over a mile a red arenaceous shale, which, followed to the northward, may be seen to pass gradually into a dark gray limestone. This formation may be taken at 100 feet in thickness, and from the organic remains which it carries has been designated the *Olenellus* shales. The following new species, as determined by Mr. C. D. Walcott, were obtained: *Acrotreta Prospectensis*, *Olenellus abnormis*, *O. Barrandi*, *O. Iddingsi*, together with an undetermined species of *Conocephalites*. From the association of forms found in these beds, and from their known stratigraphical position at the top of the Prospect Mountain quartzite, and at the base of a conformable series of limestones and shales of Cambrian and Silurian age measuring 9,000 feet in thickness, it seems highly probable that the *Olenellus* shales are not far above the true *Paradoxides* beds. Unfortunately, here at Eureka no sedimentary beds come to the surface below the Prospect Mountain quartzite. In working out the stratigraphy of the Great Basin ranges, a most needed locality is one showing a section of Lower Cambrian rocks and their relations with the Prospect Mountain group. Organic forms closely allied to the above species have been found in two localities in the Great Basin; one in the Highland Range of Western Nevada, and the other in the Oquirrh Range of Utah. In both of these localities they are described as occurring in a similar arenaceous shale, conformably overlying a body of quartzite, the base of which is not exposed; but in neither locality does it appear that the stratigraphical relations of the shales with the beds above have been satisfactorily made out.

At the mining town of Pioche, in the Highland Range, Mr. E. E. Howell obtained two new species of the genus *Olenellus*, which Mr. F. B. Meek described as *O. Gilberti* and *O. Howelli*. According to Mr. Howell they occur in a reddish-yellow arenaceous shale about 400 feet in thickness, and in the published section it is represented as conformably overlaid by a gray limestone, which he regarded as of Carboniferous age, although he found no fossils. If these beds are conformable it would seem highly probable, from the geological exposures at Eureka, that the overlying limestone belongs to the Prospect Mountain group. In the Oquirrh Mountains, the first range west of the Wahsatch, both *O. Gilberti* and *O. Howelli* have been found in a thin bed of shale, conformably overlying a quartzite, above which occur from 3,000 to 4,000 feet of limestone carrying Carboniferous and Lower Carboniferous fossils. Mr. S. F. Emmons, while engaged upon the Geological Exploration of the Fortieth Parallel, examined this range, and shrewdly suggested that there was a fault between the shales and overlying limestones, a structure which would conform more closely with the observed facts brought out at Eureka.

The relationship existing between the two species from Pioche with *O. Vermontana* and *O. Thompsoni* Hall, from the Georgia slates of Vermont, has been clearly pointed out by Meek; while Billings has shown on paleontological grounds, in his catalogue of Silurian fossils of the island of Anticosti, that the horizon of the sandstones and limestones on the north shore of the Gulf of Saint Lawrence, at the Straits of Belle Isle, should be correlated with the beds of northern Vermont. According to him the fauna is quite distinct from that of the Saint John's group below, and is equally well marked from the true Potsdam sandstone of Wisconsin, and he suggested the name of Lower Potsdam for the beds at the Straits of Belle Isle and in Vermont. The succession of the fauna and the stratigraphical position of the conformable beds of the Prospect Mountain limestone rather tend to confirm this view so far as a division of beds is concerned. Wherever in the Great Basin, so far as known to the writer, the genus *Olenellus* has been discovered, the beds do not reach a development of more than 400 feet; at least they pass from shales to limestones, in which as yet no organic forms have been observed. In the report of Mr. C. D. Walcott will be found some observations on certain embryonic features of development, and the relations of the species *O. abnormis* to *Paradoxides*.

At Eureka the *Olenellus* shales pass gradually upward into a great thickness of bluish-gray limestone, with an occasional interstratified band of shale; the beds, however, yielding no organic remains for nearly 500 feet, and then furnishing forms which might belong to both the *Olenellus* shales and the next fossiliferous stratum above.

The best locality for obtaining organic forms from the horizon next above the shale is found at the head of New York Cañon, on the long ridge south of the Fourth of July Mine. Here were obtained the following forms: *Scenella conica*, *Agnostus communis*, *Dicellocephalus quadriceps*, and *Conocephalites Prospectensis*. Of these forms *C. Prospectensis* has not been found at a higher horizon.

Above this horizon the limestone is so metamorphosed and broken up that well-defined beds favorable for the preservation of fossils are rarely met with, and only within 300 or 400 feet of the base of the Secret

Cañon shale, or 2,000 feet higher up in the strata, were there any groupings of fossils obtained. At this last horizon, near the summit of the Prospect Mountain limestone, numerous localities, extending for miles along the side of the ridge, present a fauna with very much the same grouping at each, and strikingly characteristic of the Potsdam of Wisconsin and Minnesota.

The following list contains most of the species obtained at this horizon, many of them, of course, being found at several localities:

Obolella (like *O. pretiosa*).
Lingula manticula.
Kutorgina Whitfieldi.
Orthis Eurekensis.
Stenotheca elongata.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus Richmondensis.
Dicellocephalus quadriceps.
Dicellocephalus expansus.
Dicellocephalus nasutus.
Crepicephalus Gallatinensis.
Crepicephalus Haguei.
Crepicephalus occidentalis.
Conocephalites dissimilis.
Ogygia spinosa.

In a well-defined stratified limestone exposed on the seventh level of the Richmond Mine were obtained the following forms:

Obolella ———.
Lingula manticula.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus Richmondensis.
Crepicephalus Gallatinensis.

The Prospect Mountain limestone carrying these fossils passes by a gradual transition into the Secret Cañon shale, the passage beds being mainly thin interstratified layers of limestone and shale. No fossils have been obtained from the Secret Cañon shale throughout its development, but imperfect fragments more or less obliterated have been observed in several of the more calcareous beds. At the top of this group the calcareous shales come in, which form the base of the Hamburg limestone, and which may be recognized readily all along the line of contact. In places it is well characterized by its grouping of fossils. The following species have been determined from this horizon:

Protospongia fenestrata.
Lingulepis mœra.
Lingulepis minuta.
Lingula manticula.
Iphidea depressa.
Acrotreta gemma.
Kutorgina minutissima.
Hyolithes primordialis.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus seclusus.
Dicellocephalus nasutus.
Dicellocephalus Richmondensis.
Conocephalites pernasutus.
Conocephalites laticeps.
Conocephalites bellus.
Conocephalites Linnarssoni.
Crepicephalus Gallatinensis.
Crepicephalus Haguei.
Crepicephalus similis.
Crepicephalus unisulcatus.
Crepicephalus læviceps.
Chariocephalus tumifrons.
Ogygia problematica.

After leaving the calcareous shales, at the base of the Hamburg limestone, the next fossil horizon which has been recognized occurs in the overlying shales of the same group, and in thin interlaminated limestones in the overlying Hamburg shale.

This horizon has yielded the following forms:

Lingulepis mæra.
Lingulepis minuta.
Lingula manticula.
Obolella discoidea.
Acrotreta gemma.
Kutorgina minutissima.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus prolongus.
Agnostus tumidosus.
Agnostus tumifrons.
Dicellocephalus nasutus.
Dicellocephalus angustifrons.
Dicellocephalus marica.
Dicellocephalus bilobatus.
Dicellocephalus Osceola.
Crepicephalus affinis.
Crepicephalus Gallatinensis.
Crepicephalus Haguei.
Crepicephalus granulosus.
Crepicephalus simulatus.
Crepicephalus unisulcatus.
Conocephalites breviceps.
Arethusina Americana.
Ptychaspis minuta.

By comparing these lists of fossils, it will be seen that in this group at the top of the Hamburg limestone are found seven species which first occur at the top of the Prospect Mountain limestone. They pass up through the beds at the base of the Hamburg limestone, and, together with five additional species obtained for the first time from the latter horizon, come up to the top of the epoch; making in all twelve species common to the top and bottom of the Hamburg limestone. Three species obtained from either the base or summit of the epoch are identical with forms from the Potsdam sandstone of Wisconsin—*Hyolithes primordialis*, *Dicellocephalus Osceola*, and *Ptychaspis minuta;* and another, *Lingula manticula*, first described by Dr. C. A. White, from the Schell Creek Mountains, has here at Eureka a wide range, extending from the Prospect Mountain limestone well up into the overlying Pogonip group of the Silurian. From the Pogonip group of Montana the late Mr. F. B. Meek first described the widely distributed Eureka form, *Crepicephalus Gallatinensis*, which is common to both Cambrian and Silurian beds.

SILURIAN ROCKS.

Rocks of this period have been subdivided into three epochs, corresponding with the character of their sediments, two heavy masses of limestone, with a sharply defined intervening body of quartzite. They have been designated as follows: First, the Pogonip limestone; second, Eureka quartzite; third, Lone Mountain limestone. The Pogonip limestone and Eureka quartzite occur all along the east base of Prospect Ridge, with abundant evidence of their conformable position over the Cambrian rocks; while in the Fish Creek Mountains evidence from organic remains is ample to correlate the underlying limestone, which forms so large a part of the mountains, with the Pogonip of Prospect Ridge, and to show the structural relations of the three subdivisions.

Pogonip limestone.—The name used to designate this epoch is taken from Pogonip Mountain, at White Pine, where the horizon is remarkably well developed and of much greater thickness than at Eureka. In the Fish Creek Mountains the beds lie inclined at so low an angle that there is only between 800 and 1,000 feet exposed. East of Prospect Ridge the best observed exposure attains a thickness of 2,700 feet, and is the one adopted in the general section, although the entire group probably presents a greater development in the region of the granite-porphyry dike. At the base of the series occur interstratified beds of bluish-gray limestone, argillites, and fine-grained arenaceous beds, all the strata having more or less of a siliceous character, passing gradually up into purer limestones. The limestone has a bluish-gray color, but near the top has a darker tint, in places becoming almost black. It differs from both the Prospect Mountain and Hamburg limestone bodies in having a distinctly bedded structure and a smoother weathered surface.

Throughout the entire thickness of Pogonip beds organic remains characterize the epoch. The argillaceous beds of the Hamburg shale pass gradually into the conformably overlying Pogonip limestone, the relations of the two groups being as well seen as anywhere at the base of the ridge east of the Hamburg Mine. Here there is a decided mingling of species, a number of primordial forms extending for some distance into the limestone. Passing upward, however, there rapidly comes in a numerous fauna, representing higher and higher forms until near the top of the series the grouping indicates a horizon which is probably the equivalent of the Chazy period of New York, with forms characteristic of the Trenton. In the collections made from the Pogonip beds at Eureka there are over seventy species, and as many of them are new to science, and the descriptions have not yet been published, it seems best not to publish any extended list at this time.

The following list of fifteen species comprises all those forms which have been recognized as common to the Cambrian period and Pogonip epoch:

Lingulepis mæra.
Lingulepis minuta.
Lingula manticula.
Obolella discoidea.
Acrotreta gemma.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Crepicephalus affinis.
Crepicephalus Gallatinensis.
Crepicephalus granulosus.
Crepicephalus Haguei.
Crepicephalus unisulcatus.
Arethusina Americana.

Many of these species have a wide vertical range, extending downward to the base of the Secret Cañon shale.

Only one species of the genus *Dicellocephalus* has been found as yet in the Pogonip group at Eureka, and that one, *D. finalis*, does not apparently occur at the base. Of the genus *Dicellocephalus* only two species have as yet been reported from the Pogonip beds at White Pine, *D. quadriceps* and *D. flabellifer;* the former occurring as low down as the Prospect Mountain limestone, while the latter has not been recognized at Eureka. Midway in the Pogonip group all the Cambrian genera have disappeared with the exception of *Orthis* and *Illænus*, and the genera *Receptaculites*, *Chætetes*, *Pleurotomaria*, *Maclurea*, *Bathyurus*, *Asaphus*, and *Cyphaspis*, mark a decided change in the fauna from the Cambrian types. Many of these genera gradually give way and are replaced by others characteristic of still higher horizons. From 500 to 600 feet below the Eureka quartzite the association of genera is as follows: *Receptaculites*, *Chætetes*, *Strophomena*, *Tellinomya*, *Modiolopsis*, *Maclurea*, *Cyrtolites*, *Orthoceras*, *Endoceras*, *Leperditia*, *Beyrichia*, *Amphion*, *Ceraurus*, *Illænus*, *Asaphus*, *Ptilodictya*.

Among the fossils collected from this horizon occur several Trenton species which are of special interest on account of their association and geological position, viz: *Orthis tricenaria*, *O. testudinaria*, *Orthis perveta*, *Tellinomya contracta*, and two species of the genus *Modiolopsis*, both closely allied to Trenton forms. The genus *Receptaculites* is marked by the presence of three species, and an immense number of specimens of one of them, *R. mammillaris* Newberry, occurs in the upper portion of the Pogonip limestone. They are found throughout the beds with a vertical range of several hundred feet and are abundant when all other fossils are wholly wanting. In the Pogonip epoch at Eureka, the *Graptolites*, as yet, are represented by a single undetermined species. Besides the great development of Pogonip limestone at Eureka and White Pine, the horizon occurs at many other localities in the Great Basin, among them the Schell Creek Range of Eastern Nevada and the House Range of Western Utah. At Pahranagat the upper beds of the Pogonip are evidently present, with organic forms represented by the genera *Receptaculites* and *Strophomena* and below the horizon from which these fossils were obtained lies a development of 1,000 feet of massive siliceous limestone underlaid by black limestone, in which no fossils have as yet been found.

Eureka quartzite.—The name of the district has been applied to designate this epoch, as it is so well developed at Eureka and its geological position so clearly defined. It rests directly upon the Pogonip limestone, and where the upper beds of the latter group are exposed they are generally capped by a greater or less thickness of the former group. The Eureka quartzite is made up almost exclusively of siliceous grains firmly compacted together, with a more or less granular texture and a vitreous luster. At the base of the series it is colored slightly by iron, but higher up it is white with an occasional bluish tinge. Although the formation is probably not more than a few hundred feet in thickness it can be estimated only approximately, as an uncomformity exists between the quartzite and the next overlying group. Under any circumstances, however, the formation would be difficult to measure, inasmuch as over the greater part of the area occupied by the quartzite stratification lines are wanting, and the beds are frequently broken up by a succession of small faults hard to recognize, and the amount of displacement still more difficult to estimate.

The best estimates place the thickness of the beds at 500 feet. No fossils have been obtained from this horizon.

Lone Mountain limestone.—Next above the quartzite comes a heavy body of Silurian limestone which takes its name from a bold isolated mountain which rises out of the plain a short distance to the northwest of the Eureka District, where it is seen in its full development better than in the immediate area of the map. As an unconformity exists between the two formations there is of course no direct evidence of the thickness of the limestone body. The average thickness of beds exposed has been taken at 1,800 feet. At Lone Mountain the beds attain a somewhat greater development, and the probability is that this estimate is rather under than over the true measurement. The lowest beds in the series are a black gritty limestone usually without bedding, and so altered as to have obliterated all traces of organic remains. Ascending in the strata the beds pass up into dark bluish-gray limestone, which in one locality, at the southern base of Comb's Peak, has yielded a small lot of fragmentary and poorly preserved fossils. They are of special interest, however, as filling a most important gap in the geological section, and the list is here given in full; most of the specimens being too poor for specific identification. *Asaphus gigas*, *Orthis?* (like *O. plicatella*), *Trinucleus concentricus*, *Leptæna sericea*, with representatives of the genera *Illænus*, *Streptelasma*, *Ceraurus*, *Orthoceras*, *Cytoceras*, *Chætetes*. Above this characteristic Trenton grouping the beds pass gradually into light gray siliceous limestone with a peculiar saccharoidal texture, in places becoming almost white and wholly without bedding. Rock of this character makes up the greater part of the epoch, and then by imperceptible changes becomes darker in color with more and more tendency to develop planes of bedding, and gradually passes into the overlying limestone of the Devonian period. The upper portion of the Silurian limestone presents a most forbidding aspect for the preservation of organic remains, and though diligent search was made throughout the horizon it was only rewarded by finding a few imperfect corals of the genus *Halysites*, which is so characteristic of the Niagara of the East, and here found in what should be its true geological position.

DEVONIAN ROCKS.

By imperceptible gradations limestones of the Lone Mountain epoch pass over into beds of the Devonian period, and as no definite horizon separating them has been determined, no accurate measurements of their respective thicknesses can be given. Devonian rocks cover a far larger area in the district than those of any other period; they are much more widely distributed, and present a thickness greater than either the Cambrian or Silurian. Only two subdivisions of the Devonian as yet have been made; first, Nevada limestone; second, White Pine shale, although taken together they have a thickness of about 8,000 feet.

Nevada limestone.—The name selected to designate this horizon is taken from the name of the State, where the epoch is well represented by a great development of beds, and the only State or Territory in the Great Basin where it has been recognized as attaining any great thickness, or its limits and geological relations studied. As the designation of the epoch would suggest, the beds throughout the entire series are mainly composed of limestone, although intercalated beds of shale and quartzite occur. The transition in the limestone from characteristic Silurian to unquestionable Devonian strata is so imperceptible that the boundary line between them is a purely arbitrary one, with poorly defined lithological distinctions, and without, as yet, any paleontological evidence. The two limestone horizons taken together measure nearly 8,000 feet in their broadest development. It is known that characteristic Lone Mountain beds extend for at least 1,500 feet above the Eureka quartzite, and that beds easily identified by their organic remains carry Devonian horizons down about 6,000 feet below the Diamond Peak quartzite of Carboniferous age. The district affords many continuous and overlapping sections, exposing from 3,000 to 4,000 feet of rock; the longest continuous section is estimated at 5,400 feet. In general, the lower strata are indistinctly bedded, highly siliceous, and gray in color, passing up into brown, reddish-brown, and gray beds, which are distinctly stratified, and frequently banded, producing a somewhat variegated appearance. In the upper portions the limestones are more massive, usually well bedded, and possess a normal bluish-black color. The intercalated bands of shale and quartzite vary greatly in width, but do not especially characterize any portion of the horizon.

As already mentioned, no subdivisions in this epoch have been made, although the groupings of fossils at the base and those at the top show a very considerable difference in their fauna, but the mingling of species throughout the beds has rendered it difficult to draw any sharp horizon. Neither paleontology nor geology as yet furnish sufficient evidence for drawing a sharp line, and the sediments are too uniform to afford any great change in the character of the beds. At no distant day, when the epoch becomes better studied, it may be quite possible and even desirable that such a division should be made; at present, however, it will be quite sufficient to speak in general terms of an upper and lower horizon. The Nevada limestone has yielded an exceedingly rich and well-preserved fauna; certainly no epoch in the Great Basin can surpass it in general interest. It has furnished already over one hundred and fifty species, of which one-fourth will be described for the first time in the forthcoming report; while, what is of great interest as regards geographical distribution, over one-half of them are specifically identical with Devonian forms from New York State. The Upper Helderberg, Hamilton, and Chemung are all well represented so far as species are concerned, although the vertical range of certain species by no means agrees with the limits assigned to them in New York State. Ten species not known in New York are common to both Nevada and Iowa, thus emphasizing the relations between the formations of the Cordillera, the Mississippi Valley, and the Appalachians. In the collections from Eureka occur two species, *Orthis MacFarleni* and *Rhynchonella castanea*, from the Mackenzie River Basin, first described by Mr. F. B. Meek in the Transactions of the Chicago Academy of Sciences. Both of these marked species were brought to this country by the late Mr. Robert Kinnicut, and were found associated together on the Lockhart River, a tributary of the Mackenzie, in latitude 67° 15′ north, longitude 126° west, while the *Orthis* was also obtained in a very similar limestone 40 miles below Fort Good Hope on the Mackenzie. According to Mr. A. K. Isbister, who traveled extensively in Northern British America, along the base of the Rocky Mountains, and who published a sketch map of its geology, the Devonian extends along the valley of the Mackenzie from its mouth southward for 15° of latitude, nearly, if not quite to the headwaters of the Saskatchewan River. It certainly is of considerable interest to find these two species, which occur together in the Arctic regions, associated at Eureka in the same bed in the lower horizons of the Devonian, near Woodpecker's Peak, while *R. castanea* was also obtained from the upper horizons at Rescue Hill.

While the fauna at Eureka is rich and varied, not only in genera and species, but also in classes, remains of Devonian fishes appear to be restricted to a single ctenacanthus-like tooth. Mr. S. F. Emmons, while engaged on the Fortieth Parallel Exploration, brought in a small tooth of the genus *Cladodus* from the western entrance to Emigrant Cañon, in the Tucubit Mountains, north of the Humboldt River. These two single specimens, collected at widely separated points, are all that is known of Devonian fishes from Central Nevada, although from Northern Arizona, in the Kanab Cañon, Mr. C. D. Walcott obtained abundant evidence of the presence of placoganoid fishes from Devonian beds which were represented by only 100 feet of strata as against 8,000 feet in Nevada.

At Eureka, above the light-gray highly altered strata which carry the *Halysites*, and somewhere near the base of the Nevada limestone, the beds begin to yield *Spirifera*, *Edmondia*, *Stromatopora*, and *Atrypa reticularis*, which, although not specially characteristic, have a wide vertical range extending well up into Nevada limestone. Above this occurs a shale band, well marked lithologically, and situated about 2,000 feet from the base of the Silurian. It has been recognized at Comb's Mountain, Atrypa Peak, Brush Peak, and several other localities, and always carries the same rich fauna of the lower horizons. Passing upwards in the series many beds furnish additional material, with always a grouping which in general indicates a rise in the geological section. The upper portion of the epoch represents as equally varied although not so complete a fauna as the lower horizons. So far as they have been studied the extreme upper and lower horizons furnish quite characteristic faunas, with perhaps twenty species which may be considered as common throughout the Nevada limestone.

Among species common to upper and lower horizons may be mentioned the following:

Stromatopora ——— ?
Syringopora perelegans.
Streptorhynchus Chemungensis.
Orthis Tulliensis.
Strophodonata perplana.
Chonetes scitula.
Productus Hallianus.
Productus Shumardianus.
Productus subaculeatus.
Spirifera piñonensis.
Spirifera maia.
Spirifera subumbona.
Atrypa reticularis.
Rhynchonella castanea.
Paracyclas occidentalis.
Styliola fissurella.

White Pine shale.—Conformably overlying the Nevada limestone occurs a heavy body of black shale which has been designated as above, it having been first recognized as a distinct horizon in the White Pine mining district. At Eureka the White Pine shale is best observed east of Newark Mountain, where it forms the entire rock-mass through which Hayes Cañon has been eroded, and where its geological relations with the underlying Nevada limestone and overlying Diamond Peak quartzite may be made out. The group attains its greatest development east of Silverado and Sentinel Peak, but as it is cut off by a fault from the Nevada limestone its geological relations are not as clearly shown as at the first locality. The thickness may be placed at 2,000 feet. A marked feature of the group is the rapid changes which it undergoes both in its lateral and vertical extension, passing quickly from pure argillaceous black shales into beds more or less arenaceous and frequently carrying intercalated beds of red friable sandstone appearing as lenticular masses in the shale. Cross-sections made at any great distance apart differ widely, the epoch everywhere indicating a shallow water deposit. Plant impressions, which are exceedingly rare in Paleozoic rocks of the Great Basin, form a feature of this epoch, although everything which has been collected is of an exceedingly fragmentary character. They consist of a species of *Psilophyton* preserved between beds of sandstone, a number of obscure impressions of *Cordaites*, and a few fragments of fucoidal remains.

Invertebrate remains in general appear very poorly preserved, so that specific determinations are, in most instances, out of the question. From the lower beds there were obtained an *Aviculopecten*, and a large species of *Goniatite*, while the upper and rather more sandy beds have furnished a more varied material, in which the facies is Devonian, with a foreshadowing of the Carboniferous period; among which are found *Fenestella*, *Orthis*, *Chonetes*, *Sanguinolites*, *Cypricardina*, *Goniatites*.

Unconformity at base of Lone Mountain limestone.—Upper Silurian and Devonian sediments appear to be wanting over large areas of the Great Basin. Many ranges in their geological structure present blocks formed exclusively of Carboniferous rocks, or else the Pogonip of the Lower Silurian directly overlaid by Carboniferous limestones, the intervening horizons, which here at Eureka measure nearly 10,000 feet in thickness, being entirely unrepresented. Sediments of Devonian age, although restricted in area, nevertheless play a very important part in the ranges which rib the central part of the Nevada Plateau. To the northward, as already mentioned, they have been recognized in the Tucubit Mountains; they make up the greater part of the Roberts Peak Mountains, where they probably overlie a considerable development of the Lone Mountain limestone; and the writer has traced them all along the Piñon Range connecting directly with the grand exposures in the Eureka District. To the southeast of Eureka they are well developed in Treasure and Babylon Hills at White Pine.

An interesting fact as regards the position of these rocks is this: Notwithstanding the enormous thickness of Upper Silurian and Devonian beds at Eureka, the same stratigraphical relations which exist in so many places in the Great Basin between the Carboniferous and the underlying Pogonip of the Lower Silurian may be seen here, the Upper Silurian and Devonian being absent. This structure is seen along the east base of Prospect Ridge, where a profound displacement brings the Carboniferous up against the Lower Silurian, organic forms characteristic of the two horizons being found within a few hundred yards of each other, the intervening space being occupied mainly by igneous extrusions. Within the area of the district, however, the Carboniferous strata are seen to directly overlie Devonian shales and limestone, and the latter lie conformably superimposed upon the Upper Silurian, which in turn rests, although unconformably, upon the Eureka quartzite of the Silurian.

CARBONIFEROUS ROCKS.

Although rocks of this period cover large areas, and make up the greater part of many mountain uplifts in the Great Basin, few localities afford better exposures of all the epochs than that portion of the Diamond Range which lies within the Eureka survey. To the northwest and eastward Carboniferous rocks present a greater thickness of strata than is shown here, but in most cases single monoclinal ridges fail to expose in any continuous section the entire series of rocks from base to summit. At Eureka they have been estimated to measure 9,300 feet in thickness, which, however, does not represent the full development of the Carboniferous, as the Upper Coal-measures, the top of the Paleozoic system, have suffered a very considerable amount of erosion. The Carboniferous rocks have been subdivided into four epochs: first, Diamond Peak quartzite; second, Lower Coal-measure limestone; third, Weber conglomerate; fourth, Upper Coal-measure limestone.

Diamond Peak quartzite.—This epoch, the base of the series, takes its name from Diamond Peak, where it is exposed on both flanks of the peak, dipping into the mountain with a synclinal structure. On the west side of the peak, where it attains the greatest expansion, it measures 3,000 feet in thickness. At the base of the horizon conglomerates firmly cemented together lie next the argillaceous shales of the White Pine epoch, but quickly give place to a more massive, uniformly vitreous quartzite, with a characteristic grayish-brown color, and breaking with an irregular flinty fracture. Near the summit the beds pass into thinly laminated green and brown schists and shales. The Carboniferous age of the epoch is determined by a narrow belt of blue limestone, which occurs interstratified in the quartzite about 500 feet above the base of the series, and which yielded *Productus semireticulatus*.

Lower Coal-measure limestone.—Beds of this epoch are found in a great number of ranges in Utah and Nevada, and the horizon has probably been as well studied as any other in the Great Basin. In their lithological character they do not differ essentially from the same beds elsewhere, except perhaps at their base, where they carry intercalated beds of chert, argillite, and gritty, pebbly limestone, with evidences of shallow water deposits. They pass rapidly, however, into gray and dark blue, purer limestone, distinctly stratified at varying intervals. They only measure about 3,800 feet in thickness, which is much less than is usually assigned to the same horizon in other localities. As the limestones are, in general, favorable for the preservation of organic forms, fossil-bearing horizons are found throughout the epoch, and geologists are not so dependent upon favored localities as among Lower Paleozoic rocks. About eighty species of fossils have been collected from this epoch, but most of those obtained from the upper and middle portions have already been recognized as occurring in the Lower Coal-measures of the Great Basin. At the base of the limestone the fauna is more varied, and presents more that is of geological interest. One of the most striking features of this grouping is the occurrence of a large number of species of lamellibranchiate shells, a class which heretofore has been but sparingly represented in the collections of Carboniferous fossils from Utah and Nevada, and one that shows the relations between the Coal-measures and Lower Carboniferous fauna. Prof. R. P. Whitfield and Dr. C. A. White have frequently called attention to the commingling of species in New Mexico, Colorado, and Utah, which in the Mississippi Valley have been considered as distinctly characteristic of the Coal-measures and Lower Carboniferous periods; but so far as known to the writer, in no locality in the Great Basin is this commingling of types more clearly shown than at Eureka.

On the west slope of Spring Hill, and just to the east of the Secret Cañon road, a belt of arenaceous limestone yielded over forty species, one-third of which are considered by Mr. Walcott, who has made the group a special study, as identical with species found in the Mississippi Valley in Lower Carboniferous rocks, while nearly all of them might occur at this horizon. Among genera from this locality may be mentioned *Orthis*, *Pinna*, *Modiomorpha*, *Nucula*, *Grammysia*, six species of *Sanguinolites*, and five species of *Aviculopecten*, associated with such Coal-measure forms as:

Chonetes Verneuiliana.	*Schizodus cuneatus.*
Athyris subtilita.	*Euomphalus subrugosus.*

Below this horizon occurs a well-defined bed, carrying characteristic Coal-measure species with those forms left out which would be regarded as belonging to the Lower Carboniferous epoch. From this bed were obtained:

Fenestella—sp.?	*Productus Prattenianus.*
Streptorhynchus crenistria.	*Productus semireticulatus.*
Chonetes granulifera.	*Spirifera camerata.*
Phillipsia—sp.?	*Rhynchonella Eurekensis.*

A second section across the Carboniferous limestones, two and one-half miles to the northward, behind the Richmond Smelting Works, presents much the same succession of beds; at the base a fauna mainly composed of Coal-measure types, followed higher up in the series by a grouping which would suggest both a Lower Carboniferous and a Coal-measure horizon.

As the term Lower Coal-measures has been employed by most geologists to designate this epoch throughout the Great Basin, where it is widely distributed from the Wahsatch Range to the Battle Mountains, it has been thought best to retain the name here, although by no means applicable, as the epoch includes such a commingling of species from the two horizons that a separation of the beds seems quite impossible. Moreover the distinctions which hold good in the Mississippi Valley are by no means applicable to the Cordillera.

Weber conglomerate.—Conformably overlying the Lower Coal-measures comes the Weber conglomerate, a heavy body of coarse and fine material mainly made up of angular fragments of quartz, red, brown, and green jasper and chert firmly held together by a siliceous cement. It carries interstratified in the coarser beds fine yellowish-white sandstone, which is used as a lining for the furnaces in the smelting works at Eureka, and near the top of the series occurs a belt of blue limestone. The beds have a thickness estimated at 2,000 feet. They are well shown in long parallel ridges inclined at high angles, with a synclinal followed by an anticlinal fold; and although no fossils have been found, the geological position of the beds is well determined by the underlying and overlying limestones. Moreover they may be easily correlated with the Weber conglomerate of Northern Nevada.

Upper Coal-measure limestone.—In the northern portions of the State of Nevada the upper members of the Paleozoic system attain a development of nearly 2,000 feet. In the Eureka District, however, they present a thickness of only 500 feet, the overlying beds either having suffered removal by denudation or else lie concealed beneath flows of igneous rocks. They may be seen directly to overlie the Weber conglomerate, inclined to the westward at a high angle, until cut off by the great body of basalt which forms the mass of Basalt Peak and the Strahlenberg.

To the northward the Upper Coal-measure limestone covers a considerable area along the base of Diamond Peak, inclined at a low angle; but as the slope of the ridges closely coincides with the inclination of the strata, the exposures never exceed the thickness mentioned. In the field the Upper Coal-measures may be distinguished readily from the Lower Coal-measures by their lighter colors and the greater prevalence of fine-grained beds of drab limestone.

The horizon has not yielded as large a number of species as the Lower Coal-measures, and many of the forms found in the middle and upper beds of the latter epoch are common to the Upper Coal-measures and are such as are known to occur throughout the Great Basin during Carboniferous times.

The following species, obtained from the Upper Coal-measures, were not observed in the Lower Coal-measures:

Zaphrentis—sp. ?	*Ptilodictya carbonaria.*
Polypora—sp. ?	*Ptilodictya serrata.*
Orthis Pecosi.	*Productus punctatus.*
Retzia mormoni.	*Macrodon tenuistriata.*
Myalina subquadrata.	*Pleurotomaria*—sp. ?

The Wahsatch and Kanab sections.—The Wahsatch Range, which shuts in the Great Basin on the east, combines, in amarked manner, many of the geological characters of both the Rocky Mountains and the Basin Ranges. In structure, however, it is closely related in its essential features to the ranges of Utah and Nevada. There is exposed in the range a very remarkable section of conformable beds extending through 30,000 feet of sediments and exhibiting all the periods of the Paleozoic from the Lower Cambrian to the Permian. For the purpose of comparison a section constructed by the Geological Exploration of the Fortieth Parallel is reproduced, as it shows not only certain resemblances, but also striking differences in the sequence of beds from the section as exposed at Eureka:

Wahsatch section, Utah; 30,000 feet; conformable.

PERMIAN, 650 feet	Permian	650	Clays, marls, and limestones; shallow.
CARBONIFEROUS, 1,400 feet.	Upper coal-measure limestone	2,000	Blue and drab limestones; passing into sandstones.
	Weber quartzite	6,000	Compact sandstone and quartzite; often reddish; intercalations of lime, argillites, and conglomerate.
	Lower coal-measure limestone; Waverly } Wahsatch limestone.	7,400	Heavy-bedded blue and gray limestone, darker near the base, with siliceous admixture, especially near the top.
DEVONIAN, 2,400 feet.	Nevada limestone } Wahsatch limestone.		
	Ogden quartzite	1,000	Pure quartzite, with conglomerate.
SILURIAN, 1,000 feet	Ute limestone	1,000	Compact, or shaly, siliceous limestone.
CAMBRIAN, 12,000 feet	Cambrian	12,000	Siliceous schists and slates, quartzites.

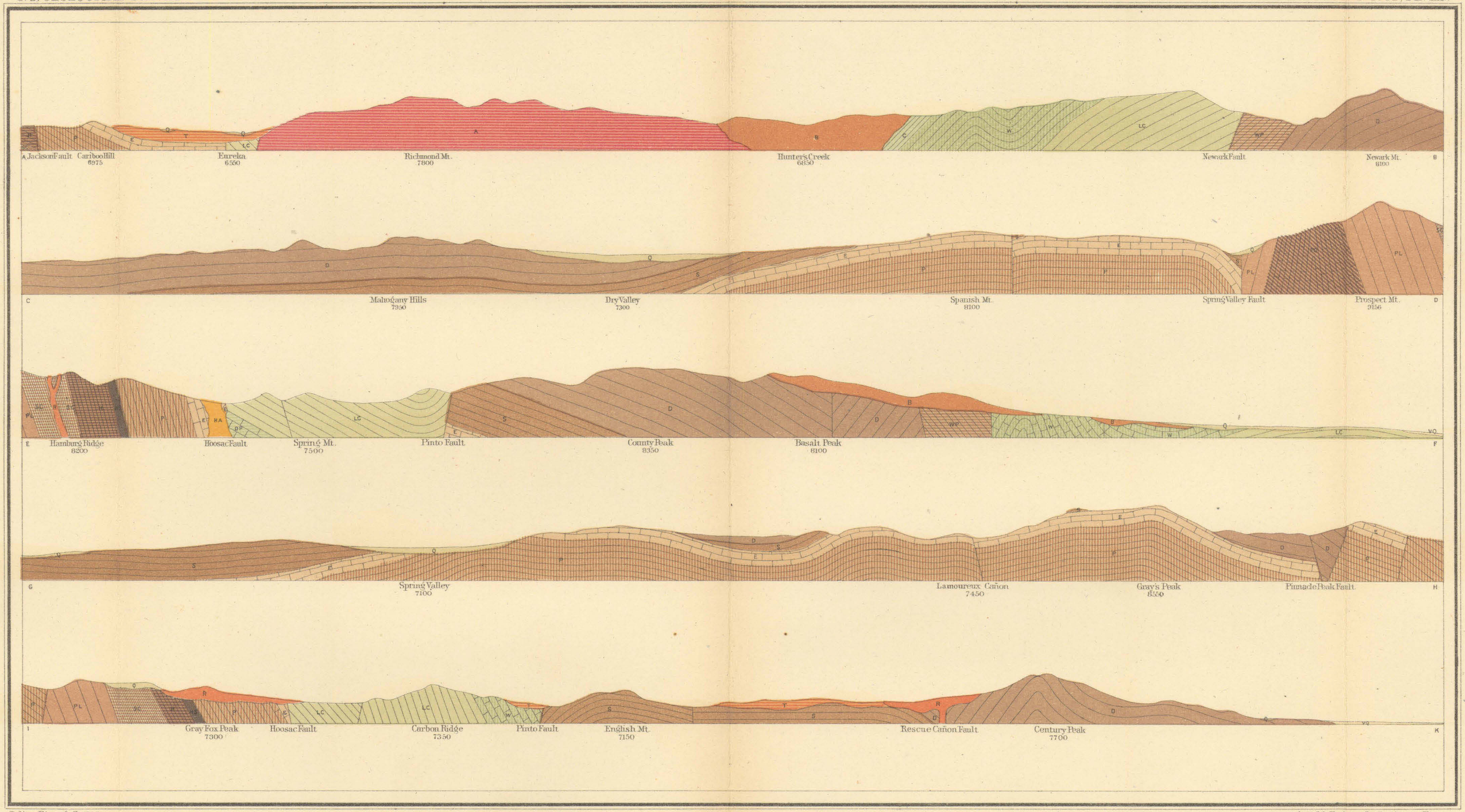
In the Wahsatch section the 12,000 feet of metamorphosed schists, slates, and quartzites, probably occur below the Cambrian beds as exposed at Eureka, except so far as they may be represented in the upper members by the Prospect Mountain quartzite, while the great thickness of Cambrian limestones and shales of the Eureka section is included within the 1,000 feet of Ute limestone in the former section. Again, at Eureka the Permian at the top of the section is wholly wanting; and the Upper Coal-measures, which in other parts of Nevada attain a development of nearly 2,000 feet, the thickness which has generally been assigned to them in the Wahsatch, are limited to 500 feet. It will be seen, therefore, that the upper and lower portions of the section as exposed in the Wahsatch, on the edge of the Great Basin, are wanting in the Nevada section. Taking out the 12,000 feet of Cambrian at the base, and 2,000 feet of Permian and Upper Coal-measures from the summit of the Wahsatch sections, there remain 16,000 feet of strata, which, from the base of the Prospect Mountain limestone to the top of the series, are represented in the Eureka section by the enormous development of 28,500 feet of sediments.

In the Kanab Valley of the Lower Colorado in the Plateau Province, Mr. C. D. Walcott has made a section (published in the American Journal of Science, September, 1880), which presents 5,000 feet of beds from the Cambrian to the Permian inclusive, and which is republished here, as it offers so much that is of interest in the study of the Paleozoic section of the Cordillera:

Kanab section, Arizona; 5,000 feet; unconformities by erosion.

PERMIAN, 855 feet	Upper Permian	710	Gypsiferous and arenaceous shales and marls with impure shaly limestone at base.
	Lower Permian	145	Same as above, with more massive limestone.
CARBONIFEROUS, 3,260 feet	Upper Aubrey	835	Massive cherty limestone, with gypsiferous arenaceous bed, passing down into calciferous sandrock.
	Lower Aubrey	1,455	Friable, reddish sandstone, passing down into more massive and compact sandstone below. A few fillets of impure limestone intercalated.
	Red Wall limestone	970	Arenaceous and cherty limestone, 235 feet, with massive limestone beneath. Cherty layers coincident with bedding near base.
DEVONIAN, 100 feet	Devonian	100	Sandstone and impure limestone.
CAMBRIAN, 785 feet	Tonto Group	235	Massive mottled limestone, with 50 feet sandstone at base.
		550	Thin-bedded, mottled limestone in massive layers. Green arenaceous and micaceous shales, 100 feet at base.

NOTE.—Planes of unconformity by erosion denoted by double dividing lines.



Julius Bien & Co. Lith.

Arnold Hague, Geologist in Charge

GEOLOGICAL SECTIONS OF EUREKA DISTRICT, NEV.

QUATERNARY: Mountain Quaternary (Q); Valley Quaternary (VQ)

CARBONIFEROUS: Upper Coal Measures (C); Weber Conglomerate (W); Lower Coal Measures (LC); Diamond Pk. Quartzite (DP)

DEVONIAN: White Pine Shale (WP); Nevada Limestone (D)

SILURIAN: Lone Mt. Limestone (S); Eureka Quartzite (E); Pogonip Limestone (P)

CAMBRIAN: Hamburg Shale (HS); Hamburg Limestone (H); Secret Cñ. Shale (SC); Prospect Mt. Limestone (PL); Prospect Mt. Quartzite (PQ)

IGNEOUS: Basalt (B); Rhyolite (R); Pumice and Tufa (T); Augite Andesite (A); Hornblende Andesite (HA)

Base Line of Sections 6000 ft. above sea level

Scale: 3600 ft = 1 inch.

PRE-TERTIARY IGNEOUS ROCKS.

In the Eureka District igneous rocks may be divided into two distinct classes: first, those which were forced upwards into their present position in Pre-Tertiary times; second, those of Tertiary and Post-Tertiary age.

Granite.—Granite, granite-porphyry, and quartz-porphyry represent the former class. They occupy very little area on the surface, and have modified the present topography of the region only to a very limited degree. Between the Sierra Nevada and Wahsatch Ranges there are probably few mountain uplifts other than those made up entirely of volcanic outflows that do not show one or more exposures of granite of greater or less extent. It is found cropping out in the foot-hills below the base of the Paleozoic series, or is seen in low passes through the range, or, as is frequently the case, is associated with the more recent eruptions of volcanic rocks accidentally left uncovered or laid bare by recent erosion.

At Eureka, however, although the mountains form an unusually broad mass, and the beds of the Lower Paleozoic series are exceptionally well exposed, only one obscure outcrop of granite is known. It occurs at the extreme northern end of Prospect Mountain ridge, on the steep south slope of the ravine which separates Ruby Hill from the main ridge. It is so insignificant and so covered with *débris* that it might easily escape attention, especially as it presents no inequalities of surface. This granite is best seen in coming up the ravine from the west, and is exposed just above the path, some miners having cut into it attracted by the red color of the decomposed rock. It extends from the foot-path up to within 50 feet of the top of the hill. The age of this granite is unknown. The Prospect Mountain quartzites, the oldest sedimentary beds in the district, lie in contact with and everywhere dip away from it in irregular, broken masses. Although the granite body upon the surface is limited in extent, and is exposed only by erosion of the quartzites, there is reason to suppose that it represents a much larger mass and has exerted a considerable influence on the geological structure of overlying sedimentary beds. A peculiarity of this granite is the varied texture which it offers over so small an area, presenting, however, a true granitic habit. The essential minerals are quartz, orthoclase, plagioclase, hornblende, and mica, the latter being very abundant. The quartz is grayish-white in color, in irregular pellucid grains. Hornblende is apparently more abundant in the fine than in the coarse-grained varieties.

Quartz-porphyry.—Only two small exposures of quartz-porphyry have been observed, both occurring on Mineral Point, north of Adams Hill, and although separated by limestone it seems probable that below the surface the two bodies are connected. One body immediately northwest of the Bullwhacker Mine occurs as a dike from 300 to 400 feet long, with a dirction north 20° west; the other or larger body, a few hundred yards to the southward, has an east and west direction. Both quartz-porphyry exposures are much decomposed and discolored by oxide of iron. They show, however, orthoclase, quartz, and mica, with characteristic isotropic glass. The feldspars are altered into kaolin with a secondary formation of potash mica. The quartzes carry both liquid and glass inclusions. In the Bullwhacker Mine the porphyry has been cut, and in one place, at least, presents a white rock differing from the surface rock not only in color but by a relatively large amount of quartz grains and by a development of modified cubes of pyrites. The quartz-porphyry differs structurally from the other igneous rocks in the immediate neighborhood, being distinct from granite on the one hand and from rhyolite on the other. No direct evidence of its age is afforded other than that it is later than the Cambrian, as it occurs breaking through lower beds of Pogonip limestone.

Granite-porphyry.—The granite-porphyry forms an irregular body lying between the Fish Creek Mountains and Mahogany Hills in the southwest corner of the district. At its northern end it occurs as an oval-shaped body, one mile and a quarter long by three-quarters of a mile wide. The most interesting portion, however, is its extension southward in an approximately north and south dike over two miles in length with a varying width, the broadest part measuring about 1,000 feet.

Between the surface outlines of the two walls of the dike there is a marked contrast. On the one hand the western wall curves slightly, but it is regular and sharply defined; while on the other hand the eastern side presents a most irregular outline, numerous branch dikes, off-shoots from the parent dike, trending for long distances in nearly parallel lines in a northeast direction. Of these branch dikes the longest has been traced on the surface for nearly two miles, while others may be equally as long, but erosion has failed to remove the overlying limestone. They vary from 50 to 250 feet in width.

By reference to the map the relative position of the dikes, as they were mapped in the field, may be readily seen.

The granite-porphyry, like the quartz-porphyry, breaks through the Pogonip limestone, but offers no other evidence as to its age. Although both sides of the main dike lie in the same formation, the beds have undergone considerable displacement—those to the eastward belonging to a higher horizon than those found on the opposite side. On the east side the beds are a pure crystalline limestone, uniform in texture and bluish-gray in color. The lower beds, on the west side, are darker in color, more siliceous and rich in cherty nodules, characteristics which everywhere define the upper from the lower horizons of the Pogonip limestone.

The chief interest attached to the granite-porphyry lies in the very variable structural differences produced in the erupted material of the dike, differences which are mainly dependent upon the width of the dikes and rapidity of cooling. There are probably few localities in the Great Basin where the results of rapid chilling and crystallization of a granite magma in narrow dikes can be studied to better advantage, or are more worthy of a detailed investigation.

The large oval-shaped area to the north and the broader central portion of the main dike are quite similar rocks, presenting the characteristics of a granite-porphyry, composed of quartz, mica, and orthoclase in Carlsbad twins, with varying proportions of plagioclase and hornblende. The rock is mainly formed of large but ill-defined crystals porphyritically embedded in a groundmass of the same composition, which under the microscope is seen to possess a micrograuitic structure. It is coarse-grained, and everywhere weathers in rounded masses and rough surfaces, disintegrating like many varieties of granites. From the normal type in the central portion of the dike, towards the outer limestone walls, there is a gradual, and at first almost imperceptible, transition to finer-grained rock, with more and more of the porphyritic and less of the granitic structure. At a distance of twenty to fifty feet from the limestone, varying with the width and position of the dike, the rock shows a decidedly porphyritic habit, though the larger crystals are usually still in excess. The quartz is very abundant, and frequently occurs in well-developed dihexahedrons. From here to the limestone contact the change is more rapid, the larger crystals becoming less and less abundant, being replaced by more and more microcrystalline groundmass. Nearly everywhere along the immediate line of contact the rock presents the habit of a quartz-porphyry, made up of a crystalline groundmass with well-developed crystals of quartz and orthoclase. Both the mica and hornblende usually fall off in amount toward the edge of the dike in the more porphyritic rocks; the hornblende being present only in the granitic types. With this change in composition the rock becomes compact in structure and weathers in angular blocks with smooth surfaces, the contact products offering the greatest possible contrasts with the central portions of the dike. Yet, in the wider dikes they can be traced so readily from the one rock into the other that the evidence is clear that they are but different structural developments of the same erupted material. In crossing the dikes one passes within 100 yards from good quartz-porphyry on to normal granite-porphyry, and then on to a rock which cannot be told from many varieties of granite, so that one is forced to believe that the only difference between granite and granite-porphyry, in many cases, is purely one of structure, dependent upon conditions in cooling rather than upon any difference in geological age. As the branch dikes are mostly narrow, the granitic and normal granite-porphyry structures are less fully developed and are frequently wanting; the effects of chilling and rapid cooling from both walls toward the interior producing the types of quartz-porphyry only found along the walls of the broader dike.

A striking feature of the cooling of the magma is seen in the marked tendency of the rock to develop a jointed structure near the line of contact in planes parallel to the walls. Under the microscope the same accessory minerals usually observed in granite have been detected in the granite-porphyry. All thin sections show the rock to be entirely crystalline, without any isotropic glass.

In the middle of the main dike occurs a narrow body of limestone several hundred yards in length, completely enveloped in granite-porphyry, which may be seen penetrating and filling up the irregular outline of limestone. Along the contact the porphyry presents the same phenomena of cooling as seen near the outer walls. The effect of the molten magma upon the adjacent Pogonip limestone seems quite inconsiderable as compared with the effect upon the ejected material by the cooling walls. This is more especially the case along the more regular or western wall. On the east side, numerous off-shoots break through the formation, not only shattering the beds but adding so many new sources of heat that the limestone has become more or less altered and metamorphosed into crystalline marble. This metamorphism, however, extends only a few inches from the dike, the limestone rapidly assuming its normal color and texture.

TERTIARY AND POST-TERTIARY VOLCANIC ROCKS.

In the Eureka District the more recent volcanic eruptions play a far more important part than the granites and porphyries just described. They occur in much grander masses, cover larger areas, and are more widely distributed over the district. While the older igneous rocks have exerted but little influence upon the surface features of the country, the volcanic rocks have greatly modified its topographical outlines, have disturbed and broken up sedimentary formations, and greatly complicated geological structure. Moreover, the volcanic rocks are of special interest from an economic point of view, from their intimate geological connection with the argentiferous lead deposits of the region. It should be understood that the district, like many other volcanic regions of Central Nevada, offers no direct evidence as to the age of the eruptions, as there are no sedimentary formations between Upper Coal-measure limestone and recent Quaternary deposits. From the unquestioned evidence in other parts of the Great Basin of the geological position of identical rocks, it is assumed that they belong to the Tertiary period. There can be but little doubt that the earliest eruptions date as far back as the Miocene epoch, but as to the duration of volcanic activity there is scarcely any evidence. That it occurred at intervals throughout a long period seems probable from the amount of erosion that has taken place, which, though not large, would have required considerable time. There is no evidence to show that volcanic activity may not have extended through Pliocene well on into quite recent Quaternary times.

Nearly every type and many of the varieties of volcanic rock found in the Great Basin, especially upon the Nevada Plateau, have been erupted within the restricted limits of the Eureka District. Indeed, the region furnishes many rocks which may be taken as typical of a broad area of country. On the geological map all volcanic rocks have been classed under the following heads: Hornblende-andesite, augite-andesite, dacite, pumice and tufa, rhyolite, and basalt.

Hornblende-andesite.—Under hornblende-andesites are classed those volcanic rocks of Tertiary age which are composed mainly of plagioclase feldspars and hornblende as essential ingredients. Here, at Eureka, the fresh, unaltered rock is of a light reddish-purple color, wholly crystalline in structure, with well-developed secretions of the two principal minerals, accompanied by varying amounts of magnesian mica. Magnetite, though not especially abundant, appears to be evenly disseminated throughout the groundmass; and quartz, wanting in most varieties, serves as an accessory mineral in certain localities. A characteristic feature of the true hornblende-andesite of the district is the absence of augite. Very little of the hornblende-andesite is perfectly fresh, and most of it has undergone a considerable decomposition, changing the color of the rock to light shades of red and yellow, while portions of it are nearly white. A typical comparatively fresh rock may be seen south of the reservoir in New York Cañon.

Augite-andesite.—Augite-andesites include those Tertiary volcanic rocks which in their geological relations are closely allied to hornblende-andesite, but in which the hornblende is mainly replaced by augite. At Richmond Mountain, Eureka furnishes a locality of augite-andesite, where it is found in the two most typical forms in which it is known to occur. One of them is quite like the rock which has frequently been called augite-trachyte, its texture, fracture, and mode of weathering exhibiting "trachytic habit." It possesses a dark purplish-gray color and a decidedly porphyritic habitus, the white feldspars standing out prominently in the fine-grained groundmass. The other variety possesses the oily, resinous luster which has frequently been described as a characteristic of many augite-andesites. It is a much more compact rock than the first variety, and is always darker in color. In certain hand specimens it approaches basalt in general appearance, although it presents on close examination the structural peculiarities and hackly fracture of andesite. In addition to the essential mineral ingredients which make up the rock, black-bordered hornblende is present in considerable quantity, but the microscope shows that it nowhere enters into the composition of the groundmass. The rock is rich in magnetite evenly disseminated throughout the mass, and mica has been identified in rock from several localities. Under the microscope both varieties are seen to be rich in glass base of a light yellow color, and to carry as accessory minerals zircon and tridymite. Among the feldspars in the Richmond Mountain andesite Mr. Iddings determined the presence of anorthite by its optical properties, which is probably the first time it has been recognized in the volcanic rocks of the Great Basin, although it has since been found in several other localities.

Dacite.—This rock is a variety of andesite rich in secretions of quartz, and may be related in mineral composition and structural habit to both hornblende and augite-andesite. Here, at Eureka, it is associated geologically with the hornblende variety, none being found with the large masses of augite-andesite. All the occurrences are very similar in physical characteristics, presenting a light ash-gray color, a rough, hackly fracture, and a pumice like texture, which relates them closely to certain varieties of rhyolite with which they are occasionally associated. The feldspars are nearly all plagioclase. Together with the large secretions of quartz occur numerous thin laminæ of black mica, in amount greatly in excess of that usually found in hornblende-andesite. Near the entrance to Sierra Cañon occurs a characteristic variety of dacite.

Rhyolite.—In mineral composition rhyolite, in its essential ingredients, bears the same relation to trachyte that dacite does to andesite. While the latter may be regarded as a quartz-andesite, the former is mainly an orthoclase rock rich in quartz. The rhyolites of Eureka, like those of many other regions, present an almost infinite variety of color, texture, and structural peculiarities, but are remarkably uniform in mineral composition and mainly made up of sanidin, plagioclase, quartz, and mica. The sanidin, in nearly all cases, appears as the prevailing feldspar, in well-developed crystals with a vitreous luster. Plagioclase is usually not present in as large individuals as the sanidin, and both macroscopically and microscopically is occasionally entirely wanting. Quartz is very abundant in broken fragments, and varies from colorless pellucid grains to others almost black. From geological considerations, the important areas occupied by the rhyolitic pumices and tufas are distinguished on the map by a separate color from the rhyolites proper, although they are, of course, closely connected rocks. Among the extrusions of rhyolite proper occur two principal varieties, which cover large areas and embrace the greater part of the outbursts, and for the purposes of the present paper may be designated by local names, one the Rescue Cañon rhyolite, the other the Pinto rhyolite. The Rescue Cañon rhyolite, when fresh, has a decidedly reddish tint, not unlike the famous Aberdeen granite of Scotland. It is largely composed of glass base, in which are porphyritically embedded brilliant grains of dark quartz and glassy sanidins, many of them presenting the beautiful opalescent hues frequently observed in Great Basin rhyolites. The Pinto Peak rhyolite is characterized by a much more microcrystalline groundmass than is found in the Rescue Cañon rock. In general, it is much lighter in color and more varied in tints. Augite, hornblende, magnetite, apatite, zircon, and garnet have all been detected by the microscope in the rhyolite of Eureka, brilliant red garnet being recognized by the unaided eye in the light gray pumices.

Basalt.—Basalt is a Tertiary volcanic rock which has for its essential ingredients plagioclase feldspar, augite, and magnetite; olivine, which occurs as a common accompaniment, in varying proportions, of most basalts, is, however, too frequently wanting to be regarded as an essential constituent. Basalt is the most basic of all volcanic products, augite being the prevailing mineral in the typical rock.

The basalt of Eureka presents, for the wide field which it covers and the great number of its extrusions, an exceedingly uniform appearance, and, although a rock rich in glass base, may be regarded as a typical occurrence of large areas in Nevada. It is a fine-grained, compact rock, frequently passing into vesicular forms, with but few macroscopic secretions, and by far the greater part grayish-black in color. Olivine frequently occurs in large grains, and in such quantities as occasionally to modify the external character of the rock, yet over large areas it is wholly wanting, the microscope failing to detect its presence in many thin sections examined. A curious accidental mineral to be seen in a number of specimens of the basalt is quartz, which always occurs in macroscopic grains, doubtless of primary origin. In one of these quartz grains a liquid inclusion with gas bubble may be recognized, the latter disappearing upon application of moderate heat, showing the presence of carbonic acid.

Mode of occurrence of volcanic rocks.—In the Eureka District there are no central volcanic vents through which the greater part of the ejected material has poured forth. Indeed, one of the most marked features in the distribution of volcanic products is that their ejection occurs either along great meridional lines of faulting, or else bordering and intimately associated with large uplifted blocks of sedimentary strata. The two main sources through which igneous material has reached the surface are the two great lines of displacement—the Hoosac and Pinto faults. As already mentioned, these two faults lie respectively on the west and east sides of the depressed block of Carboniferous limestone, extending in approximately north and south lines across the Eureka Mountains. Along the Hoosac fault, from New York Cañon southward, one continuous body of volcanic material has been ejected; while along the Pinto fault from the extreme northern end at Richmond Mountain southward to South Gate the line of fault is concealed by overflows of lava, except for a short distance northeast of Dome Mountain, where the displacement of strata is sharply defined by the Carboniferous strata lying against Silurian beds. By reference to the map it will be seen readily that the Carboniferous limestone block is surrounded or hemmed in on nearly all sides by extrusions of Tertiary lava. Both Rescue and Sierra Cañons mark lines of meridional faults along which volcanic lavas have reached the surface.

The tendency in volcanic rocks to break out along lines of displacement is seen in the way they almost completely encircle the uplifted block which forms the Silverado and County Peak group. On the west occurs the lavas of the Pinto fault; on the north the broad mass of augite-andesite of Richmond Mountain, which, to the southeastward, unites with extended masses of basalt; on the south are basalts and rhyolitic pumices, connecting directly with the rhyolites of Rescue Cañon on the east. Along the entire border of this enormous block of uplifted strata only two localities occur where volcanic activity has not taken place; one the locality already mentioned, east of Dome Mountain, along the Pinto fault, the other along the line of faulting which brings the White Pine shale up against the Nevada limestone, east of Sentinel Peak.

One of the most interesting features connected with the geological position and mode of occurrence of these lavas is their distribution with relation to the Pinto fault. All the many outbursts of hornblende-andesite and the closely related dacite have been erupted to the westward of this fault, while the mass of augite-andesite and the broad fields and numerous small extrusions of basalt invariably occur either along the Pinto fault or to the eastward of it. When, however, the orthoclase rocks are considered, no such division is observed, but they are found irregularly scattered about without much recognized order, so far as geographical distribution or the preëxisting structural features of the country are concerned. Another feature in the mode of occurrence of the volcanic rocks which deserves mention is the great number of individual outbursts, and the limited areas which they cover. There are, especially among the acidic types, few extended flows emanating from some central source; but, on the contrary, numerous local extrusions, which are quite independent on the surface from neighboring masses of lava.

Relative age of volcanic rocks.—The Eureka District affords no direct evidence as to the relative age of the hornblende-andesite and augite-andesite eruptions, as they nowhere occur together superimposed one upon the other, or with dikes of a later rock breaking through an earlier body. The main bodies of hornblende-andesite and augite-andesite are, as regards their geological position, quite distinct. Although no direct superposition is seen here, all indirect evidences point so strongly to the true order of succession of the two rocks that the proof seems all but conclusive that the same sequence exists as observed in other parts of the State, where, wherever the rocks occur together and their geological relations can be determined, hornblende-andesite appears as the older body. Typical hornblende-andesite, wherever it occurs in the district, is a highly crystalline rock, and forms a central body, which, by insensible transitions, passes into a rock with a more and more glassy base until it becomes a characteristic andesitic pearlite. These andesitic pearlites form a very considerable portion of the rocks designated on the map as hornblende-andesite, but the transition from the one into the other is so gradual that a dividing line could only be drawn with great difficulty, and even then such a division would be more or less arbitrary. Moreover, there seems no good reason why they should be separated, inasmuch as geologically they form one body, and present the same mode of occurrence.

Both macroscopically and microscopically they possess many features in common, with, of course, such distinctions in physical habit as always exists between a rock that exhibits a purely crystalline groundmass and one that is made up largely of glass base, the extreme types varying very considerably. There exists, however, one marked difference in mineral composition between the two extremes of the rock, and one not without considerable geological significance. In the crystalline hornblende-andesite, as already mentioned, no augite has been detected; but the andesitic pearlites, on the contrary, carry considerable augite, and in one or two places over restricted areas, among which may be mentioned the locality south of Carbon Ridge, the hornblende is very largely replaced by augite. This replacement produces a rock which strongly resembles augite-andesite, not only in composition but in microscopic structure, and although these occurrences present certain points of difference from the rock-masses of Richmond Mountain and

Cliff Hills, they are rocks which judged simply from the hand-specimen might properly be classed as augite-andesite. They hold the position of transition rocks between the two classes of andesite, and as they overlie the hornblende-andesite, their place is geologically of great interest as bearing directly upon the relative age of the two types of andesitic eruption. Their occurrence points directly to the conclusion that the augite-andesites of Richmond Mountain and Cliff Hills followed the hornblende-andesite. Another mineralogical difference between the two rocks is the relative proportion of mica present. As the andesitic pearlites become more and more acidic the proportion of mica increases and the rock gradually passes over into dacite. The dacite usually occurs in obscure hills and low ridges, and although covering comparatively limited areas, it is clearly seen to overlie the hornblende-andesite in all the local centers of eruption, wherever the two rocks are observed together.

The rhyolitic pumices, tufas, and pearlites are, in most cases, older than the rhyolites proper, and by rhyolites proper are meant the more crystalline compact varieties represented by Rescue Cañon and Pinto Peak rocks. While it is by no means evident that all the outbursts of pumice and allied rocks preceded the rhyolites, yet there is abundant proof that the great mass of the former rocks was poured out and spread over wide areas of country, especially along the line of the Pinto fault, before the great bulk of the latter rock was forced to the surface. Rhyolites occur penetrating the pumices, overflowing them, and in many places concealing them from view, except where the lower rock is exposed by deep cuts in the ravines. The pumices and associated rocks, although irregular in their distribution, occur usually in low hills, skirting the mountains and closely following the main lines of faulting. The rhyolites are the most widely distributed igneous rocks of the district, appearing not only along the main lines of volcanic activity but breaking out in small isolated masses in the most distant and unlooked-for places. An exceptional feature in the mode of occurrence of rhyolites is the numerous narrow dikes which penetrate the limestones, many of them so obscure as to be recognized only with difficulty on the surface, erosion having worn them down equally with the inclosing sedimentary strata. Indeed, they are frequently detected only by finding fragments of volcanic rock among limestone *débris*.

From the northern end of the large body of hornblende-andesite at New York Cañon, a line of small outbreaks of rhyolite, penetrating the Pogonip limestones, extends in a northwest direction, connecting the igneous rocks of the Pinto fault with the rhyolite of Purple Mountain. Similar extrusions of rhyolite penetrate the Prospect Mountain limestone, Secret Cañon shale, and Hamburg limestone along the east side of Prospect Ridge, from Ruby Hill southward to the Geddes & Bertrand mine. Many of these dikes are so narrow and others cover so little area that it is quite impossible to represent them all on the map. Lithologically all these dikes present the same general habit and mineral composition, and possess important economic as well as scientific interest, as the ore deposits of Prospect Ridge and Ruby Hill are intimately connected with these rhyolitic extrusions.

The district affords abundant evidence of the relative geological position of rhyolite to hornblende-andesite, dikes of the former penetrating broad masses of the latter rock. In low hills near the entrance to Sierra Cañon instances may be seen of finely banded rhyolite lying in direct superposition upon good exposures of dacite. This dacite, though a moderately compact rock, possesses many of the characters of pumice, and in a marked degree strongly resembles many forms of rhyolite, but especially the variety with which it is here associated. Both rocks are highly acidic, but the dacite is the richer of the two rocks in mineral secretions, and is characterized by a great abundance of laminæ of black mica. Between the two rocks there exists this fundamental difference, that while the dacite is rich in plagioclase feldspar without any appreciable amount of sanidin in the thin sections examined under the microscope, the rhyolite, although carrying triclinic forms, shows the prevailing feldspar to be sanidin.

Richmond Mountain and Cliff Hills present the only two occurrences of augite-andesite known in the district, but they play so prominent a part that the rock forms one of the most important of the volcanic products. Of the two localities only Richmond Mountain properly lies within the district of the Eureka Mountains; as Cliff Hills, although embraced within the limits of the survey, are situated to the southward of the broad valley of Fish Creek. Richmond Mountain is formed almost wholly of augite-andesite. From its highest peak it extends northward for nearly three miles, and in an east and west direction is somewhat broader. It rises abruptly above the town of Eureka, the culminating point having an altitude of over 2,000 feet above the valley. To the south and west the mountain presents a cliff-like face, falling away gradually towards the northeast with an average slope of 14°. The mountain lies at the extreme northern end of the Pinto fault, where the Silverado and County Peak block of Devonian limestone is abruptly broken down—the position being one of profound geological disturbance. The Cliff Hills take their name from the abrupt, irregular walls which rise above the Quaternary valley on their west side, presenting much the same physical features and forms of erosion, although on a less extensive scale, as Richmond Mountain. Lithologically, the rocks are identical in composition.

Unlike augite-andesite, the outbursts of basalt present a considerable variation in their mode of occurrence. They form broad, table-like masses and numerous small extrusions in dikes and rounded knobs, but closely connected with either the augite-andesite of Richmond Mountain or else encircling the uplift of Silverado and County Peak. Although the two rocks are closely related, they may be easily distinguished from each other in the field by broad characteristic features of the rock masses, and as to their order of succession there exist, fortunately, abundant proofs to show that the augite-andesite preceded the basalt. Evidence of their relative age may be seen on the summit of Richmond Mountain, where several dikes of dense glassy basalt cut the andesite in sharply-defined lines of contact. The relations of augite-andesite and basalt to rhyolite are of importance, as bearing not only on the order of succession of the former rocks, but as indicating the geological position of rhyolite. By reference to the map, it will be seen that the rhyolitic pumices and tufas encircle more or less completely the base of Richmond Mountain on the west, south, and east. Along this line, wherever the two rocks come in contact, there is no evidence to show that the augite-andesite has ever broken through the rhyolitic rocks, but, on the contrary, numerous instances show the tufas occupying the accidented surfaces of Richmond Mountain, which must have been an earlier eruption. Moreover, whenever the two rocks are seen in immediate contact, and continuous exposures occur along the southern base of the mountain and east of the Richmond Company's smelting works, there is an entire absence of alteration products arising from a remelting of the highly acidic and easily fusible tufas and pumices, which would be the case if the augite-andesite had penetrated the rhyolitic rocks. With basalt, on the other hand, the case is unquestionably different, and any number of instances may be observed, notably east of the town of Eureka and in the immediate neighborhood of Hornitos Cone, where basaltic dikes appear in the most striking manner as intrusive masses in the tufa. Away from the intrusive dikes this tufa is always white or light yellow in color, porous and crumbling in texture, and of the nature of an exceedingly fine pumiceous breccia. Near the intrusive masses the pumices present the greatest variety of products, altered into yellow, purple, black, and gray pearlites, with frequent instances in the basalts of jointing planes parallel to the lines of contact.

These observations demonstrate several points in the geology of the igneous rocks: First, that the hornblende-andesite is older than the associated andesitic pearlites; second, that dacite followed the hornblende-andesite; third, that the rhyolite followed the dacite; fourth, that the augite-andesite preceded the rhyolite; fifth, that the basalt followed the rhyolite.

While the rock masses of both augite-andesite and basalt are readily distinguished in the field by marked differences in physical features, it is by no means always easy on a superficial examination to refer correctly from hand-specimens certain varieties which approach each other in structure and composition. Mineralogically, no sharp distinction can be drawn between the two rocks, but a careful investigation of the Eureka varieties brings out certain differences which not only hold for this region, but probably for other areas of the Great Basin. Augite and magnetite, although essential minerals in the composition of both rocks, occur much more abundantly in basalt. Hornblende in macroscopic crystals, and occasional flakes of mica, occur scattered through the augite-andesite, but are wholly wanting in the basalt. With one exception the microscope has failed to detect olivine in any thin section of the augite-andesite, the exception, however, furnishing quite a remarkable rock, and one that might with some justice be placed among basalts. It occurs in a low hill just east of Cliff Hills, and from its association, and from the fact that its microscopic structure bears the closest relation to surrounding rocks, it has been referred to augite-andesite.

Although olivine is absent from the augite-andesites of the district, it will not serve, as has been suggested, as a mineralogical distinction to separate the two rocks, inasmuch as over wide areas of basalt it is wholly wanting. It occurs so irregularly scattered through the rock that any attempt to separate the basalts themselves into two divisions on a basis of olivine seems futile, its presence depending mainly on the chemical composition of the basalt.

The numerous extrusions of basalt in their relations to each other appear uniform and simple enough, the diversities in the physical habit of the basalt depending mainly upon the condition of the groundmass, which frequently passes by insensible gradations from a highly crystalline rock to one rich in glass base. In general the crystalline varieties are basic and the glassy rocks acidic. A number of rock-masses exhibit extreme forms of both types, although the latter variety greatly predominates, the basalts of the district being characterized as a whole by a large amount of glass. While field observation, as already mentioned, offers abundant evidence of the position of the augite-andesite relatively to basalt, and divides these closely-related rocks upon broad geological grounds, the microscope in a marked manner corroborates the work of the field. Mr. Iddings, who has submitted a large number of thin sections of both groups to a searching microscopic investigation, is able to substantiate the geological division based upon structural peculiarities observed in the field. He finds that all those rocks which have been classed as augite-andesite possess their own microstructure, characterized by that peculiar felt-like structure of the groundmass which Professor Ferdinand Zirkel long ago pointed out as a feature of augite-andesite. The basalts present in their structure a uniform groundmass made up of coarse-grained aggregations of feldspar and augite imbedded in a globulitic glass base. Prof. Zirkel, in his report upon the crystalline rocks of the Fortieth Parallel Exploration, recognizes this type as occurring in a number of localities throughout the Great Basin, and adds:

"Without doubt this variety has the closest affinities to augite-andesite. This well characterized type, which occurs in other basaltic regions only as a well-known exception, is the most common along the Fortieth Parallel, a fact that tends to sustain a previously mentioned result, namely, that the mode of structure which most frequently occurs in

European basaltic regions is rare in the herein examined territory of North America."

There are two very marked peculiarities of these basalts: One, the very varying amounts of silica which they carry; the other, the very high percentage of silica contained in the great mass of the rock. Chemically, these rocks possess far more silica than is ordinarily supposed to occur in normal basalt, the amount reaching as high as the percentage found in many andesitic rocks, and in one case equaling the amount in the andesite of Richmond Mountain.

In order to determine the amount of silica present in these rocks, a number of chemical analyses were made from specimens which both field observation and microscopic study of thin sections had shown to belong to basalt. The subjoined table gives the result of ten such chemical analyses, arranged in order according to the percentage of silica obtained. The presence or absence of olivine in the thin sections from the same rocks, as determined by the microscope, is also given in the table.

Number.	Silica.	Olivine.
1	49.23	Rich in macroscopic secretions.
2	51.86	Rich in microscopic secretions.
3	57.42	Abundant in microscopic secretions.
4	58.06	Easily recognized under the microscope.
5	58.26	Only a trace.
6	58.60	None detected.
7	58.64	Detected under the microscope.
8	59.51	None detected.
9	59.64	None detected.
10	60.11	None detected.

No. 1. *South of Alhambra Hills.*—This rock occurs as a low hill rising out of the Quaternary plain, and isolated from all other volcanic outbursts. It is a highly crystalline rock.

No. 2. *Dike northeast of summit of Richmond Mountain.*—An intrusive body penetrating the augite-andesite.

No. 3. *East of Basalt Peak.*—A vesicular black basalt.

No. 4. *Basalt Cone.*—A compact dark rock characteristic of a large area of country.

No. 5. *Basalt Peak.*—A compact rock passing into vesicular varieties.

No. 6. *West base of Richmond Mountain, near the town of Eureka.*—A grayish-red vesicular rock lying between augite-andesite and rhyolitic tufa.

No. 7. *West of Basalt Peak.*—It occurs on the broad saddle just west of the peak, not far from the great body of Devonian limestone, and is a characteristic rock rich in glass base, black in color, mottled with gray.

No. 8. *West base of Richmond Mountain, not far from the town of Eureka.*—In its geological relations it is quite similar to No. 6. It is found in contact with rhyolitic tufa, and is a compact dark rock with a characteristic basaltic habitus.

No. 9. *A dike from the summit of Richmond Mountain.*—Under the microscope the rock resembles No. 2, which occurs not far distant penetrating the same body of andesite. This rock, however, is much richer in glass and correspondingly richer in silica. It is black in color, without macroscopic secretions, and has a decidedly conchoidal fracture.

No. 10. *West of Toll Road, west of Dome Mountain.*—It occurs as one of the largest extrusions of basalt along the Pinto fault. The broad mass lies in contact with hornblende-andesite, and flows from the same body are seen to directly overlie rhyolitic tufa. It is exceedingly rich in glass, and so mottled as to present a gray color. Although the highest on the list in the percentage of silica, it possesses a strongly-marked basaltic habitus, quite as characteristic under the microscope as in the hand-specimen.

It will be seen, with the exception of numbers one and two, that the silica percentage in all the rocks is higher than is usually found in basalts; they show between the two extremes on the list a variation in silica of 10.88 per cent.

Although olivine is not an essential constituent in the basalts, the above table shows an interesting relationship between the amount of olivine and the percentage of silica present in the rock. In the low hill south of Alhambra Hills, the silica is low, while the olivine is present in comparatively large secretions. In the dike from the summit of Richmond Mountain, the second in the table, there is an increase in the amount of silica of over 2½ per cent., with a large falling off in olivine. From the rocks with 58 to 59 per cent. of silica, there is only a small and varying quantity of olivine, while in the three specimens which gave over 59 per cent. of silica the microscope failed to detect its presence.

Chemical determinations of the amount of silica in the augite-andesite from four localities, gave the following results:

No. 1, 59.52. No. 2, 60.26.

No. 3, 61.90. No. 4, 62.41.

Nos. 1, 3, and 4 are from Richmond Mountain; No. 2, from Cliff Hills.

GEOLOGICAL CROSS-SECTIONS.

As the principal object of this paper has been to present as succinctly as possible a description of the Paleozoic rocks, and their relations to the different classes of igneous rocks, with some account of the relations of the latter to each other, no extended discussion will be made here of the dynamic movements which have brought about the present complicated structure of the different mountain blocks. By reference, however, to the accompanying plate of cross-sections (Plate XXV) the broader structural features of the mountains of the Eureka District will be readily understood when examined in connection with the geological map, and the history of the Paleozoic section, as described in the text may be easily followed without much additional explanation.

On the geological map are laid down the lines of the cross-sections, which have been accurately constructed along carefully selected east and west lines. The sections are a reduction from the large double plate in the atlas which forms a part of the final report, and are drawn on a scale of 3,600 feet to the inch, with the base-line taken at 6,000 feet above sea-level, the height of the adjacent valleys.

Section CD–EF is constructed across the central portion of the Eureka Mountain, and therefore presents more of the principal structural features of the region than is shown in either the northern or southern sections. It is drawn through Mahogany Hills, Spanish Mountain, Prospect Ridge, Spring Hill, and County Peak Group, and crosses the Spring Valley, Hoosac, and Pinto faults. The section intersects Prospect Ridge just to the north of the summit of Prospect Peak, and brings out the anticlinal structure in the quartzite on the west slope overlaid on both sides of the fold by the Prospect Mountain limestone, which to the east forms the summit of the main ridge. This is in turn overlaid by Secret Cañon shale, Hamburg limestone, and Hamburg shale, the remaining subdivisions of the Cambrian, all of which stand inclined at about 70° to the east. As the section is drawn across quite a high saddle at the head of New York Cañon, connecting Prospect Peak and Hamburg Ridge, the erosion of the Secret Cañon shale is not so well shown as it would be if the section were drawn either to the north or south of this point, but is quite sufficient to bring out the prominence of the Hamburg Ridge, which is everywhere parallel to the main mountain. Overlying the Hamburg shale occurs the Pogonip limestone and Eureka quartzite, which occupy the long slope down to the Hoosac fault. The Hoosac fault extends along the base of the ridge approximately parallel with its trend. It follows up New York Cañon as far as the reservoir, where it turns and runs south until lost in the Quaternary deposits of Fish Creek Valley. As the line of the fault has been the center of volcanic action, its outline can only be traced approximately, inasmuch as it is almost wholly concealed by extrusions of hornblende-andesite and rhyolite, the former variety only appearing on the line of the section. Beyond this narrow belt of andesite comes in the Lower Coal-measure limestone, dipping at first to the eastward, followed by a synclinal fold, which is abruptly cut off by the Pinto fault, beyond which the Lone Mountain Silurian of the County Peak Group rises in a precipitous wall. The Pinto fault starts in along the southwest base of Richmond Mountain, and runs southward just east of Dome and English Mountains, and, like the Hoosac fault, is finally lost in Fish Creek Valley, the two faults being roughly parallel in their trend.

Between the two faults the thickness of the Carboniferous limestone, where it is best observed, has been estimated at 3,800 feet. If the uppermost beds on the west side of the Hoosac fault belong to the summit of the Eureka quartzite, and the base of the Lower Coal-measures is exposed on the east side of the fault, then the amount of displacement would be measured by the combined thickness of the Lone Mountain limestone, Nevada limestone, White Pine shale, and Diamond Peak quartzite, which in the general section is given at 12,800 feet. As a portion of the Carboniferous limestone has also been carried down, it may be assumed that the vertical displacement amounts at least to 13,000 feet, or nearly two and one-half miles. The displacement along the Pinto fault is even greater, as along Carbon Ridge the overlying Weber conglomerates are brought down against the Lone Mountain Silurian. The section shows, then, two parallel displacements of not less than 13,000 feet, which, in the neighborhood of Spring Hills, are nowhere more than two miles apart. Continuing along the line of the section east of the Pinto fault, the Lone Mountain limestones are partially exposed, followed by a great development of Nevada Devonian, measuring 4,500 feet across the middle and lower beds, and well characterized by organic forms. At Basalt Peak igneous extrusions conceal the sedimentary beds, but the section is constructed from exposures observed both to the south and east, and may be readily understood by reference to the map. Returning to the west side of Prospect Ridge, the Prospect Mountain limestone exposed at the base is abruptly cut off by the Spring Valley fault bringing up the Eureka quartzite, as shown at Spanish Mountain, with a complete change in geological structure. Spanish Mountain presents in general a broad anticlinal fold, although broken by numerous cross-faults and dislocations. To the westward the quartzite is overlaid for a short distance by Lone Mountain beds passing under the Nevada limestone of the Mahogany Hills, which in gentle folds extends to the Quaternary deposits of Antelope Valley.

Section GH–IK is drawn across the southern end of the mountains in a continuous line from west to east, passing through Gray's Peak, Gray Fox Peak, Carbon Ridge, and Rescue Cañon. The only Cambrian rocks found at the surface are the Prospect Mountain limestone, the overlying epochs, together with Pogonip limestone and Eureka quartzite, being buried by flows of rhyolite. Between the Hoosac and Pinto faults the section again crosses the Carboniferous block, which here includes a portion of the Weber conglomerate as well as the Lower Coal-measure limestone, both members lying inclined at angles varying from 60° to 70° to the eastward. At the entrance of Rescue Cañon the rhyolites which follow the line of faulting along the cañon are shown breaking through the Nevada Devonian. An interesting structural feature brought out in the western end of this section shows the relation between the Eureka quartzite, the main surface formation, with the underlying Pogonip limestone, and the overlying Lone Mountain Silurian and Nevada Devonian.

Section AB is drawn but halfway across the map, showing only so much of the structure as is represented on one double atlas sheet of the final report, extending from Cariboo Hill eastward to Newark Mountain.

Upper members of Devonian limestone form the strata of Newark Mountain, followed by the White Pine shales of Hayes Cañon, in turn overlaid, unconformably, along the line of the section, by the Lower Coal-measure limestone. By reference to the map, however, it will be seen that the Diamond Peak quartzite comes in to the northward, resting upon White Pine shale, overlaid conformably by Lower Coal-measure limestone.

The two epochs of Carboniferous limestone are nowhere better shown in the district than along the line of the section. The lower limestone dips uniformly to the west at an angle of 25° to 30°, with a development of 3,700 feet of beds, overlaid by the Weber Conglomerate 2,000 feet in thickness, showing a synclinal and anticlinal fold, beyond which come in the Upper Coal-measure limestones, but only represented with a thickness of 500 feet. The position and outline of the augite-andesite of Richmond Mountain, together with the associated basalts of Hunter's Creek, and their relations to the Carboniferous rocks, are clearly defined.

PRELIMINARY PAPER

ON THE

TERMINAL MORAINE

OF THE

SECOND GLACIAL EPOCH.

BY

THOMAS C. CHAMBERLIN.

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ILLUSTRATIONS.

TERMINAL MORAINE OF THE SECOND GLACIAL EPOCH.

By T. C. Chamberlin.

CHAPTER I.

PRELIMINARY DEFINITIONS.

Perhaps no department of geological investigation has greater need of careful discrimination than that which deals with the complex deposits of the Quaternary age. Most formations betray their origin in their salient characteristics, but those of the Quaternary age are apparently capable of diverse interpretations if their general nature alone is considered. It is only by critical discrimination of their special and often quite unobtrusive features that they can be decisively referred to the several agencies that produced them. Most formations owe their origin to the action of some one dominant agency. The Quaternary deposits are, on the contrary, the product of a combination of agencies, the relative work of which is often distinguishable only with difficulty. In these discriminations the individual judgment of the investigator plays an important part. The influence of personal predisposition, therefore, is here liable to be most gravely felt. Probably no investigator is entirely free from the influence of his own preconceptions and methods of interpretation. He, perhaps, does best who, while duly appreciating these influences and assiduously applying checks for their correction, frankly submits his methods of interpretation to the correction of others. It may be serviceable, therefore, to any who may be inclined to differ from the writer in the interpretation of the phenomena under consideration, to indicate the bases of discrimination that have been employed in their study and the senses in which descriptive terms are used; the more so, since, in this article, it is not proposed to enter into a minute description of local details, the great extent of the formation rendering this wholly incompatible with the plan and purpose of this sketch of progress and results. Independently of this, it will greatly facilitate subsequent discussion if some elementary views and definitions are distinctly put forth at the outset.

STRUCTURAL CLASSIFICATION OF DRIFT.

It is unnecessary here to dwell upon the usual classification of drift into (1) *the assorted* and (2) *the commingled*, the former embracing clays, sands, gravels, and beds of bowlders essentially uncommingled and usually stratified, the latter including confused mixtures of these, usually unstratified. These are simple distinctions of material and arrangement, easily determinable and well understood.

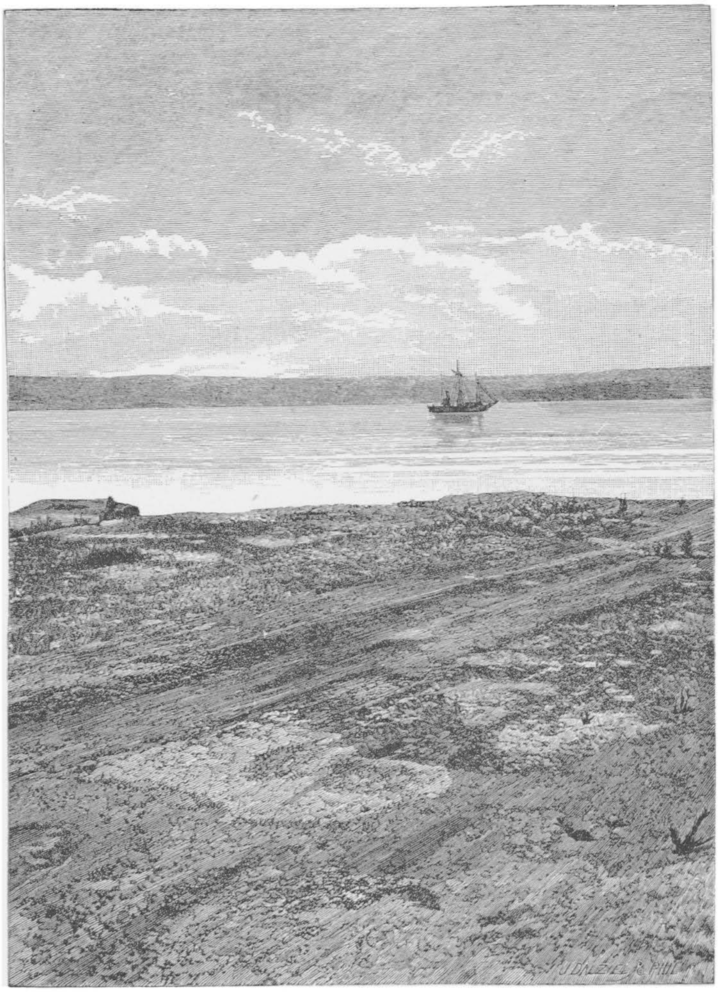
GENETIC CLASSIFICATION OF DRIFT.

It is quite otherwise with an attempt to classify Quaternary deposits by associating such as have a common origin or a like method of formation without regard to those distinctions of material and structure which are incidental to the special phases of the producing agencies or the local conditions of their operation. Such a classification involves greater difficulties in clearly apprehending the criteria of classification and in decisively applying them in practice.

The following classes lie habitually or occasionally in such close association with the moraine under consideration as to force themselves upon attention. The characteristics by which they are thought to be distinguished are briefly indicated.

TILL.

Subglacial Till.—The most prevalent of these associated deposits consists of a broad, irregular sheet of commingled clay, sand, gravel, and bowlders, in varying proportions and of diverse character, with which is usually associated a greater or less amount of assorted stratified material. When undisturbed it is usually firmly compacted, tough, and resistant, but these characters are quite dependent on the local composition, which is in turn largely dependent on the parent formations. The bowlders and pebbles lie imbedded in the clayey base in all attitudes, and are irregularly distributed through it, manifesting often an obscure tendency to aggregation into clusters. The whole aspect of the formation betrays irregularity of origin. The material was gathered from divers sources. Almost uniformly a large percentage is derived from the underlying and immediately adjacent formations, and usually smaller proportions are derived from formations that lie back along the drift course to the northward at varying distances up to several hundred miles. The agency which produced the deposit gathered its material all along its extended course. The embraced rock fragments are commonly rounded, and frequently polished and scratched on their flattened sides. The rock floor on which the sheet usually lies is likewise planed, polished, and scored with parallel striæ. This deposit is the well-known



GLACIAL STRIATION. NORTH SHORE OF LAKE ERIE.

(From photograph.)

and widely recognized bowlder clay or till—the greatest of drift deposits. It is regarded as a ground moraine. The writer inclines to the view of those glacialists who maintain that it was deposited mainly under the thinned edge of the ice sheet rather than at its margin, or, to any great extent, under the deeper portions remote from the edge.

While recognizing the greatness of this deposit, there seems good reason to believe that there have been classed, and perhaps confounded with it, deposits of quite another origin. Nowhere perhaps is there need of closer discrimination, and nowhere probably is the discrimination more difficult than in drawing the line between true till and closely similar formations of a different derivation, presently to be considered.

UPPER TILL.

Englacial or Superglacial Till.—Professor Torrell has distinguished from this true till an overlying drift sheet of somewhat similar character, recognized in Sweden and in the hilly regions of eastern America, which has been designated Upper Till. It is held to be distinguished from the true till (1) by its looseness; (2) by the usually large size and angular form of its rock fragments; (3) by the more sandy and porous character of the earthy base, and (4) by the higher oxidation of its iron compounds. This is regarded as having been the material embraced *within* the glacial ice, or borne on its surface, and, by its melting, let loosely down upon the true till formed beneath the ice. The term *Upper Till* applied to it is unfortunate, as it is liable to confusion with a second true till overlying the first, the existence of which a number of European and American geologists claim to have demonstrated. Some such term as *Englacial or Superglacial Till* (since the material embraced in the ice must have become superficial by ablation before it was deposited) would be less liable to confusion and in some degree self-definitive.

SUBAQUEOUS TILL.

Berg Till, Floe Till.—A much more important distinction is that between true glacial till and the very similar deposit formed under water through the agency of floating ice. This latter may be designated *Subaqueous Till*, *Berg Till*, or *Floe Till.* If I discriminate correctly, this is distinguishable from true till (1) by a more homogeneous clayey base; (2) by a more uniform distribution of imbedded erratics; (3) by occasional traces of indistinct lamination; (4) by its surface expression; (5) by its distribution, and (6) by its stratigraphical relations. It is manifest, upon consideration, that the finer material, settling down from suspension in water, would distribute itself with greater uniformity than is possible to clay accumulated under a moving glacier. It is also evident under the law of probabilities that erratics, falling from floating ice as it melts, would be dispersed with a general regularity unless there were currents or other circumstances that determined concentration along certain lines or in certain areas. The rock fragments often stand in the clay on their edges or points, as though they had been received on a soft mud bottom as they fell through the water. Where lamination is observed, the lower clayey leaves may sometimes be seen to be flexed beneath the stone, while the upper ones curve over it as though it had depressed the former in its fall, while the latter had been subsequently formed over it.

The deposits of the continental interior referred to this class are regarded as having been formed in lakes that gathered along the margin of the melting glacier, and which were the receptacles of the issuing silt-laden glacial waters, and of the ice-blocks that broke off and floated away from the glacier's margin. As these lakes varied greatly in area, depth, and glacier frontage, the relative amounts of coarse and fine material vary correspondingly. In some the relative proportion of bowlders to clay is nearly that of the true till, and in such instances the distinction between the two is of difficult and often very doubtful determination. At the other extreme bowlders are very rare, though pebbles are usually abundant in all deposits referred with any confidence to this class.

The surface aspect of these deposits greatly assists in their correct identification. Where they occupy broad areas the surface contour is of a subdued undulatory or plane type, which is usually readily distinguishable from the characteristic surface expression of glacial till. Where they occupy confined areas, as narrow linear valleys, they form concave sheets, the sides of which lean against the slopes of the valley, and terminate at a definite height in shoulders on either side. These deposits are somewhat more erodible than till, and have usually been more symmetrically and sharply channeled where the slopes in post-glacial times have permitted it.

LACUSTRINE AND MARINE DEPOSITS (*non-glacial*).

The face of the drift-bearing area is thickly overstrewn with existing and extinct lakes. These in a generalized view may be regarded as the lineal descendants of the marginal glacial lakes, and have formed deposits of clay, sand, marl, and peat, which are usually distinguishable without difficulty from true glacial deposits. In their transition, however, from the stage when they were contemporaneous with and marginal to the glacier, they appear to have given rise to deposits of a character intermediate between the homogeneous, purely lacustrine clays, and the stony clays of ice origin. How far ordinary lake ice in the more severe climate of the immediately post-glacial epoch may have contributed to the formation of stony clays by freezing to shore pebbles and subsequently floating them backwards and dropping them on melting, it is difficult to determine. It is quite certain, at least, that extensive deposits of subaqueous clays containing abundant smoothed, often polished and scratched, pebbles, with very few bowlders, were formed during or immediately after the retreat of the ice-sheet. Just where the line is to be drawn between deposits formed through the partial agency of glacial blocks and bergs and those due merely to lacustrine ice is certainly of difficult determination, and is probably only to be safely decided by extensive and refined stratigraphical investigation.

Marine deposits differ in no essential respect from lacustrine, except in containing the remains of marine life, and perhaps in something more of coarseness; but as they do not fall within our immediate province, they will not be dwelt upon.

BEACH RIDGES.

Along the margin of the lacustrine deposits, and occasionally within their areas, and concentric with their margins, lie ridges of sand and gravel, stratified largely in oblique attitudes, which are undoubtedly beach formations produced by wave-action, contemporaneously with the lacustrine and marine deposits which they border. Their identification is usually not difficult when their structure and relations to adjacent and subjacent formations are critically considered. In some instances they somewhat resemble certain phases assumed by moraines, and are subject to possible incorrect interpretation.

ÅSAR, KAMES, ESKERS, RAER.

These terms of foreign origin have been used to designate a group of closely similar deposits, which doubtless need more strict classification since they are probably to be referred to diverse agencies.

Åsar (anglicized Osars.)—The best characterized class consists of long, narrow, sharp ridges of gravel and sand with some associated bowlders. The sand and gravel are discordantly stratified in oblique, arching and anticlinal attitudes. The bowlders are mainly superficial, though not infrequently imbedded. The constituents are often very coarse. These ridges in the main extend from higher to lower levels following in general, but not in detail, the course of the greater valleys and the direction of glacial striation. While their general courses are direct they are more or less winding in detail, and are often joined by lateral branches, as are rivers. In short, in position, direction, and branching, they may be regarded as great river-like streams of gravel. To these the Swedish term *Åsar* is more strictly applicable than Kames, and has, I believe, the sanction of prior use in the American literature of the subject.

These deposits are most plausibly attributed to glacial streams, though the precise conditions and method of their action are more doubtful.*

*See Juke's and Geikie's Manual of Geology, pp. 706–713; The Great Ice Age, by James Geikie, p. 231; The Kames of New Hampshire, by Warren Upham; Geol. of N. H., part III, chapter I; The Kames of Maine, by G. H. Stone; Proc. Boston Soc. Nat. Hist., vol. XX, March 3, 1880, pp. 430–469; Kames of Ohio, by J. S. Newberry, Geol. Surv. of Ohio, vol. II, pp. 41–46; Kames of the Connecticut Valley, by J. D. Dana, Am. Jour. Sci., vol. XXII, Dec., 1881, Feb., Mar., May, and Aug., 1882.

Kames.—Associated with these in the literature of the subject and sometimes actually connected with them in nature are assemblages of conical hills and short irregular ridges of discordantly stratified gravel, between which are irregular depressions and symmetrical bowl-shaped hollows that give to the whole a peculiar, tumultuous, billowy aspect. Such accumulations sometimes occur along the line of linear ridges such as those above described, and seem to be local developments of otherwise symmetrical Asar. These irregular accumulations are, however, more abundant in connection with deep, rapidly descending valleys, being especially abundant where they are joined by tributaries or where they make a sharp turn in open portions of their valleys, and especially where they debouch into open plainer country. In such instances they are usually associated with gravel terraces and plains. Preciselysimilar accumulations are very common associates, if not constituents, of terminal moraines, and in these instances they are arranged in irregular belts transverse to the direction of glacial movement, and often stand in various attitudes to the inclination of the surface. To this class of deposits the term *Kames* is more especially applicable. In the latter association they stand in contrast with the Åsar above described, in that they are *transverse* to the slope of the surface, the course of the valleys and the direction of drift movement.

While both may doubtless be said to have a common origin, in the sense of being largely due to the action of running water, it is quite manifest that the special conditions of its action in producing the two formations must have been quite different. It is also quite clear that our present method of classification and use of terms need revision. Either the names Asar and Kames should be used simply as structural terms, in which case they should be more closely confined to definite types, or they should be exclusively used to designate formations believed to have a given origin. Much vagueness and uncertainty is introduced into the literature of the subject by their synonymous use to designate at times linear ridges coincident with slope and glacial movement, and, at other times, belts of irregular tumultuous hills transverse to slope and glacial movement, or disposed without evident relationship to glacial phenomena. It would seem to be of service to American science and in reasonable conformity to the native use of the terms, to designate the first class *Åsar* and the second *Kames*, and to use the names in a structural sense simply, until views as to their origin shall be more generally harmonious. The almost constant association of the latter with moraines is such as to entitle them to be regarded as one of the characteristic constituents of the complex accumulations of well-developed morainic belts. While not due to the direct mechanical action of the ice, they seem to be dependent on the special conditions furnished by a glacial advance to such a degree as to be nearly as distinctive as the mechanically-formed moraine itself. They, therefore, come constantly under consideration in morainic studies.

MORAINES.

The material borne by glaciers belongs to two diverse classes: 1st, that which falls upon the ice from cliffs and towering peaks; and, 2d, that which is abraded from the rocks over or against which it moves. The first class is borne passively *on* the ice stream, while the second is pushed or rolled along *beneath* it. The first is due to the accident of the glacier's position; the second is the direct result of its own action. The first is characterized by angularity of material; the second by its worn and comminuted character. The first is superficial; the second basal. An intermediate class embraces the material detached from peaks and cliffs that rise high into—but not through—the ice mass, and yield to its interior blocks of rock detached from their summits. These are borne along within the ice mass, and suffer little abrasion; and, at length, by the melting of the superficial portion of the ice, appear at the surface and constitute a portion of the superficial moraine. We have already briefly described the true till which embraces the basal material, and the upper or superglacial till, which is formed by the superficial *debris*. These terms in their simple use are, however, only applicable when the material has been left by the retreating ice in broad sheet-like deposits, essentially as it was accumulated under, in, or on the ice. When the material is ridged or corrugated by the action of the frontal or lateral edge of the ice it passes into the classes more commonly included under the simple name moraine. Concerning these only a few preliminary observations are here pertinent.

Lateral Moraines.—With true lateral moraines, formed by the edge of an ice stream rubbing along the sides of the valley through which it moves, we have little to do in the study of the products of the great American ice-field. They do occur, however, on the flanks of the deep valleys of the Appalachian region, where narrow glacial streams became differentiated from the great *mer de glace*, and flowed a few miles farther onward, forming lateral embankments on the sides of the valleys. But these are special and local developments, and will be sufficiently considered in their local relations.

Medial Moraines.—With medial moraines, in the usual sense, *i e.*, those formed by the junction and coalescence of two glaciers, we have little or nothing to do, since no such junction and coalescence falls within the phenomena under consideration. That instances of the kind occur in our drift is highly probable, as in the case of the union of the currents that passed on either side of the Wisconsin driftless area, and as also, in some instances, in the mountainous regions where separated currents re-united. But these are exceptional cases and are not involved in our present study.

Intermediate or *Interlobate Moraines.*—There is, however, a very important class of moraines—the most remarkable perhaps within the purview of our knowledge—that are, in a sense, medial in position, though they are radically different in character from conventional medial moraines. They were formed by the joint action of two glacial lobes pushing their marginal moraines together, and producing a common one along the line of their contact. They are terminal moraines in character, but intermediate, *i. e.*, interlobate, in position. Their nature will be more fully set forth in the body of the paper. For this class a new name, as *Intermediate* or *Interlobate Moraines* seems to be needed.

Terminal Moraines.—The most extensive and remarkable known example of this class constitutes the central theme of this paper, and will receive special description a few pages beyond. It is only necessary here to note a distinction of some practical importance. In the broadest sense, any special aggregation of drift along the margin of a glacier is a terminal moraine. Such an accumulation may mark the limit of a great advance of the ice, and so possess much historical significance, or, on the other hand, it may be due simply to a temporary halt of a retreating glacier, and so be of only trivial import. Between these extremes there may be moraines formed by advances of various degrees of importance. While there are difficulties in fixing upon and maintaining a definite line of distinction, it seems desirable to distinguish those moraines that mark the termination of important glacial advances from those much more numerous and unimportant ones that only signify a temporary halt, or insignificant advance. I have proposed to limit the name *terminal moraines* to the former class, and use that of *peripheral moraines* for the latter.*

To the former class belongs the subject of our discussion, which is held to mark a very important advance of the great ice-sheet at a date considerably later than the stage of greatest glaciation, or, in other words, to outline the ice limit of a second glacial epoch. A similar moraine should, theoretically, mark the extent of extreme glacial advance in the earlier epoch, and such an one has been traced in the Coast and Appalachian regions by Messrs. Cook, Smock, Upham, Lewis, and Wright, though a considerable portion of this is believed to be a part of the later moraine, as will be seen in the further discussion of the subject. In the interior this supposed extreme outer moraine has not been traced out.

FLUVIATILE DEPOSITS.

While the Åsar and Kames are probably due in large measure to running water, the action took place under peculiar conditions, and cannot, therefore, appropriately be classed as simply fluviatile, as that term is commonly understood. But extensive deposits occur in association with the moraine under consideration that are more exclusively due to streams of water acting under ordinary or, at least, not so especially extraordinary conditions.

Valley Drift.—The melting of the glacial ice, reinforced by rains, gave rise presumably to streams of exceptional extent and sustained action.

* An. Rep. Wis. Geol. Surv., 1878, p. 14.

As a result there is to be observed in all the valleys that led away from the glacial margin, and that presented the requisite slope and other conditions, great streams of assorted gravel and sand widely spread over the bottoms of the valleys and filling them to various and often very considerable depths. These gravel streams often stretch far on beyond the limit of the general drift area, but usually with diminishing force. In the interior, while yet imperfectly correlated, it is currently held that these streams converge with the gathering branches of the Mississippi, and form a great trunk stream that occupies the Great Valley and reaches to the Gulf. Those of the eastern coast presumably reach out beyond the present shore line.

Marginal Plains.—In addition to these trains of drift that stretch far down the valleys, the margin of the moraine—where the topography was not too rough on the one hand, nor so low and flat as to be submerged on the other—is flanked by broad plains of gravel and sand that abut against it on the one side and stretch out to varying distances on the other. The relation and structure of these is such as to make it clear that they are the work of glacial waters pouring over the moraine and through minor gaps in it while it was still being pushed from the opposite side by the ice. The little escaping streams, being overburdened with detritus, rapidly filled the channels through which they flowed, and were consequently forced to repeatedly take new courses and thus wandered widely, forming considerable plains. In this they were doubtless aided by each other mutually, since they probably issued from the ice front in numerous adjacent rivulets, and formed a belt of interosculatory streams, such as are exhibited on some glacial plains of the present day. The inner side of the moraine is also sometimes flanked, though much less conspicuously so, with gravel and sand plains that seem to be due in part to streams flowing laterally to find exit across the moraine, and in part perhaps to the wave action of very shallow lakes that gathered within the moraine. It is difficult and not very important to distinguish between these, but the coarser deposits seem to have been mainly due to the former agency, the lakes mainly recording themselves by finer depositions.

Terraces.—Fluviatile action is also clearly displayed in connection with the moraine by terraces of assorted drift which are, if I judge correctly, in part contemporaneous with the morainic accumulations, and in part of later age, dating down to the present. The terraces formed simultaneously with the moraine were probably in larger part of the constructive class, *i. e.*, they were built up as terraces rather than formed by the cutting down of plains, which is the more common method of formation.

Over-wash Terraces.—An interesting class is conceived to have been constructed by over-wash through whose agency the crest of the moraine was leveled back for a certain distance forming a plane-topped bank with an abrupt outer face. These belong to the same genetic order as delta terraces.

Delta Terraces.—Where streams of only temporary glacial duration crossed the moraine they seem sometimes to have been the cause of high delta deposits on the outer side, which, being abruptly terminated, constitute a class of fan-shaped terraces. Instances of this kind are not uncommon along the outer margin of the moraine. Whether or not they were always assisted in formation by marginal bodies of water is undetermined.

Torrential Terraces.—In quite a different way terraces were probably formed by glacial floods sweeping down the valleys, distributing gravel and other assorted material along their banks and strewing the contributions of lateral tributaries along the valley sides in terraced trains.

Morainic Terraces.—There is another class of terrace-like embankments associated with the moraine that is believed to have been due in part to the direct assistance of the glacier. In the deep valleys of the more hilly regions long tongues of ice were thrust forward beyond the common ice-margin, along the sides of which drift terraces seem to have been formed, which, at their upper or ice-ward extremity, take on a morainic character, but, at their lower or distal extremity, grade away into a smooth, irregular terrace which either gradully dies away or abruptly ends. The term "morainic terraces," used in the Geology of Vermont in a different sense and one not likely to be retained, seems a fit term for this class.

EOLIAN DEPOSITS.

In connection with the more sandy portions of the moraine wind-drift accumulations of sand occasionally occur, which take the characteristic form of dunes, whose surface contours are very similar to those of the moraine and its associated kames. There is no difficulty, however, in making the discrimination between them upon an examination of the material. There are instances, however, in which the sand-drift overlies the moraine in such a way as to make it uncertain how much of the undulatory character is due to the action of the wind and how much to the kames or moraines beneath, and there are likewise instances where drift of an unknown character is thus concealed, so that the two formations have an interesting, though rarely important, relationship.

ASSOCIATED TOPOGRAPHICAL TYPES.

One of the most important criteria by which the moraine under consideration is distinguished consists of its peculiar topography. As this varies through a somewhat wide range, and sometimes simulates very closely the surface aspect assumed by other formations, the study of topographical types becomes one of essential importance. It will be serviceable, therefore, at the outset, to name the several types which the associated drift area presents, and the characteristics which distinguish them.

1. THE OROGRAPHIC TYPES.

Under this head are included those surface features that owe their origin to flexures and dislocations of the earth's strata. With these, however, we are here little concerned, since the flexures of the earth's crust produce features on too broad and grand a scale to be in any way comparable to those relatively minor irregularities which arise from glacial accumulations. They are further unessential to our subject because over the larger part of the drift area under consideration the strata have never suffered any considerable orographic disturbance.

2. THE DRAINAGE-EROSION TYPES.

Before the advent of the glacial period the old surface of the area had been channeled and creased by the ordinary agencies of atmospheric denudation. The result was a worn surface whose reliefs conformed to the laws of ordinary drainage erosion. Characteristic traces of the carving agency are everywhere betrayed in valleys which successively gather into each other in dendritic fashion, in slopes which conform to a common law of sub-aerial degradation dependent for its special expression on the relative endurance and attitude of the strata, in hills and ridges whose positions and contours are strictly subservient to the drainage system, except where flexure of the strata had previously taken place—in short, by uniformly exhibiting the well-known action of drainage sculpture.

3. THE GLACIO-EROSION TYPE,

Or the Drainage-Erosion Type modified by glaciation.

To this type are to be referred those surface contours in which the predominance of the preglacial erosion features is still clearly discernible, but which have suffered modification by glaciation. This modification may attain to various degrees of importance, from the merest subduing of the drainage-erosion features to their almost entire obliteration. Two general stages may, however, usually be well distinguished—the first, in which the preglacial features are entirely dominant, and the effect of drift-erosion and covering is merely to soften and subdue the earlier surface expression; the second, in which the preglacial rock-contour has been thoroughly subdued (1) by the cutting off of projecting peaks, shoulders, and spurs, and the filing of the whole down to a system conformable to the demands of glacial flowage in distinction from those of surface drainage, and (2) by the filling up of the valleys in various degrees according to situation and attitude toward the glacial movement; so that while the main ridges and valleys remain the same as in preglacial times, and even many minor features still find expression, the whole aspect is very markedly changed, and has assumed a parallel linear arrangement and a softened expression quite in contrast to the dendritic arrangement of ridges and valleys and the rough, abrupt contour lines of the preglacial erosion type. The former of these two types of glacial subjugation prevails to a large extent over the region included between the margins of the earlier and later glaciers—an area which has been but once rasped by a glacier, and that only by its relatively thin margin and during only a comparatively short period, while the other characterizes the area within (north of) the margin of the later glacier, a territory which was a second time overrun by glaciation.

4. THE TILL TYPES.

In the regions of heaviest glaciation and deepest drift accumulation, the preglacial contour of the rock surface, so far as its minor features are concerned, is thoroughly obscured or obliterated, and the existing surface aspect is mainly dependent upon the disposal of the drift. This statement is not intended to be interpreted so broadly as to mean the obliteration of the wider valley basins, nor, indeed, often of the valleys of tributaries, but is intended to cover the local topographical details. While the heaping up of the till on the surface was subject to many irregularities not readily classified or described, there are certain prevalent modes that admit of generalization.

Linear Ridges and Elliptical and Mammillary Hills.—A prevailing tendency to accumulation in elongated ridges coincident with the direction of drift movement is very generally observed and often becomes a very pronounced feature. Ridges of till of very moderate width and of varying heights, not often exceeding 100 feet, and of lengths varying from several miles down to scarcely more than their diameter, occupy large areas of the more heavily drift-covered regions. In some localities the shorter forms are prevalent, constituting the lenticular hills of Professor Hitchcock or the mammillary hills of the Wisconsin reports. While the elongated and the short varieties have not usually been observed to be prevalent in the same districts, yet they seem to be of the same nature and to represent the results of the same causal action, whatever that may have been in precise detail. These ridges and hills usually present beautifully softened and flowing contours. In some instances they are thickly set upon the surface, giving a closely ridged or rapidly undulatory contour; more frequently, perhaps, they are disposed at moderate distances from each other, the intervals being occupied by plane or gently depressed valleys. Sometimes these linear ridges of till are replaced by those of sand or gravel in whole or in part but they still retain a more flowing and less abrupt contour than the physically similar Åsar, which are to be distinguished from them. In some instances these elongated drift-domes possess a nucleus of rock, but in very many instances—the majority in the plainer country—deep cuts and wells fail to reveal any. It is to be suspected, however, that a deeply hidden boss of rock is usually, and perhaps universally, the determining cause of these peculiar accumulations.

Transverse Drift Ridges.—As remarked, the foregoing ridging of the till conforms to the direction of glacial movement. A less conspicuous tendency to a ridged accumulation is sometimes manifested in a transverse direction. This is presumably due to different rates of glacial recession and different degrees of intensity of glacial action. Ridges of this class stand in a relation to glacial movement analogous to that of terminal and peripheral moraines, and sometimes they approach the latter to a greater or less degree in character. Through them the till type grades into the peripheral morainic type.

5. THE MORAINIC TYPE.

In this discussion, for convenience, the term morainic will be used in the restricted sense of referring solely to terminal moraines, unless otherwise indicated. As this type will be the subject of special description in the body of the discussion, it will suffice here to describe it as a formation whose surface is of an exceedingly irregular, intricate character, formed by knobs, peaks, short irregular hills and spurs associated in complex order, interspersed with hollows and depressions of like irregular character often without outlet. It is a topographical species absolutely impossible of formation by drainage agencies, and is usually quite clearly distinguishable from the surface aspects presented by the drift in general. The type embraces several sub-varieties dependent on the nature of the bottom on which the moraine was formed, the material of its constitution and its relation to aqueous agencies.

6. THE KAME TYPE.

Of the Kame type, Professor Geikie gives the following graphic description:

> The sands and gravels have a tendency to shape themselves into mounds and winding ridges, which give a hummocky and rapidly undulating outline to the ground. Indeed, so characteristic is this appearance, that by it alone we are often able to mark out the boundaries of the deposit with as much precision as we could were all the vegetation and soil stripped away and the various subsoils laid bare. Occasionally ridges may be tracked continuously for several miles, running like great artificial ramparts across the country. These vary in breadth and height, some of the more conspicuous ones being upwards of four or five hundred feet broad at the base and sloping upwards at an angle of 25° or even 35° to a height of 60 feet and more above the general surface of the ground. It is most common, however, to find mounds and ridges confusedly intermingled, crossing and recrossing each other at all angles, so as to inclose deep hollows and pits between. Seen from some dominant point, such an assemblage of *kames*, as they are called, looks like a tumbled sea—the ground now swelling into long undulations, now rising suddenly into beautiful peaks and cones, and anon curving up in sharp ridges that often wheel suddenly round so as to inclose a lakelet of bright, clear water. *

This, as a topographical type, if not in origin, is certainly to be distinguished from the linear Åsar ridges. It is scarcely possible to distinguish kame topography, as above described, from the true morainic. The latter embraces precisely the same features, but in situations in

* Great Ice Age, Revised Ed., 1876. p. 211, by James Geikie.

which its material is coarse, it assumes less smooth and gracefully sinuous contours. Considered bodily, it assumes a massiveness and strength of expression not possessed by the other.

7. THE DUNE TYPE.

Very similar to the preceding is the topographical expression very commonly assumed by sand drift. There are minor features of difference, but the character of the material furnishes so decisive a means of discrimination that topographical distinctions are of no importance.

8. THE BEACH TYPE.

Drift heaped up by beach action is commonly arranged in a linear ridge or group of parallel ridges of moderate height and low slope which, from their relation to adjacent lacustrine plains, leave little ground for error of determination. Occasionally, however, the ridges are broken into undulatory hills and occupy a considerable breadth. If to this is added the not uncommon circumstance of a general plain on either hand and the consequent setting forth of the ridges into undue importance, by contrast, this topographic phase may be a possible source of misinterpretation. The capabilities of beach action have been by some regarded as much more potent than that here indicated. Portions of the great moraines themselves have been ascribed to beach action.

9. THE LACUSTRINE OR MARINE TYPE.

It is scarcely necessary to observe that the topography produced by lacustrine and marine deposition is of the plane type. The tendency of such deposition is to level up whatever of irregularity may have originally existed, and to produce a surface that approaches an absolute plane. But when the submergence is of limited duration the result may be merely a subduing of the previous irregularities by the deposition over the whole of a mantel of silt, which, for obvious reasons, gathers more largely in the depressions than on the prominences. There results from this action a series of modified topographic types, the discrimination of which is of supreme importance in the study of Quaternary deposits and of scarcely less than supreme difficulty. This is especially true in cases of submergence beneath bodies of water which bore floating ice and deposited mixed material which can only be distinguished with difficulty from the true glacial drift. Where till areas were submerged beneath waters producing iceberg deposits, the resulting topography is a subdued form of the till type. The superficial material closely resembles till, and the true determination of the composite formation is manifestly difficult. Where the terminal moraine was thus submerged its characteristic features were modified and its material concealed, so that its tracing sometimes becomes difficult and unsatisfactory. When plains of assorted material have been submerged and buried under such floating ice deposits the latter are liable to be mistaken for a second glacial deposit.

A similar series of modifications arise where the basal formation is produced under water, and is directly modified by aqueous action. Where the glacial edge was submerged beneath marginal lakes it is safe to assume that the terminal moraine underwent important modification in the very process of its formation as well as by the subsequent action of the water. It is certain that in situations interpreted as being instances of submersion it presents a strikingly modified character. The whole subject of the modification effected by water action upon the fundamental glacial drift presents a wide field which invites the most critical study of all workers in Quaternary geology.

10. FLUVIATILE TYPES.

It is scarcely necessary to dwell upon the topographical features produced by fluviatile action in their relations to the present discussion, since what has been already said under the previous topic of *Fluviatile Deposits* sufficiently indicates the surface contours resulting from river action. The subvarieties are embraced under (1) channels, (2) plains, produced by widely wandering streams, (3) valley streams of drift, producing flat-bottomed valleys, and (4) terraces.

CHAPTER II.

THE MORAINE.

The formation under consideration consists of an extensive belt of peculiarly ridged drift, stretching from the Atlantic in a sinuous course across the Northern States of the Union to Dakota, and thence onward into the British Possessions to an undetermined distance. It constitutes a broad, irregular range of confusedly heaped drift rather than a simple continuous ridge or group of definite parallel ridges, as has perhaps too often been the conception of a terminal moraine. Genetically considered, it embraces two or more such ranges, which sometimes coalesce into a common massive belt, and sometimes separate so as to reveal their distinct individuality and to occupy a width of twenty or thirty miles. The individual ranges in such instances are from one mile to five or six miles or even more in breadth, and embrace in themselves, on a smaller scale, the same confusion and complexity of structure that is presented by the united whole. These individual belts are themselves sometimes further resolvable into several subordinate ridges, but these are rarely distinct and definite for any considerable distance, and the analysis of the belt into two leading and perhaps one subordinate moraine is all that is deemed serviceable in the general discussion here attempted.

Surface configuration.—Conceiving each moraine to be as a whole a broad range of much massiveness, but not usually of very abrupt or impressive height, we may descend to the peculiarities of its surface relief. The superficial aspect of the formation is that of an irregular, intricate series of drift ridges and hills of rapidly, but often very gracefully, undulating contour, consisting of rounded domes, conical peaks, winding and occasionally geniculated ridges, short, sharp spurs, mounds, knolls, and hummocks, promiscuously arranged, accompanied by corresponding depressions, that are sometimes even more striking in character. These depressions, which to casual observation constitute one of the most peculiar features of the range, are variously known as "potash kettles," "pot holes," "pots and kettles," "sinks," &c. Those that have most arrested popular attention are circular in outline and symmetrical in form, not unlike the homely utensils that have given them names. But it is important to observe that the most of these depressions are not so symmetrical as to merit the application of these terms. Occasionally they approach the form of a funnel, or of an inverted bell, while the shallow ones are mere saucer-like hollows, and others are rudely oval, oblong, elliptical, or are extended into trough-like or even winding hollows, while irregular departures from all these forms are most common. In depth, these cavities vary from the merest indentation of the surface to bowls sixty feet or more deep, while in the irregular forms the descent is not infrequently one hundred feet or more. The slope of the sides varies greatly, but in the deeper ones it very often reaches an angle of 30° or 35° with the horizon, or, in other words, is about as steep as the material will lie. In horizontal dimensions those that are popularly recognized as "kettles" seldom exceed five hundred feet in diameter, but, structurally considered, they cannot be limited to this dimension, and it may be difficult to assign definite limits to them. One of the peculiarities of the range is the large number of small lakes, without inlet or outlet, that dot its course. Some of these are mere ponds of water at the bottom of the typical "kettles," and from this they graduate by imperceptible degrees into lakelets of two or three miles diameter and into elongated irregular lakes of greater extent.

The depressions have their counterpart in rounded hills and hillocks, that may not inaptly be styled inverted "kettles." These give to the surface an irregularity sometimes fittingly designated "knobby drift." The trough-like, winding hollows have their correlatives in sharp, serpentine ridges. The combined effect of these elevations and depressions is to give to the surface an entirely distinctive character.

These features are to be regarded, however, simply as subordinate elements or modes of relief of the main range, since these hillocks and hollows are variously distributed over its surface. They are usually most abundant upon its more abrupt face, but occur, in greater or less force, on all sides of it, and in various situations. Not infrequently they occur distributed over comparatively level areas adjacent to the range. Sometimes the knobs and basins prevail in the lower portions, the stouter ridges having smoother contours; and, again, the reverse is the case, or they are promiscuously distributed over both hill and valley.

The moraine exhibits its composite character in a series of rudely parallel ridges, that unite, interlock, separate, appear, and disappear in an intricate and eccentric manner. Several of these subordinate ridges are often clearly discernible. It is usually between these component ridges, and occupying depressions evidently caused by their divergence, that most of the larger lakes embosomed in the moraine are found. Ridges running across the trend of the range, as well as transverse spurs extending out from it, are not uncommon features. The component ridges are themselves exceedingly irregular in height and breadth, being often much broken and interrupted. The united effect of all the foregoing features is to give to the formation a strikingly irregular and complicated aspect.

Structure and material of the formation.—Considered in respect to its internal constitution the formation is distinguishable into two portions, the one, usually the uppermost but not occupying the heights of the range where it has its best development, consists almost wholly of assorted and stratified material. To this class belong not only the material of the level areas within the belt, and of undulatory sheets overlying and masking the more irregular deposits beneath, but many of the sharp ridges, knolls, and peaks are likewise composed of well-rounded, water-worn pebbles and sand. This material is arranged in definite and usually discordant stratification, the constituent layers being in part horizontal, but more frequently inclined, undulatory, arching, or irregular. The layers decline, much more frequently than otherwise, toward the outer side of the moraine—that is, usually to the southward—but this is not by any means universal. In the knolls and ridges an anticlinal arrangement is common. This portion of the formation coincides very closely with the descriptions of the irregular, undulatory variety of kames, as delineated by Geikie and others.

The other element of the formation, and the one which constitutes its basal portion and its great core when developed under favorable conditions, consists of a confused commingling of clay, sand, gravel, and bowlders of the most pronounced type. There is every gradation of material from bowlders of many tons weight down to the finest rock flour. The erratics exhibit all degrees of angularity from those that are scarcely abraded at all to thoroughly rounded bowlders. The corrasion of these is of the glacial type, and examples presenting polished and striated faces abound. The finer material, when derived from limestone, demonstrates its mechanical origin by brisk effervescence in response to the application of acids.*

In some cases this material is indistinguishable from true till, and is doubtless to be regarded merely as till pushed up into corrugations by the mechanical action of the ice, but for the greater part there is a relative preponderance of stony material, indicating, as it would seem, a partial removal of the finer constituents by water during the corrugatory process which gave it its special form. Even this portion of the range is not, however, without its stratified constituents. Intercalated in various ways with the heterogeneous material are local beds of assorted and stratified drift, the product doubtless of the abundant glacial waters that washed over or escaped through the moraine while the ice pressed against it, or that gathered in pools and lakelets along the glacial margin, catching and stratifying the over-wash previous to its burial by subsequent glacial oscillations.

The source of the material.—In this preliminary definition of the formation it will suffice to remark that a notably large ingredient of its material was derived from the formations that lie subjacent and immediately adjacent to it on the side whence the drift came. This is so conspicuous a fact that the constitution of the range is observed to be continually undergoing change as it is traced linearly in its course across the various formations traversed by it. These transitions are some-

* The fact that the *character* of drift clays largely demonstrates their mechanical origin in the absence of disintegrating agencies seems to be generally overlooked by those who suppose them to be formed from preglacial residuary clays rearranged.

PARTIAL SECTION OF THE MORAINE NEAR WHITEWATER, WIS.
(From photograph.)

times surprisingly abrupt and pronounced. But, in addition to this local material, there is always present a greater or less amount representing the formations that lie in succession backward along the line of drift movement for 500 miles or more. There is everywhere present an important element of crystalline rock that is mainly derived from the Canadian highlands.*

As a result of this diverse derivation the material is of the most heterogeneous character, embracing constituents derived from the entire geological series and representatives of nearly every common lithological class.

DISTRIBUTION.

Waiving for the moment any doubts or qualifications that may arise as to the correct interpretation and correlation of portions of the moraine, and viewing it comprehensively, it may be said to stretch entirely across the Northern States, from the peninsula of Cape Cod to the northern boundary of Dakota, where it passes into the British Possessions, and reaches on northwesterly to a determined distance of 400 miles (Dawson), beyond which its extension is yet only a matter of hypothesis.

Morainic loops.—It does not span this broad area, however, in anything like a direct course, or even in those moderate sinuosities which mark the southern margin of the drift as at present outlined, but, on the contrary, it is disposed in a series of great loops which give to the whole a peculiar arcuate expression. A remarkable peculiarity is the extraordinary fact that the lateral portions of these loops do not simply join, forming re-entrant angles, but coalesce and are prolonged sometimes a hundred miles or more between the lobate areas embraced by the loops, forming a peculiar morainic type, to which the term *intermediate* or *interlobate moraines* will be applied. It is scarcely necessary to remark that the convexities of these loops are turned to the southward.

It is a significant fact, as will appear in the further discussion, that each of these loops embraces a broad valley-basin, sometimes forming its water-shed, and at other times occupying various attitudes on its slope. It will subserve present convenience to anticipate the conclusion, which has been already elsewhere announced,† that these loops were severally formed by great ice-tongues which occupied the included valleys, and heaped up the moraines about their margins. Twelve such great loops make up the major links of the morainic chain, while several subordi-

* In the coast region, where local crystalline formations yielded the larger proportion of the crystalline drift observed, the Canadian contribution is undoubtedly present though it may not be distinguishable.

† On the Extent and Significance of the Kettle Moraine. Trans. Wis. Acad. of Sci.

nate ones constitute interesting minor features. The easternmost which falls under our present purview has for its main axis the Champlain-Hudson Valley; next which, on the west, lies the Finger Lake loop of South-Central New York, followed, in order, by the Grand River loop of Eastern Ohio; the Scioto loop of West-Central Ohio; the Maumee loop of Northwestern Ohio, Northeastern Indiana, and Southeastern Michigân; the Saginaw loop of Northeastern Michigan; the Lake Michigan loop, embracing almost concentrically that grand body of water; the Green Bay loop of Eastern Wisconsin; the Chippewa Valley loop of Northern Wisconsin; the Lake Superior loop of Northwestern Wisconsin and Northeastern Minnesota; the Minnesota River loop of Southern Minnesota and Northern Iowa; and the Dakota or James River loop of Eastern Dakota. A compendious view of the general geographical disposition of these loops may be obtained by reference to the accompanying map.

Relations to drift margin.—Preliminary to its special description, it is important to observe that the moraine does not lie on the extreme margin of the drift area. While it is in part marginal at the east, it is divergent from the extreme drift limit to the extent of some hundreds of miles in the Mississippi Valley, but again approaches and subsequently diverges from it toward the northwest. That a portion of this outer area suffered active glaciation is indicated by abrasion and striation, by local transportation, and by marginal moraines, and the presumption is justified that the greater portion was overspread by an ice-sheet, though positive evidence of this in certain parts is yet scanty. A portion of this area may perhaps have been covered with drift by transporting agencies other than land ice. The essential fact, however, that concerns us here is that a large area outside the arcuate line of our moraine suffered glaciation, and that the moraine is to that extent medial rather than marginal in position, separating a large drift area on the south from a still larger one on the north.

SPECIAL DESCRIPTIONS OF MORAINIC LOOPS.

In the special study of the individual loops of this great chain, that of the Green Bay glacier, though one of the smaller members of the series, presents strong claims to precedence: First, because, historically, it earliest received critical delineation and demonstration of its remarkable characteristics; and, second, because it presents in greater fullness, definiteness, and decisiveness the evidence on which rests the determination of the laws of glacial movement that governed the formation of the entire chain, but which are not everywhere equally demonstrable. This arises from several circumstances: 1. The bottom of this glacial valley is largely free from concealment by subsequent formations

Julius Bien & Co. lith.

Scale 1 Inch = 150 Miles

T. C. Chamberlin, Geologist

GENERAL MAP OF THE TERMINAL MORAINE
OF THE SECOND GLACIAL EPOCH.

DRIFT-BEARING AREA — STRIAE — MORAINE — GLACIAL MOVEMENTS (GENERALIZED) or by lake occupation, and the original glacial drift is presented to investigation in an essentially unmodified exposure. 2. The rock floor reveals with sufficient frequency the glacial planing to which it was subjected, and exhibits its varying modes and degrees. 3. The disposal of the underlying rock formations is favorable for furnishing unequivocal evidence of the character and direction of drift transportation. Exceptional means of determination are afforded by knobs of Archæan rock, which protrude through the horizontal beds of the Paleozoic series, and whose abrasion, striation, and *trains of bowlders* are not less than demonstrative of the method of drift dispersion. 4. The topographical features of the area were such as to furnish free opportunity for the unobstructed deploy of the glacier, while at the same time its surface relief was such as to exhibit at once glacial dependence upon certain physiographic circumstances and practical independence of others. No other loop that has been thus far studied presents the essential data of determination in an equally clear and satisfactory manner, though several exhibit some characteristics on a grander and more striking scale, and possess special characteristics of superior interest. It is improbable that the whole glacial field, when fully explored, will offer a better type-example of the formation of a glacial tongue in open and comparatively plane country, and of the remarkable laws that governed its action, than did the little glacier of the Green-Bay-Rock-River Valley, one of the least among its brethren. This, together with, possibly, a touch of fatherly affection for this mentally first-born, must be my excuse for commencing the detailed description in the midst of the chain.

MORAINE OF THE GREEN BAY GLACIER.

The moraine of the Green Bay glacier parts from that of the Lake Michigan lobe near the northwestern corner of Walworth County, about 20 miles north of the southern limit of Wisconsin, and about 45 miles west of Lake Michigan. From this point a common intermediate moraine, formed jointly by the action of the Lake Michigan and Green Bay glaciers, extends northerly and northeasterly across the southeastern corner of Jefferson County, through the center of the western half of Waukesha County, somewhat diagonally through the center of Washington County, across the southeastern corner of Fond du Lac County, somewhat diagonally along the west side and across the northwestern quarter of Sheboygan County, across the west-central portion of Manitowoc County, entering the county of Kewaunee at its southwestern corner, and penetrating it diagonally to near its center. The townships principally involved are Richmond, Whitewater, and La Grange, of Walworth County; Palmyra, of Jefferson County; Eagle, Ottawa, Genesee, Summit, Delafield, Oconomowoc, and Merton, of Waukesha County; Erin, Hartford, Polk, West Bend, Kewaskum, and Farmington, of Washington County; Auburn, Scott, Osceola, Mitchell, Forest, Greenbush, Plymouth, and Rhine, of Sheboygan County; Schleswig, Meeme, Liberty, Cato, Franklin, Cooperstown, and Gibson, of Manitowoc County, and Franklin, Montpelier, and Casco, of Kewaunee County. Its margin touches slightly upon several other townships and lateral spurs project into still others, but it is not my purpose, in this sketch, to enter into tedious details of distribution.

Parting from this common intermediate moraine, at the point named, the western limb, which marks the outer margin of the Green Bay glacier, extends westward across the valley of Rock River in a gentle curve, beyond which it turns more rapidly northward, and extends to the northwest diagonally across Dane County, forming the summit between the Catfish and Sugar Rivers. Near the northwestern corner of Dane County, it descends into the valley of the Wisconsin River, from which it again rises and mounts the Baraboo ranges in a vertical undulation of over 700 feet,* beyond which it again crosses the Wisconsin River in the northeastern corner of Sauk County, and thence rises to the watershed between the Wisconsin and the Fox Rivers. Passing a little east of north, it embraces the boundary line between Adams and Marquette Counties, traverses the western portion of Waushara County, there turning more nearly north along the watershed between the Wisconsin and Wolf Rivers, it embraces the boundary line between Portage and Waupaca Counties, and that between Marathon and Shawano, and enters Langlade County, whence a range runs curvingly to the northwest and crosses the Wisconsin River in the south-central part of Lincoln County, near the mouth of the Tomahawk River. This portion here becomes the southwest moraine of the Chippewa Valley glacier. In the dense forest which prevails in this northern region, the moraine has not been consecutively traced, and its precise details and connections are as yet unascertained, though it has been seen at a sufficient number of points to determine the more important facts.

A moraine which is, without much doubt, a member of the series, extends in a northerly and southerly direction through the western portion of Marinette County as now established, into the central portion of Oconto County, and probably joins that above described in southern Langlade County. Portions of this have been described by Colonel Whittlesey.†

Topographical relations.—By forming a mental picture of the Green-Bay-Rock-River Valley, the topographical relations of the moraine may be readily conceived. The region is mainly underlain by the Paleozoic series, ranging from the Niagara limestone downward to the Archæan.

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*Irving, Geol. of Wis., vol. II, p. 616.

† On the Fresh Water Glacial Drift of the Northwestern States. Smithsonian Cont., 1866.

MAP OF THE GREEN BAY LOOP OF THE TERMINAL MORAINE OF THE SECOND GLACIAL EPOCH.

DRIFT-BEARING AREA — STRIAE — MORAINE — GLACIAL MOVEMENTS (GENERALIZED)

The strata dip gently to the eastward, and the valley is grooved along their slightly upturned edges, being essentially coincident with the strike. The trough has been mainly excavated from the soft Hudson River or Cincinnati shales, the massive Niagara limestone forming a projecting cliff-face upon the east, and the Lower Silurian strata constituting, in the main, the bottom of the valley. A smooth bottom, a gentle westerly slope, an abrupt margin 200 to 400 feet in height on the east, and a gentle descent toward Lake Michigan, constitute the essential features as exhibited in cross-section. Viewed longitudinally, the valley rises from Green Bay by a gradual ascent on a smoothed rock-floor to the watershed of the Rock River, about 300 feet above the bay, or nearly 900 feet above the ocean, whence the slope falls by a gradual descent 100 feet to the point where crossed by the moraine, beyond which it continues, in essentially uninterrupted descent, to the Mississippi. The intermediate moraine above mentioned, at the point of separation of the Green Bay and Lake Michigan glaciers in northwestern Walworth County, and in Waukesha County, lies upon the crest of an easterly sloping rock ridge formed by the projecting edge of the Niagara limestone, but instead of following this to the northward, it gradually declines on the eastern slope until at its termination opposite the head of Green Bay it lies midway the slope between the shore of Lake Michigan and the escarpment that overlooks Green Bay. At its southern extremity, as remarked, the Green Bay loop crosses the Rock River Valley, descending perhaps 300 feet, beyond which it gradually climbs a southerly slope to the watershed between the tributaries of the Rock and the Wisconsin, beyond which, as already remarked, in crossing the great bend of the Wisconsin, it twice descends into the valley with an intervening rise over the high Baraboo ridges. Beyond this point it slowly ascends the long southern slope that characterizes Central Wisconsin. In this part of its course, as also in that lying between the Catfish and Sugar Rivers in Dane County, it is difficult to determine in how far it lies upon a pre-existing watershed, and to what extent it, of itself, constitutes the watershed. That to some extent it determines the water-parting by its own massiveness, scarcely admits of doubt.

It will be observed that, even in this limited loop, the moraine shows its disregard of minor topographical features, while in its general distribution it reveals a dependent relationship to the grander features. It occupies watersheds, lies obliquely on rock slopes, crosses considerable valleys, with vertical undulations of several hundred feet, and, to some extent, determines drainage systems by its own massiveness.

That portion of the loop which marks the western margin of the glacier is more diffuse in its development than the interlobate moraine on the opposite side. Its constituent members separate more widely so as to reach a breadth of 25 miles, and, on account of this something of diffuseness, it is less pronounced in its special features, but nevertheless constitutes a well characterized belt standing in marked contrast to the linear ridges and dolphin-backed hills of the adjacent area of till.

Relation to driftless area.—In a portion of this course it lies immediately adjacent to the remarkable driftless area of Wisconsin, Minnesota, Iowa, and Illinois, and here forms the boundary of the drift-bearing area, representing the greatest glacial advance attained in this particular region. The indented outline of the driftless area (see map) strongly suggests an encroachment of the ice upon its previous territory.

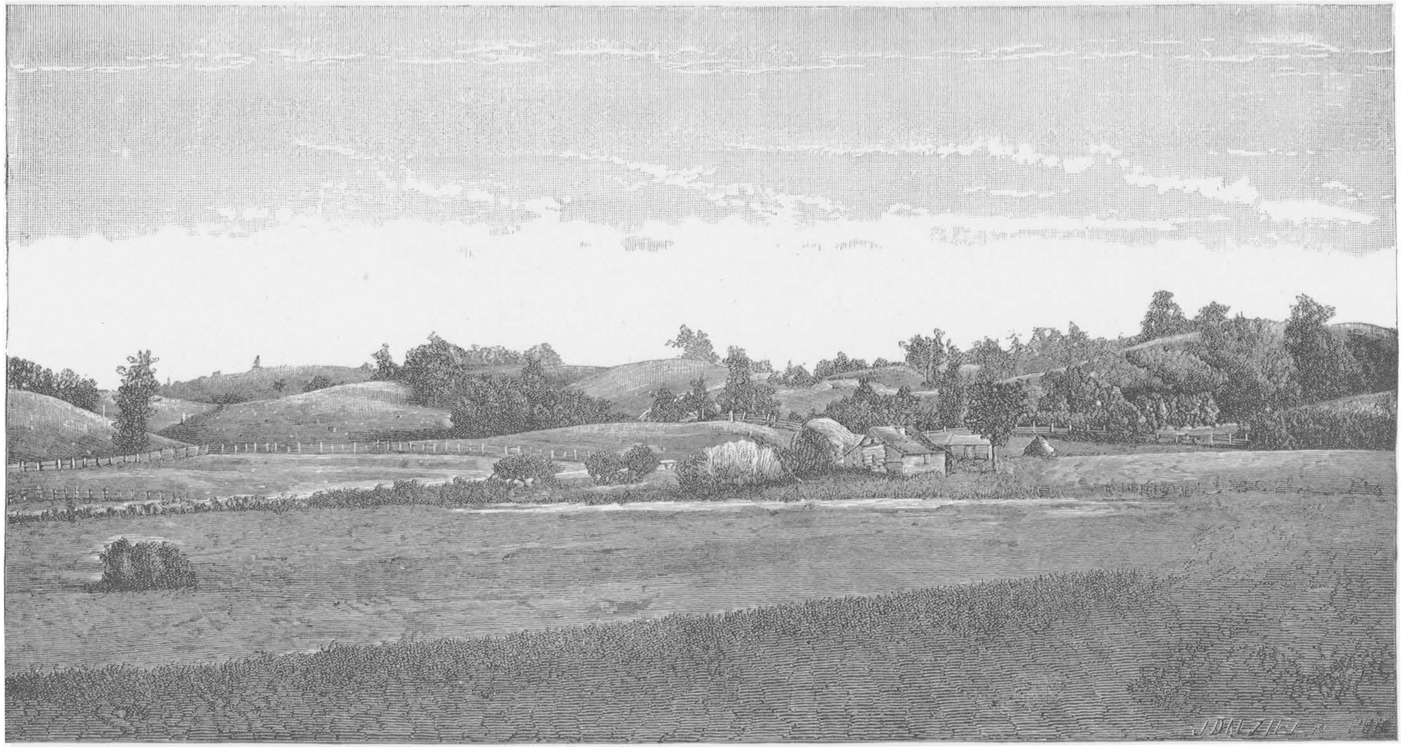
The interlobate moraine that forms the eastern side of the loop constitutes the range of hills locally known as the Potash Kettle Range, or simply Kettle Range, and forms one of the best marked and most characteristic portions of the moraine observed throughout its great extent. This, by priority of investigation, as well as by the typical character of its development, and the significant nature of its name, is fairly entitled to give name to the range as a whole, if convenience of reference shall make a specific title needful.

Character of the Moraine.—Concerning the characteristics of this portion of the moraine, it is only necessary to say that the general description already given is strictly applicable to it.

GLACIAL MOVEMENTS.

Linear topography.—The area embraced within this loop affords evidences of glacial action of a highly instructive and demonstrative character. Over a considerable portion of the region the drift is heaped up in linearly-arranged hills, elongated domes, or lengthened ridges, interspersed with lowlands, marshes, and lakes of similar elongated character. A general survey will reveal a symmetrical arrangement of these significant features. Along the central belt of the valley the linear arrangement is south-southwesterly, coincident with its axis. On the eastern side the trend diverges gradually to the eastward, and near the moraine stands almost directly transverse to it. On the west side the lines diverge in like manner until they run well to the west, and often due west, standing approximately at right angles to the moraine on that side.

Striation.—If the rock floor be examined it will be observed that the central bottom belt of the valley, in all the northern portion, is a smoothed floor, planed and polished in the most beautiful manner, and striated in a direction parallel to the general axis of the trough. Passing out of the axial bottom upon the westerly slope, the striations are found to be more and more divergent until they trend in an almost direct westerly course, approximately at right angles to the moraine on that border. On the easterly side of the axis, on rising above the Niagara escarpment that borders the valley on that side, the groovings are found to point southeasterly toward the moraine. On the opposite side of the intermediate moraine, between it and Lake Michigan, the striations run nearly at right angles to the moraine in its vicinity, while, on the lake shore, their



WESTERN FACE OF THE MORAINE NEAR EAGLE, WIS.
(From photograph.)

trend is, on the average, more nearly coincident with the axis of the lake.

*Striæ within the area of the Green Bay glacier.**

I.—*In the axis of the trough.*

Fort Howard, sec. 10, Bennet's quarry, Duck Creek, Brown Co	S. 29° W.
Fort Howard, sec. 10, north quarry, Duck Creek, Brown Co	S. 20° W.
Peshtigo, T. 30, R. 22, sec. 4, near center Marinette Co	S. 41° W.
Peshtigo, T. 30, R. 22 E., sec. 21, E h'f, SW. qr., Marinette Co	S. 27° W.
Oneida Reserve, mill on Duck Creek, Brown Co	S. 20° W.
Menasha, sec. 11, E. h'f of SW. qr., Winnebago Co	S. 21½° W.
Neenah, sec. 34, NE. qr., Winnebago Co	S. 27° W.
Fond du Lac, Moore's quarry, Fond du Lac Co	S. 15° W.
Taycheedah, Fond du Lac Co	S. 15° W.
Byron, sec. 10, Fond du Lac Co	S. 3° W.
Beaver Dam, sec. 20, SE. qr., Dodge Co	Due south.
Koshkonong Prairie, Jefferson Co	S. 7° E.
Fulton, sec. 12, NE. qr., Rock Co	S. 13° W.
Albion, SW. qr., sec. 14, T. 5, R. 12 E., Dane Co	S. 35° E.
Christiana, NW. qr., sec. 35, T. 6, R. 12 E., Dane Co	S. 5° W.

II.—*On the east side of the axis.*

Casco, sec. 14, SW. qr., T. 24, R. 23, on summit of ridge, Kewaunee Co	S. 4° E.
Marshfield, J. Steffer's quarry, sec. 30, SW. qr., Kewaunee Co	S. 28° E.
Taycheedah, T. 16, R. 18, sec. 29, SW. qr. of SE. qr., Fond du Lac Co	S. 10° E.
Empire, sec. 5, NW. qr., Fond du Lac Co	S. 18° E.
Ashford, R. R. cut, sec. 11, Fond du Lac Co	S. 59° E.
Elmore, Ashford, sec. 26, NE. qr., Fond du Lac Co	S. 44° E.
Delafield, sec. 20, SE. qr., Waukesha Co	S. 26° E.
Whitewater, near Kinney's, Walworth Co	S. 7° E.
Whitewater, SE. of Cravath Lake, Walworth Co	S. 12° W.

III.—*On the west side of the axis.*

Portland, sec. 35, SE. qr., Dodge Co	S. 30° W.
Milford, sec. 33, SW. qr., Dodge Co	S. 30° W.
Calamus, sec. 18, near center, Dodge Co	S. 36° W.
Westford, sec. 19, middle SE. qr., Dodge Co., first set	S. 24° W.
Crossed by second set	S. 46° W.
Trenton, McFarland's quarry, Dodge Co	S. 50° W.
Green Lake, sec. 33, Green Lake Co	S. 45° W.
Green Lake, sec. 3, Green Lake Co	Due west.
Ripon, sec. 19, Fond du Lac Co	•S. 82° W.
Metomen, sec. 1, NE. qr., Fond du Lac Co	S. 45° W.
Nepeuskin, sec. 4, near middle south line Winnebago Co	S. 94° W.
Nepeuskin, sec. 15, NW. qr., Winnebago Co	S. 87° W.
Nepeuskin, sec. 15, near center, Winnebago Co	S. 84° W.
Black Creek, watering station G. B. & M. R. R., Outagamie Co	S. 72° W.
Peshtigo, T. 33, R. 20, sec. 21, E. h'f of SW. qr., Marinette Co	S. 82° W.
Sun Prairie, NW. qr., sec. 14, T. 8, R. 11 E., Dane Co	S. 19° W.
Blooming Grove, NW. qr., sec. 17, T. 7, R. 10 E., Dane Co	S. 47° W.
Madison, NW. qr., sec. 21, T. 7, R. 9 E., Dane Co	S. 57° W.
Springfield, NW. qr., sec. 14, T. 8, R. 8 E., Dane Co	S. 73° W.

*Geol. of Wis., vol. II, pp. 201 (Chamberlin) and 626 (Irving).

Springfield, NE. qr., sec. 15, T. 8, R. 8 E., Dane Co	S. 81° W
Lodi, SE. qr., sec. 23, T. 10, R. 8 E., Columbia Co	Due west.
Freedom, NE. qr., sec. 2, T. 11, R. 6 E., Sauk Co	S. 65° W.
Fairfield, NW. qr., sec. 26, T. 12, R. 7 E., Sauk Co	S. 85° W.
Fairfield, NW. qr., sec. 25, T. 12, R. 7 E., Sauk Co	S. 50° W.
Caledonia, NE. qr., sec. 26, T. 12, R. 8 E., Columbia Co	S. 85° W.
Columbus, SE. qr., sec. 3, T. 10, R. 12 E, Columbia Co	S. 47½° W.
Randolph, SE. qr., sec. 1, T. 13, R. 12 E., Columbia Co	S. 63° W.
Neskoro, NE. qr., sec., 2, T. 17, R. 11 E., Green Lake Co	S. 68° W.

Bowlder Trains.—If the foregoing lines of observation left any doubt as to the directions of drift movement, it could scarcely survive the consideration of the phenomena connected with the knobs of granite, quartzite, and quartz-porphyry which protrude through the horizontal Palæozoic strata. These are so far isolated and peculiar in their characteristics that there is no occasion for mistake in interpretation. These knobs are abraded upon the stross side, and are striated in lines curving over their domes, and from their lee sides there stretch away trains of bowlders that spread more and more widely into comet-like trains, and become progressively more and more rounded with increased distance of transportation. The location and direction of these trains will be found on the accompanying map.

Law of movements.—The testimony of these three classes of evidence as to glacial movements is entirely harmonious and coincides with such minor and less definite testimony as can be drawn from the peculiarities of constitution and arrangement of the drift and from other lines of observation. Taken together, they clearly demonstrate that the central movement of ice was south-southwesterly along the axis of the valley, while on either flank the lines of movement diverged toward the lateral margins, as diagrammatically illustrated on the accompanying map. This divergent method of flow, here so well demonstrated, is found to be a prevalent characteristic of all the lobes thus far investigated, and may be regarded as a well established law.

Taken altogether, these facts beautifully demonstrate the former existence of a distinct glacial lobe, not only separated from that of Lake Michigan by an intermediate moraine 170 miles in length, but possessing a flowage entirely independent for even a greater length, and what at first seems strangest, its marginal flowage on the left was almost directly opposed to that of the adjacent margin of the Lake Michigan glacier.

An inspection of the peninsula between Green Bay and Lake Michigan shows that it is indented on opposite sides by fiord-like channels which stand obliquely opposite each other in pairs. From a study of the surface contours and of a single locality where striations are preserved, it appears quite clear that the ice of the Green Bay lobe pushed over the peninsula into the Lake Michigan basin, instead of suffering encroachment from its greater neighbor as might, perhaps, naturally be expected. This may have been true, however, only of the closing phase of action, when the greater glacier had shrunk within the deep lake channel and permitted the smaller Green Bay stream to encroach upon its margin, which its position would incline it to do.

It is a further observation that the glacial movement was quite independent of the minor slopes. The ice moved from Green Bay *up* the valley to the watershed of Rock River, roundly 300 feet higher, beyond which it flowed down a gentle decline. On its left hand it surmounted the Niagara escarpment, 200 to 400 feet in height, and then flowed down the slope to the interlobate moraine on the left. On the right hand it flowed up the western slope to the morainal margin. It is a somewhat strange fact that the current flowed over the watershed into the Rock River Valley, instead of following up the valley of the Fox River, which is 100 feet lower at the watershed between it and the Wisconsin River. This is but one of a series of similar phenomena whose consideration will be deferred until a fuller collocation of facts is made.

Associated deposits.—Intimately connected with the coarse, unassorted material of the moraine proper and the stratified, gravelly hills of the associated kame-like accumulations, are plains of stratified drift of varying extent, though usually not large. These are situated to some extent (1) between the branching morainic ridges, (2) to a greater extent along the inner border of the moraine, but (3) more abundantly and extensively flanking the range on its outer margin. These plains by their position, extent, and especially inclination, determine the side of the moraine which was last occupied by the ice, in the case of interlobate moraines, and, in others, the side from which they were formed. These plains are interpreted as being mainly due to contemporaneous overwash of glacial waters, and, in lesser part, to subsequent modification.

Intimately connected with these plains are streams of gravel stretching far away down the principal valleys—the product of escaping glacial waters. The chief of these are found in the valleys of the Wisconsin, the Rock, and the Sugar Rivers.

Aside from these more intimate associates of the moraine, the adjacent region is largely occupied by typical till, forming an almost universal covering of the indurated rocks, and presenting the surface contours usual to the formation, especially elongated ridges and rounded domes of gracefully flowing contour. But at its northern extremity, the intermediate moraine—the Kettle Range proper—is bordered on both flanks, and to some extent overlapped, by a pebbly red clay, which forms a belt along the shore of Lake Michigan, and is held to have been deposited by its expanded predecessor in the immediately postglacial epoch. The sharp distinction given by its color is of service in everywhere distinguishing it, and so illustrating the effects of lacustrine encroachment and deposition on the moraine. Those effects are a subduing of its irregularities and a mantling of its surface with a sheet of lacustrine pebble clay. It is somewhat remarkable, however, how little modification was in some instances effected, and how steep some mounds which are crowned with a superficial sheet of clay still remain. But if the submerging body of water was choked with floating ice, as may have been the case, wind and wave action would have been slight, and steep-sided mounds might have suffered submersion without much reduction.

MORAINE OF THE LAKE MICHIGAN GLACIER.

Distribution.—Parting from the interlobate moraine lying between the glaciers of Lake Michigan and Green Bay, near the Southern Wisconsin line, as before noted, the moraine which marks the margin of the former runs in a general southerly direction, essentially parallel to the shore of Lake Michigan, to a point about opposite to the commencement of the lake's terminal curvature, when it bears eastward nearly concentric with the lake shore, and 15 to 20 miles distant. Swinging around the head of the great lake it runs northerly, sweeping out from the shore so as to traverse the west central portion of the Lower Peninsula of Michigan, until nearly opposite the head of Saginaw Bay, beyond which it is not yet determined which of two courses suggested by present evidence is pursued by the moraine.

In a general view—including the Wisconsin moraine on the west—it may be likened to an immense U embracing the great lake between its arms. This gigantic loop, in the main the limbs of which are interlobate moraines, is over 200 miles in length and from 90 to 150 miles in width. The parallelism of this moraine to the lake shore is one of its most striking features.

Tracing more in detail, the belt leaves Wisconsin from eastern Walworth and western Kenosha Counties, extends southward into Illinois through eastern McHenry and western Lake counties, and onward through eastern Kane, western Cook, and Du Page Counties, in the last of which it begins to curve easterly, embracing the zigzag border of Cook and Will Counties, and passes into Indiana through central Lake County, being broadly distributed from below Cassville to Schererville. It traverses Porter County in its north central portion, the city of Valparaiso lying upon it. Thence it extends northeasterly across La Porte County, Otis and Rolling Prairie lying near its inner margin. It passes into Michigan in the southeast corner of Berrien County, being distributed from Dayton to Niles. Thence it passes obliquely across Cass County—Cassopolis lying upon it—crosses northwestern Kalamazoo County, being fairly developed in the vicinity of Kalamazoo. Still pursuing a northeasterly course, it traverses Barry County diagonally west of its center, developing well in the vicinity of Hastings, which lies on its eastern side. It here turns somewhat more to the north, embracing the boundary line between Kent and Ionia Counties, Ada lying near its western margin, and Saranac near its eastern. It traverses

Julius Bien & Co. lith.

T. C. Chamberlin, Geologist

MAP OF A PORTION OF THE TERMINAL MORAINE OF THE SECOND GLACIAL EPOCH

Montcalm County nearly centrally. Beyond this it is not now certain what line is to be regarded as its continuation. Some incomplete observations suggest that it turns northwesterly and joins a morainic loop that embraces Grand Traverse Bay. On the other hand, present knowledge does not forbid the hypothesis that, jointly with the Saginaw moraine, it continues onward northeasterly, in which case the Grand Traverse moraines must be regarded as of later date.

Prof. L. C. Wooster has examined this moraine, under my direction, at frequent points all along its course and gathered many details that cannot find a place here, besides making many of the determinations here included and verifying and connecting the identifications of my previous reconnaissances.

Topographical relations.—Following its course topographically, it leaves Wisconsin at elevations from 200 to 500 feet above Lake Michigan, or a little less than from 800 to 1,100 feet above the ocean, Lake Michigan being 589 feet (Gardner) above tide. Thence it descends a gentle southward decline, flanked on the east by a smooth or very gently undulatory plain, and on the west, at first, by alternating plains and gently rolling land, but farther to the south largely by plains. On this smooth surface the moraine deploys widely, but is compensatingly low and inconspicuous. It follows the descent to the Illinois River, where its base is essentially at the level of Lake Michigan. As it curves eastward it rises gently, but continues at a very moderate relative elevation throughout its whole curve about the head of the lake. (At Hebron and Crown Point, 717 feet; Valparaiso, 739 feet; La Porte, 823 feet above tide, or 128 feet, 100 feet, and 234 feet, respectively, above Lake Michigan.) Here it is bordered on the interior by the flats of Lake Michigan, and on the exterior by the great Kankakee Marsh and adjacent lowlands. As it enters Michigan it rises somewhat and correspondingly develops in strength. Passing over the low swell in southwestern Michigan, it is depressed somewhat in crossing the low belt of country which stretches southwesterly from Saginaw Bay to Lake Michigan, its base being less than 100 feet above those bodies of water. Thence its altitudes gradually increase as the highlands which form the elevated apex of the Lower Peninsula of Michigan are ascended. On the summit plateau its elevations, judging from such observations as have been made, must frequently exceed 1,000 feet. The highest portion is probably to be found in Wexford County, where it is estimated to reach about 1,500 feet above the sea.

This arm of the loop is cut across by the Saint Joseph River near the Michigan line, and by the Kalamazoo, Thorn Apple, Grand, and Muskegon Rivers in succession toward the north, all of these producing gaps of considerable width in their passage, and all flowing westward into Lake Michigan.

Modifications of character.—Following the moraine over its course again, with attention turned to its successive changes under the varying conditions which affected its formation and subsequent history, we observe that where it leaves Wisconsin, being developed on a moderately elevated rock-slope beyond the reach of contemporaneous and subsequent submergence, it displays in distinctness and something of boldness the characteristic irregularities of structure and constitution that have already been described as typical of the well developed moraine. As it descends the sloping plain southward it gradually becomes flatter and less conspicuous, the material becomes finer, and the proportion of rolled and washed constituents is notably increased.

With the progress of this change there is a gradual encroachment of the stony clay deposits that are prevalent about the head of Lake Michigan. These are not, however, the typical lacustrine clays that form the extremely flat plains immediately adjacent to the lake. They belong to the class of stony clays described in the introduction to this discussion as consisting of a homogeneous clayey base, through which is distributed pebbles, bowlderets,* and occasional bowlders, dispersed with something of the uniformity which the calculus of probabilities gives as the result of pure hazard, rather than in the irregular aggregate manner of true till. They are characterized, usually, by a gently undulatory surface intermediate between the very level lacustrine flats on the one hand and the more irregular, rolling till on the other. They are interpreted as being subaqueous deposits formed along the glacial margin through the aid of its silt-laden, ice-burdened waters—the subaqueous till of our preliminary definitions. In the lowlands about the head of Lake Michigan marginal accumulations of water are believed to have been present at the time of the formation of the moraine as well as subsequently. These stony clays make their appearance on the western shore of Lake Michigan a little above Milwaukee, and from thence southward they gradually spread westward until, at about the north line of Cook and Kane Counties, Illinois, they largely overlap the moraine. On the opposite side of the moraine they extend northward to within about twenty miles of the Wisconsin line.

As the moraine enters upon this region of prevalent clay plains it becomes still more subdued and loses most of those superficial irregu-

*I think the introduction of this term to designate a class of erratics intermediate between pebbles and bowlders will prove serviceable, especially if something more of dimensional fixity be given to them. At present the term pebbles is often extended to erratics two or three feet in diameter, while the name bowlder is occasionally carried down to those of only six or eight inches diameter. There is a very natural tendency to increase the dimensions assigned to each class when the drift is very coarse, and to diminish them when the stony constituents are generally small. I have used, as seemingly best applicable to the whole drift territory, the limitation of six or eight inches average diameter for pebbles, using the term cobble-stones or cobbles as synonymous for the larger class of pebbles, and the limits from six or eight inches to twelve or fifteen inches for bowlderets, throwing erratics above the latter dimensions into the class of bowlders. In running descriptions of course these limitations are largely neglected.

larities which characterize it in its unmodified development. Its surface material is the stony clay or berg till of the adjacent plains, with something of added stoniness, the result, probably, of the more exposed situation of its accumulation on the morainic ridge. The steep hills and hollows are subdued to gently undulatory swells and sags. Wells and other deep excavations show underlying assorted and stratified deposits and bowlder clay. This obscured condition of the range is continuous throughout the curving portion in Illinois, and through Lake and, in part, Porter Counties, in Indiana. At Valparaiso the modification is conspicuously less than to the westward, but at Shuman, in the vicinity of Jackson Centre, although the general formation is less subdued, the superficial material is composed of the subaqueous till, above described.

In Porter County the clayey character gives place to sandiness, which prevails throughout the remainder of its course. The irregularities of surface become here more pronounced, but still not strikingly developed. This portion is probably to be correlated with the somewhat gravelly portion on the opposite side of the lake, just below the Wisconsin line, both segments probably indicating the point of emergence of the moraine from the glacial foot-lake that occupied the lowland at the extremity of the lake.

From the southern line of Michigan, as far northward as it has been examined, the moraine is more sandy than the corresponding arm on the opposite side of the lake, is less sharply and characteristically developed, more indefinitely graduated into the adjacent drift, and more extensively flanked by plains of assorted material, which is also predominantly sandy. At the same time the total amount of drift is very much greater. There appears also to be a larger relative proportion of crystalline material on the eastern side, limestone and sandstone being less abundant. Locally, however, these latter develop much importance. The northern extremity of the moraine presents a larger proportion of palæozoic limestone than the southern (Wooster), due, doubtless, to its greater proximity to the Silurian and Devonian formations so forcibly glaciated about the northern extremity of the lake. It is a very noteworthy and important fact, agriculturally as well as theoretically, that much of the sand of the moraine is highly calcareous. Such sands can be referred with the utmost confidence to a mechanical origin, since disintegration essentially removes the calcareous element, as extensive observation on residuary clays has amply demonstrated.

GLACIAL MOVEMENTS.

On the Wisconsin side of this lobate area the testimony of striation, transportation, and drift arrangement is sufficiently full to be quite satisfactory. The observed striations are as follows:

Horlick's quarry, Racine (doubtful), Racine Co.	S. 26° W.
Schwickhart's quarry, sec. 26, NW. qr., Wauwatosa, Milwaukee Co.	S. 49° W.

Moody's quarry, 4th ward, Milwaukee, Milwaukee Co	S. 86° W.
Pelton's quarry, Pewaukee, Waukesha Co	S. 82° W.
Pewaukee, sec. 18, NW. qr., Waukesha Co	S. 92° W.
Lisbon, sec. 35, Waukesha Co	S. 96° W.
Sheboygan Falls, village, Sheboygan Co	S. 64° W.
Sheboygan light-house, Sheboygan Co.—	
First set	S. 56° W.
Second set	S. 4° W.
Howard's quarry, sec. 16, Sheboygan Falls, Sheboygan Co	S. 78° W.
Kuntz's quarry, on Manitowoc River, sec. 15, Manitowoc Rapids, Manitowoc Co	S. 81° W.
One-half a mile below the above, sec. 15, Manitowoc Rapids, Manitowoc Co	S. 79° W.

These are well supported by evidences drawn from abrasion, transportation, and the arrangement of drift. They indicate an axial current through the deep lake trough with a lateral divergence on the Wisconsin slope toward the moraine. On the Michigan side, and about the head of the lake, the direct evidence thus far gathered is very scanty. I have made but few observations, except in the immediate vicinity of the moraine and I glean but little from the publications of others, beyond that which indicates a general southerly movement. Perhaps the most significant is that cited by Prof. Alexander Winchell,* relating to the occurence of large blocks of Corniferous limestone in Ottawa and Van Buren Counties, Michigan, on areas underlain by later formations. Their size, numbers and angularity indicate that they have suffered little transportation, for, although floating ice could carry them long distances without abrasion, they must, in that case, have been more widely scattered. The nearest supposable source is the submerged Corniferous horizon beneath Lake Michigan. This would indicate a lateral movement from the glacial axis on this side, precisely like that on the opposite. I entertain no doubt that a careful examination of the region would develop much corroborative evidence, and render the law of lateral divergence demonstrative here, as it is so generally elsewhere.

MORAINE OF THE GRAND TRAVERSE GLACIER.

It is an interesting and in some regards quite significant fact that the little basin of Grand Traverse Bay differentiated a minor, though apparently sturdy, little glacier.† Something of the surprise is abated

*Am. Jour. Sci., Nov., 1865, p. 331.

†The actual demonstration of this was made by Professor Wooster. In my paper on the Kettle Moraine, before cited, the following remark is made: "The lake survey charts show that Grand Traverse Bay has the remarkable depth of over 600 feet. This great depth, together with its linear character and the form and arrangement of the associated inlets and lakes, has suggested that it may have been the channel of a separate minor glacier, analogous to that of Green Bay, on the opposite side of the great lake, but I have no direct evidence that such was the fact."

by considering the extraordinary depth of over 600 feet which the bay presents. The linear topography finds expression in the elongated bays, narrow lakes, and associated river valleys, and is a signal feature of the Grand Traverse region. The divergent nature of these impresses itself by a mere glance at any accurate map of the region. The deep valleys and radiant linear topography of the region seem to be a fair illustration at once of the control of pre-existent topography over glacial movement, and of the subduing and reducing effect of glacial action upon surface configuration. The result is a combination of troughs and ridges that is at once cause and effect.

Around the margin of this area of divergent ridges and valleys there runs a concentric morainic belt. Professor Wooster regards this, with good reason, as a double belt, though the observations on the outer one are insufficient to make this quite certain. He would, at the present stage of investigation, regard this loop as contemporaneous with the general moraine, but this ought not to be accepted as a confirmed view. There is room for the suspicion that this may be the product of a later advance with a newly differentiated margin. Much additional observation is needed in this region.

MORAINE OF THE SAGINAW GLACIER.

The outline of the Saginaw glacier seems to manifest the effects of the constraining circumstances under which it was formed. Situated between the powerful Lake Michigan and Maumee glaciers, it was prevented from the full lateral development which it would doubtless otherwise have attained, and, in lieu of this, prolonged itself in the narrow space between its larger neighbors. This morainic loop, therefore, exhibits a distortion significant of the situation in which it was formed.

The left hand moraine of the Michigan glacier appears to have been common to it and the Saginaw glacier from near the southern line of Michigan to a point about due west of the head of the Bay, where, perhaps, it bifurcates into moraines marginal to the two glaciers, which here become separate. The moraine of the Saginaw glacier, at least, curves to the eastward, passing diagonally across the center of Clare County; thence it traverses the southwestern corner of Roscommon and the northwestern corner of Ogemaw Counties. Throughout this region it lies approximately on the border between the lowland plains which surround Saginaw Bay and the high sandy plains which occupy the plateau of the northern portion of the peninsula. The course which the moraine pursues northeastward from Ogemaw County is not known from personal observation, but from testimony and topographical study it is presumed that it extends directly onward until it crosses the Au Sable River near its bend in western Alcona County, from whence Professor

Wooster thinks it probable that a moraine extends northwesterly to the southwestern corner of Cheboygan County, this latter portion being presumed to be marginal to an ice movement southeasterly through the northern part of Lake Huron. The glacial features of this highland region and of the northern point of the peninsula present an interesting field needing further observation, which is, however, embarrassed by the prevalence of forest and the comparatively unsettled condition of the country.

Frontal moraine.—Returning to the southern line of the State, Professor Wooster maps the frontal moraine of the Saginaw glacier as parting from the common interlobate one on the west in the vicinity of Cassopolis, and thence running easterly through southern Saint Joseph and Branch Counties to its junction, in Hillsdale County, with the joint moraine of the Saginaw and Maumee glaciers. He finds this moraine well developed at Burr Oak and between Sturgis and Perrin and westerly toward Constantine.

There is some evidence, not enough at present to warrant a very confident opinion, but still sufficient to be worthy of record, that at the stage of the greatest glacial advance of this epoch the apex of the Saginaw ice lobe pushed forward 30 or 40 miles into Indiana, halting near the southern line of the second tier of counties. Accumulations of a subdued morainic aspect, supposed to be formed at this stage, I have observed near South Bend, in central Saint Joseph County; near La Paz and west of Plymouth, in Marshall County, and on the opposite side of the supposed tongue, in southeastern Kosciusko, western Noble, and central La Grange Counties. This conjecture is in harmony with the widely-observed fact that, with trivial exceptions, the moraine skirts the limit of the lake-bearing drift. It also explains very naturally the somewhat peculiar drainage features of Northern Indiana. A few observations also seem to indicate a possible third but later line across the extremity of the loop in the vicinity of the Kalamazoo River.

The eastern limb.—The common eastern moraine stretches from Hillsdale to the northeastward in a gentle curve nearly to the point of the peninsula east of Saginaw Bay, essentially lying upon or forming the watershed between the Saginaw and Huron-Erie Basins. In this course it traverses Hillsdale County nearly centrally and diagonally, crosses the southeastern corner of Jackson, the northwestern of Washtenaw, the southeastern of Livingston, the northwest-central part of Oakland, the central portion of La Peer, in which it becomes very much narrowed, and curves more northerly, passing through the western side of Sanilac County and onward to near the center of Huron County.

Throughout this course the moraine appears in great strength but assumes a broad, massive, rather than a very rough, ridged development. Peaks and ridges 100 or 200 feet above their bases are, however, not uncommon. The proportion of assorted material in the constitution of the range is relatively large, as indeed is common to most intermediate moraines. This fact finds ready explanation in the conditions under which it was formed. Lying between two glacial lobes, it must necessarily have formed one of the important drainage lines for the abundant waters that arose from the melting of the ice. The sloping ice margins may be safely assumed to have discharged their waters into the common valley between them, and thus made it the avenue of exceptional torrential action. Consonant with these conditions the kame-like element of the moraine attains an important development. Sandy and gravelly knolls, and ridges, and undulatory plains, filled with sinks and basins, are notably abundant. Coarse unstratified material is not, however, absent, and the direct effects of ice action are manifest, though much masked by the associated aqueous action.

Topographical relations.—This moraine occupies, and in part forms the swell of land which constitutes the watershed between the Saginaw Basin and the southeastern slope of the State. In its northern portion, in Sanilac County, the known surface elevation of this watershed is about four hundred feet above the lake. In La Peer and Oakland it rises to 500 feet. Farther south, in Washtenaw and Jackson Counties, it falls again to about four hundred feet, while in Hillsdale County, near the southern State line, some points 600 feet in elevation are recorded, but the watershed is probably not over 500 feet high.*

The number of lakes that lie along this belt is quite notable, but this is a phenomenon, as already indicated, quite characteristic of the moraine.

ASSOCIATED DEPOSITS.

The immediate drift associates of the moraine, on the southeast, consist of a superficial sheet of exceptionally bowldery, mixed, unstratified material, overlying, quite generally, as it would seem from the observations of Winchell, Rominger, and Wooster,† a bed of stratified assorted material, below which again lies mixed drift. This deposit occupies a low plateau bordering the moraine, but not having great width. Beyond this the surface drops to a smooth plain which slopes gently to the axis of the valley, and is undoubtedly a portion of the former expanded lake bottom.

On the opposite side of the moraine the immediate drift associates consist of bowldery clay and stratified deposits, interspersed seemingly without definite order, the whole characterized by a moderately undulatory surface. Further away toward the center of the Saginaw Basin, the surface becomes plainer and is occupied by deposits of stony clay, supposed to be of subaqueous origin. Considerable areas within the basin are occupied by superficial lacustrine sand. The basin of Saginaw appears to have been occupied post-glacially by water covering the larger portion of the area within the moraine.

*Dr. Rominger, Geol. Surv., Mich., Vol. III, p. 2.

†Geology of Washtenaw County, by Alexander Winchell, Geol. of Mich., Vol. III, p. 11, by C. Rominger, MSS. report of L. C. Wooster, 1881.

DRIFT MOVEMENTS.

Unfortunately, owing to the almost universal concealment of the rock surface, glacial groovings, which constitute an important dependence in plane regions, for determining the course of drift movement, here fail us, and other classes of evidence derived from the constitution of the drift and its topographical arrangement are likewise less satisfactory than could be desired. Nevertheless, such evidence as can be gathered from the several sources justifies the somewhat confident conviction that the axial movement was southwesterly coincident with the trend of Saginaw Bay, and that from this there was a lateral divergent movement to the right and left toward the moraine on either hand, in accordance with the general law found to be elsewhere prevalent.

MORAINE OF THE WESTERN ERIE, OR THE MAUMEE GLACIER.

*The northwestern limb.**—As previously remarked, the eastern arm of the Saginaw morainic loop is regarded as a joint intermediate moraine, in part the product of a glacier occupying the Huron-Erie Basin. Taking up our delineation of this range where it passes into Indiana, the more conspicuous portion is found stretching southwesterly through Steuben County, the southeastern part of La Grange, the central part of Noble, the northwestern corner of Whitley, and the southeastern portion of Kosciusko. Beyond this point it is less strongly developed, but is traceable onward through southeastern Fulton, northwestern Miami and Cass Counties, where it encounters an area of superficial sand, largely assuming the form of dunes, which conceals the glacial drift. These dunes are a portion of a somewhat extensive tract, or perhaps rather a series of tracts, in Northwestern Indiana, the precise distribution and origin of which are yet undetermined. They lie mainly in the Kankakee Basin, which was formerly occupied by an extensive lake or lacustral river—"Old Lake Kankakee" of Bradley†—and have been thought to be its shore accumulations; but their very wide extent and great mass relative to the lake area, as well as certain features of their known distribution, throw doubt upon the adequacy of this explanation. It would seem, from a consideration of the glacial distribution of the second epoch, that this region must have been the avenue of discharge of vast quantities of water shed from the adjacent slopes of the great glaciers occupying the basins of Lakes Michigan, Huron,

* This and the following nine pages have been recast since the completion and printing of the body of the report, and the preface, index, and a few expressions in other portions of the paper will be found defective or inconsistent in respect to it.

† Geol. of Ill., Vol. IV, p. 236.

and Western Erie. The great accumulations of sand probably had their ulterior origin in this exceptional drainage, and were subsequently modified by lacustrine, fluvial, and æolian action. Their history is one of much interest, and its satisfactory determination can scarcely fail to reward industrious investigation when pursued in the light of the glacial phenomena now under consideration, and may, in turn, cast reflex light upon them. But however that may be, for the present, these dunes interpose an element of uncertainty in the tracing of the moraine at what would, in any event, be a critical portion of its course, for it is impossible to determine the character of the drift which they conceal.

The margin of the ice-lobe seems, however, to have traversed this sandy area approximately in the line of its previous course, and, curving southward, to have reached the Wabash in eastern Warren County, for, on the south side, well characterized, though not obtrusive, morainic belts here reach to the river.

From the vicinity of Fowler, an especially bowldery tract, attended by low mounds and hollows, curves southward through Talbot, and then southeastward to Williamsport, on the Wabash (Salisbury). This probably represents the outer terminal curve of the Wabash ice-lobe.

There may be no more fitting place to make a qualifying remark in regard to the whole region between the moraine above traced and that adjacent to Lake Michigan. The drift of this area bears undoubted evidence of being recent, and, though this is in considerable part due, superficially, to aqueous agencies, it seems to me probable that the region will prove to have been largely, possibly completely, covered by ice in the earliest stage of the second glacial epoch. It is not, however, traversed by conspicuous moraines, at least not by any as well developed as those above outlined. Low ridged belts of subdued morainic aspect have been observed at numerous points, but their relations have not yet been traced out.

A similar qualifying remark may be here made concerning a considerable area in Northern Illinois, outside the moraine described in this paper. The freshness of its drift, and the unsculptured contour of its surface, bear evidence of recent origin. Some portions of this area seem clearly to be of lacustrine and fluviatile origin, at least superficially, and I have at times supposed that all might be due to waters marginal to the adjacent glacier, since there is no conspicuous bordering morainic ridge; but the tendency of recent evidence, gathered in a special study of this class of deposits, seems to favor the hypothesis of more extensive glacial occupancy, even where the evidence of it in obvious moraines is feeble or wanting. This questionable region is now under investigation. The dotted lines on the map indicate some of my working hypotheses.

The southern limb.—On the south side of the Wabash the inner morainic belt comes down to the river near the northeast angle of Fountain County, while the outer belt strikes it farther down, near Attica. These tracts extend southeasterly, and as they rise upon the watershed they become fairly well characterized, and assume a phase which deserves special description. There is no striking assemblage of rough hills and hollows, but rather a wide tract, characterized by undulations, whose range lies mainly below 40 feet, and whose curves are gentle and flowing. The drift material is mainly till, but over the surface are scattered kame-like mounds of gravel, the internal structure of which is interesting and significant. In part they are composed of rounded and well-assorted sand and gravel, which assume horizontal, or, more frequently, oblique stratification. But in most instances, where excavation has exposed any considerable section of the interior, a portion, frequently the larger part, of the mound is found to be composed of *angular gravel*, if such a phrase is permissible. This is mainly composed of limestone fragments whose angles have been abraded in a moderate measure, and whose sides are partially polished and scratched. Clear examples of glacial striation are frequent. It is manifest that this angular gravel is but the rock-fragments of the till from which the clay has been washed, but which have not been subjected to any notable attrition by running water. Similar aggregations of angular fragments characterize the moraine in other portions of its course, but have their most pronounced and characteristic development, so far as I have observed, on the highlands between the Scioto and the Great Miami rivers in Ohio. The sand associated with this angular gravel, instead of being composed of well-rounded quartz particles, is made up in large measure of particles of limestone and shale which have suffered little attrition. These sometimes constitute seventy-five per cent. or more of the material of the sand. In some instances the angular gravel, instead of having its interspaces filled with sand, has a clayey matrix, which, in its several degrees of abundance, forms a gradation towards the parent formation. The stratification of this angular gravel is commonly either discordant or disturbed, very commonly the latter. Warped, contorted, and disrupted bands, having all attitudes, and standing at all angles up to verticality, are very commonly seen. It is not unusual to find one side of a mound composed of distorted beds and angular material, more or less associated with clay, and even true till, while the other side is composed of more rounded and better assorted undisturbed beds.

Another interesting feature is the association of this feebly expressed moraine with a bowlder belt. This becomes more pronounced in Montgomery County, where the tract has been mapped and described by Professor Collett under the term "bowlder dike."* This belt is from one half to two or three miles in width, and consists of a very unusual accumulation of bowlders, embracing many of exceptional size. Similar tracts in like association occur north of the Wabash and in Western Ohio, presently to be noted. This bowlder belt lies on the inner border

* Geol. Surv. of Ind., 1875, p. 404. See, also, accompanying map.

of the composite morainic tract, and is a dependent of the second or inner moraine. In their southeastward course both the bowlder tract and the swell-and-sag topography lose their distinctiveness, and scarcely merit the designation of a moraine in the restricted sense in which the term is here used. The border of the newer drift, slightly ridged, may be traced diagonally across the northeastern part of Montgomery County, the center of Hendricks, the northeast corner of Morgan, the southwest portion of Johnson, striking the basin of the East White River near Edinburg. It here closely approaches the border of the unglaciated area of south-central Indiana; but, if my discriminations are correct, it does not come in contact with it. There are heavy accumulations of drift near the northern border of Brown County, and along the eastern border of Morgan County, which take the form of morainic hills, especially in the latter region; but these, I think, belong to the earlier drift, since they have suffered much erosion, resulting in complete drainage, deep oxidation, and seeming ferrugination of the subsoil. The newer drift is composed of fresher clays, less deeply oxidized, and but feebly modified superficially by drainage erosion. The aspects of the older and newer drifts are here, as elsewhere, quite clearly differentiated, though the border limit is not always clear and conspicuous.

East White River, or Collett's Lobe.—On encountering the basin of East White River, the newer drift border comes into association with the remarkable fluvial phenomena of "Collett's Glacial River." This was one of the great avenues of discharge from the ice border, and has left its record in broad belts of gravel gathering into a great trunk stream. The edge of the newer drift sheet is interrupted and obscured by these fluvial deposits, but it seems to have formed a lobe, reaching down the basin into Jennings County, the glacial river lying on its western border. The eastern edge of the loop runs north diagonally across Decatur County, the southeastern portion of Rusk, the northwestern part of Fayette and of Wayne, in the northern portion of which, and the southern part of Randolph, it recurves to the southeast to form the Great Miami loop.

At Greensburg, and several points in the vicinity, the interesting phenomenon of the superposition of the newer upon the older drift is well shown. The best exhibit is in the southeastern part of the city, where the superficial deposit consists of about seven feet of gray stony clay of fresh aspect, having suffered but a limited amount of superficial oxidation, and containing pebbles with polished and scratched surfaces, unleached and unweathered. This stratum is sharply terminated below, and lies upon drift contrasted with it in high oxidation colors and the weathered character of the constituents. Examining more closely, the upper two or three feet of this lower stratum is found to be a loamy clay, partially stratified, and containing numerous molluscan remains. This is manifestly the superficial deposit of an old drift surface.

The morainic tract in Wayne County embraces the drift ridges that lie between Noland's, Green's, and the West Fork of the White Water River, recognized by Professor Cox as lateral moraines in his report of 1878. The bowlder tract, representing the inner member of the belt, makes its curvature in southern Randolph County, entering it near Losanville, in the southwestern corner, and leaving it near Arba in its southeastern, crossing, as it descends into Ohio, the northwestern corner of Wayne County. It is here associated, as before, with swell-and-sag topography, and mounds of gravel of the subangular variety and disturbed stratification.

The Great Miami Loop.—Upon entering Ohio in the northwestern corner of Preble County, both outer and inner members are well characterized, the outer by the mound-and-basin topography, the inner by its extraordinary bowlder-belt and slightly ridged surface. This latter, which is here the more interesting, leads down to the more remarkable tract near West Alexandria, described specifically by Professor Orton.* On approaching the Great Miami River it curves to the northward and joins a belt descending from the east of north, across Miami County, described by Mr. Hussey.† At the point of curvature the bowlders of the belt are somewhat more scattered, and, in the aggregate, perhaps less numerous; so that the relations of the southeastward and southwestward trending belts seem to have escaped previous recognition. This belt crosses the Great Miami between Tadmer and Dayton. Opposite the latter place it encroaches upon the valley, and the ice may, at its most advanced stage, have obstructed it; but I have no proof of this. In the angle between Stillwater Creek and the Miami a range of drift hills, embracing billowy gravel deposits, deflect the former stream to the west, notably narrowing its valley. The valley of the Great Miami at and near Tadmer is notably contracted by drift, and stands in marked contrast to the broad, capacious flood plain below.

West of New Carlisle the valley of Honey Creek is choked by very notable morainic accumulations, which display, in pronounced development, the typical characters of the moraine in its stouter portions. The material embraces a large variety of assorted and unassorted drift, and its heaping takes the more irregular and varied arrangements. The vertical oscillations range up to 70 feet or more, and some of the closed depressions are 40 feet or more in depth. Northward this graduates into the gentler undulations that characterize the moraine in the planer regions. Its course is north-northeast across Champaign County and into the center of Logan. Notable choked valleys occur near Millerstown and Spring Hills. In the vicinity of the latter the moraine resumes its more strongly undulatory characteristics, embracing kame-like hills and kettle basins (Wooster). Extreme oscillations here reach 100 feet. On the highland slopes, east of Bellefontaine, the angular

* Geol. Surv. of Ohio, Vol. III, pp. 412–414.
† *Ibid.*, p. 475.

gravels present their most typical development. This limb of the Miami loop has its essential culmination on the highlands northeast of Bellefontaine, where it is joined by the west limb of the Scioto loop.

TOPOGRAPHICAL RELATIONS.

Recalling what has been previously remarked concerning the altitude of that portion of the range which lies within the State of Michigan, it may be repeated that where it crosses into Indiana the moraine has a general altitude of 500 feet above Lake Erie, or about 1,073 feet above the sea. On the line of the Lake Shore and Michigan Southern Railway the highest elevation attained is at a point three miles southeast of Kendallville,* where the range rises to 445 feet (1,018 feet A. T.). In central Noble County the elevation is from 400 feet to 440 feet (973 feet to 1,013 feet A. T.); in southeastern Kosciusko County, about 400 feet (973 feet A. T.); while in Cass County it has descended to about 200 feet (773 feet A. T.). The Wabash, where crossed by it, is about 80 feet below Lake Erie. On the watershed between the Wabash and Sugar Creek the altitude is about 300 feet. The surface of the White River, where crossed below Indianapolis, is about 50 feet above Lake Erie; Edinburg, where the Blue River is crossed, is 104 feet (677 feet A. T.); Vernon, which represents approximately the altitude of its southern limit, is 88 feet (661 A. T.). From this point it ascends gradually to the northeast, reaching, at Greensburg, 393 feet (966 feet A. T.), and at its culmination, in Randolph County, the highest portion of the State, an altitude of about 680 feet above Lake Erie (about 1,250 feet A. T.) is attained. From this culmination, in forming the Great Miami loop, it descends gradually into the Miami Basin, reaching to within about 200 feet of the level of Lake Erie in the vicinity of Dayton. From its curvature at this point it ascends along its course to the northeast, reaching, in central Logan County, the height of 800 feet and upwards.

It will thus be seen to undulate deeply along its crenate course, descending from 300 to 500 feet in crossing the great river basins. It is further to be noted that its re-entrant angles, in Randolph County, Indiana, and Logan County, Ohio, *coincide with the highest areas in the two States respectively.* It is to these prominences, associated with the intervening valleys, that the lobation of the ice margin is undoubtedly due.

GLACIAL MOVEMENTS.

Striæ.—Though not abundant, except on the famous islands of western Lake Erie and about Sandusky, the glacial groovings fall into beautiful harmony with the general system which characterized all the glacial lobes of the epoch.

* J. S. Williams, Geol. Surv. of Ind., 1878.

Concerning those on the Michigan side, Prof. Alexander Winchell has made the following observations:

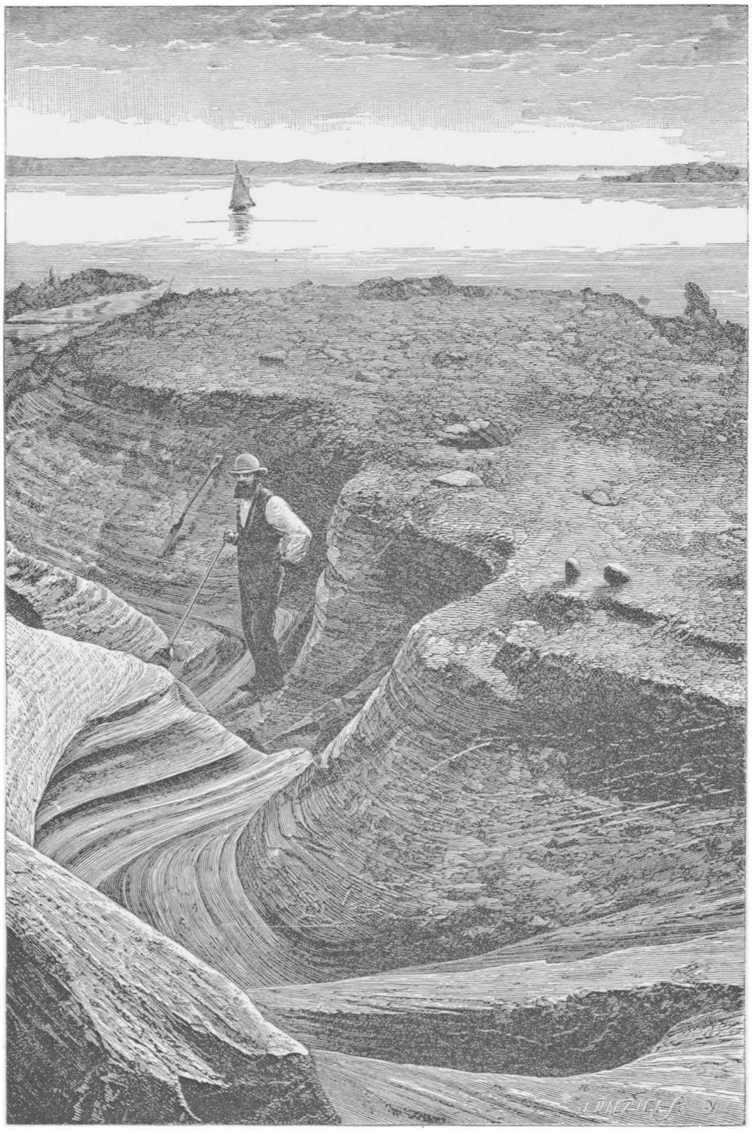
> At Stony Point the surface of the limestone has been denuded of soil by the action of the waves over an area of several acres. The whole surface is level, smooth, and floor-like, and covered with a set of striæ running in perfectly parallel lines N. 60° W. One deep groove is seen belonging to this set. The most remarkable feature seen here, however, is the occurrence of two parallel grooves crossing the first set, and bearing N. 60° E. These grooves are 4 feet 6¼ inches apart, 1⅝ inches deep, 2 inches wide, and 25 feet long, issuing from under the cover of diluvial materials, and terminating at the point to which the waves have broken away the rock. The first impression which irresistably forces itself upon the mind is the conviction that a loaded wagon has been driven over the surface while in a yielding condition, and a couple of grooves parallel to these, seen for a part of the distance, like the tracks of the second pair of wheels, greatly confirms the illusion.*

The more prevalent striations are here directed toward the moraine, and manifestly belong to the diverging lines which characterized the lateral portions of glacial lobes. The secondary set belongs to the axial group whose trend was parallel to the central depression of the Maumee trough, through which the great ice-current flowed. The coexistence of the two at this point, intermediate between the margin and the axis, is not surprising when consideration is taken of the probable fluctuating volume of the ice-current due to meteorologic variations, and the consequent fluctuations in the relative strength and width of the axial and lateral flowage. Beautifully coincident with these observations are the facts cited, in 1865, by Professor Winchell relative to some remarkable instances of northwestward transportation.† The essential facts are that immense tabular masses of Corniferous limestone are found in the drift now identified with the morainic belt, which rationally must be supposed to have been derived from the summit of the low anticlinal arch of the Corniferous limestone lying in the basin under consideration in the southeastern part of Michigan. These are found scattered over areas underlain by the Hamilton group, the Marshall sandstone and the Subcarboniferous limestone. Similar blocks of Hamilton rock, manifestly derived from a parallel outcrop of that formation, have been borne in a like direction and deposited over the areas of the Marshall sandstone and the Subcarboniferous limestone. In a similar way the Marshall sandstone has been borne on to the area of the Subcarboniferous limestone. A significant fact is, that this transportation was from lower to higher levels as the strata now lie.

These phenomena, in all the fullness of detail given by the author quoted, are precisely what might be expected from the action of a glacier advancing through the Erie-Maumee Valley, and having a

* Geol. Surv. of Mich., 1860.

† Some Indications of the Northward Transportation of Drift Material in the Lower Peninsula of Michigan, by Prof. Alex. Winchell. Am. Jour. Sci., XI, 331, Nov., 1865. Professor Winchell there suggested an explanation of the facts quite different from that here proposed.



TORTUOUS GLACIAL GROOVING, KELLEY'S ISLAND, LAKE ERIE.

(From photograph.)

[The great groove is thought to have originated as the channel of a stream (perhaps subglacial), and to have been subsequently occupied and modified by ice.]

diverging lateral movement. The massiveness and angularity of these blocks may find satisfactory explanation in the consideration that the glacial advance which formed this moraine followed an earlier retreat, and that in the interval the superficial rock, where exposed, as it probably was on the anticlinal referred to, was subjected to surface agencies, especially frost, which at the stage of readvancing glaciation must have been intense in its action, and must have loosened the exposed beds and rendered them especially subject to removal by the advancing ice. It is especially to be noted further that the attitude of the strata of Southeastern Michigan was such as to especially invite the removal of large tables of rock, massively, since the beds dipped at a moderately low angle away from the moving ice—a position which peculiarly favored the disruption of their edges. These tables of rock, in being forced from their bed by the advancing ice, would naturally be thrust edgewise up into its mass, because of their oblique attitude to it, and would therefore be borne along thus imbedded, without the abrasion that would be suffered by smaller cubical or spherical masses rolled beneath the ice. At best, the distance transported was not great, and such masses could not be presumed to be much rolled or rounded, because of their magnitude. The assumed tilting of the tables is in harmony with observations made on inclined blocks (of much smaller size, to be sure), occurring at Smith's quarry, near Burlington, and at Castleman's quarry, near East Troy, Wis., and described in Vol. II, Geol. Wis.* Similar blocks of limestone constitute elements of the moraine in Rock, Walworth, Jefferson, and Waukesha Counties, Wisconsin, being derived from the Niagara and Galena limestones, which projected in cliffs and inclined ledges against the glacial current.

On the opposite side of the Maumee Valley, near Middle Point, Van Wert County, Ohio, the movement was S. 15° W.† At Lima it was S. 35° W., indicating divergence on that side of the valley. In the axis of the trough the striæ are more abundant and decisive. Near Defiance, in Defiance County, and near Junction, Paulding County, the groovings point south-southwest. In Lucas County, at Whitehouse, the course is S. 50° W.; at Fish's quarry, S. 55° W.; at Monclova, S. 62° W.; at Sylvania, S. 50° W.; at Genoa, Ottawa County, S. 65° W.; at Belleville, Sandusky County, S. 65° W.; and at Sandusky City, Erie County, S. 80° W. West Sister Island, in Lake Erie, affords abundant and impressive striation, which has a course S. 80° W., crossed by feebler lines running south. On Kelly's Island magnificent groovings trend S. 78° W.; on South Bass Island the strong prevailing series runs S. 80° W., with an intersecting one S. 15° W. The westward movement and the characteristics of glacial action, as distin-

* Pages 203 and 204.

† This and the following observations are from Gilbert's Report on the Maumee Valley, Geol. of Ohio, Vol. I, p. 538.

guished from all other natural methods of planing and grooving, are placed beyond question by the boldly characteristic phenomena of the islands so fully described by Whittlesey, Newberry, and Gilbert.* It is manifest that the great central current moved southwesterly up the Maumee Valley, deploying toward the margin on either hand to supply the peripheral waste.

To give complete satisfaction striæ nearer the periphery are needed; but these, unfortunately, have not been found. The region is so extensively covered with a thick mantle of drift that rock is rarely accessible except in the channels of streams where its original surface has been destroyed. A few observations have been made around the extreme margin, but it is quite probable that in all these cases the striation is the work of the older glacier. It appears quite clear from a study of the region that the thin margin of the later ice sheet passed *over* the old drift without in any notable degree plowing it up, for there is no massive corrugation of it such as would inevitably have resulted had the later glacier pushed all the drift of the earlier one before it. The facts cited from Greensburg, and less decisive observations elsewhere, sustain this view. It is improbable, therefore, that along the extreme margin the rock was often reached, but, on the contrary, remained covered and protected by the older drift, and retained the polishing and scoring it had previously received. The courses of the striæ support this view. At Williamsport, in the immediate Wabash Valley, Mr. Salisbury reports striæ pointing S. 8°–10° W. In Montgomery County, Professor Collett† reports striæ at the Horseshoe (Durham's farm), on Walnut Branch, trending S. 22° W.; on Sugar Creek, near Troutman Station, S. 8° E.; on Coal Creek, three miles west of Waynetown, S. 18° E. At Greencastle, Putnam County, I observed feeble abrasion and scoring in a direction varying from S. 28°–45° W., on three surfaces near each other, and at an adjacent locality, S. 33°–48° W.; and at a third, doubtful scratches pointing S. 44° W. These all indicate very feeble action, and the thin drift and deeply corroded surfaces of the rock indicate that this locality suffered very slight glaciation. My impression was that this locality lay near the limit of ice movement from the east in the earlier glacial epoch. Striæ are reported from near Maple Grove and Putnamville, in this county,‡ but their exact direction is not given, though it is implied that they point southward. If they trend nearly due south, the testimony of the feeble scratches observed by me, and the inference drawn from them, should have but little weight. In Wayne County, just above the falls of West Fork of the White Water River, Professor Cox notes grooves whose course is nearly N. and S.§

* Gilbert, Geol. of Ohio, Vol. I, 1873, pp. 538–540. Newberry, Geol. of Ohio, Vol. II, 1874, pp. 76, 77. Whittlesey, Proc. Am. Assc. Adv. Sci., Vol. XXVII, 1878.

† Geol. Surv. Ind., 1875, pp. 370–393.

‡ Second Annual Report of the Bureau of Statistics and Geology, 1880, p. 400.

§ Geol. Survey of Ind., 1878, p. 205.

MORAINE OF THE SCIOTO GLACIER.

Starting from its junction with the left limb of the Miami loop on the heights of Logan County, the west marginal moraine of the Scioto glacier extends southward on the east border of the highlands of Logan and Champaign Counties. Here the topography favored the development both of ridged accumulations and gravel trains stretching away from the ice-border. Fine examples may be seen near Mingo, at and east of Cable, and west of Mechanicsburg. Descending to the planer country the moraines are inconspicuously developed. The outer line identified follows—perhaps may be said to constitute—the watershed between the Scioto and Little Miami Rivers as far south as Clinton County, where it curves to the eastward. An inner line, characterized by ridges and mounds of till and angular gravel, passes just west of London, and was traced to the vicinity of Bloomingburg, but not attempted beyond. The southwestern curve is not very sharply defined, and the southeastern raises some undetermined questions of discrimination between the earlier and later accumulations. Both need further study. The differentiation of the lobe, however, is established by the striæ, which show that the ice movement was divergent from the axis toward either margin. I am in doubt whether the somewhat strong morainic hills near Latasville, Ross County, belong to the earlier or later epoch. The moraine blocking the valley of Paint Creek west of Chillicothe, described by Professor Orton, and later by Professor Wright, has the fresh appearance of the later epoch. The Adelphi deposits described by Wright, I have not seen. North of this two belts have been partially traced; the inner running north, through western Fairfield, Licking, and Knox Counties (Wooster), the outer passing through eastern Licking and Knox Counties near the margin of the drift, as since traced by Wright. Thence, in close proximity, they cross northwestern Holmes, southwestern Wayne, northwestern Stark, southeastern Summit, and northwestern Portage into Geauga. This latter portion, from northern Stark County onward, is an interlobate moraine, formed between the Scioto and Grand River glaciers. It is quite characteristically developed, though it here has a predominant gravelly constitution and takes on the kame-like phase of accumulation. It is, however, inferior in strength, roughness, and coarseness to some of the more striking portions of the range elsewhere. This is the most pronounced development of the range in Ohio, and is the only portion, I think, to which attention had been called previous to the recent geological survey of that State. Colonel Whittlesey* long since directed attention to the peculiar "moraine hillocks and cavities" which characterize this region. Dr. Newberry, in the recent report on the geology of Ohio, has made these the illustrative type of the kames of Ohio.†

TOPOGRAPHICAL RELATIONS.

The area embraced within this loop is exceptionally plane and smooth. The axis of the valley is not very greatly depressed, but its breadth and smoothness were highly favorable to glacial movement. A section across it, near Columbus, shows a central depression of about 300 feet, the axis of the valley being about 700 feet above tide. A section across the center of Delaware County, north of this, shows a downward curve of over 500 feet, but the average depression north of Columbus is about 300 feet. On the watershed the depression is only about 100 feet, the eastern side being much the higher.

The western rim of the basin rises gradually to the north, and near Bellefontaine reaches what is asserted to be the highest point in Ohio, 1,540 feet above the sea. As the highland area of which this is the summit altitude lies near the point of separation of the Miami and Scioto glacial streams, it doubtless was an influential agency in determining their divergence. The eastern rim likewise rises to the northward, reaching a height of about 1,400 feet, near the point where the moraine makes its easterly deflection, and is there joined to the high, hilly region that extends northeasterly in the general direction of the moraine, as already sketched.

STRIÆ.

Owing to the extensive prevalence of the drift, observations upon glacial striation are lacking over a considerable tract, and are comparatively few in some other parts, but they are very significant. In the axis of the lobe a single observation at Grand Prairie, Marion County, indicates that the movement was directly southward. On the western flank I observed striæ at three adjacent localities, near Reesville, Clinton County, trending respectively S. 45° W.; S. 56° W.; S. 55° W.; also near Leesburg, Highland County, on the southwestern curvature of the loop, pointing S. 10° W. On the eastern side, at Sunbury, in eastern Delaware County, and near the eastern limb of the moraine, Professor Wooster observed grooves running S. 45° E. Two miles north he found others trending in the same direction. These, it will be observed, point toward the adjacent moraine Midway between Mansfield and Lexington, opposite the point where the moraine turns eastward, the same observer noted striæ trend-

* On the Fresh Water Glacial Drift of the Northwestern States. Smithsonian Contributions to Knowledge, 1866.

† Geol. Surv. of Ohio, Vol. II, pp. 41-46.

ing S. 15° E. Again at Mount Eaton, in the southeastern corner of Wayne County, he found them running S. 40° E. and S. 45° E., almost directly against the moraine. In the Ohio reports the following are given:[1]

In Medina County, at Mills' quarry, Wadsworth township, they run SE. with a secondary set S. 60° E., and at Sharon S. 40° E. Mr. M. C. Read's map of the striæ of Northeastern Ohio shows the following directions in successive order from southwest to northeast: In Summit County, S. 35° E., S. 10° E., S. 40° E., S. 90° E., S. 60° E., S. 45° E., S. 30° E., S. 35° E., and S. 45° E.; in northwestern Portage County, S. 45° E.; in western Geauga County, S. 40° E., S. 70° E., S. 50° E., S. 10° E., S. 15° E., S. 10° W., and S. 30° E. These are, with one exception, all directed toward the moraine, and taken together fall beautifully into the system of striation pervading regions adjacent to the moraine. The accompanying maps show diagrametrically their correlation. They indicate an axial movement down the Scioto Valley, with a lateral movement on the left toward the margin of the ice. There was presumably a similar divergence to the right.

MORAINE OF THE GRAND RIVER GLACIER.

That portion of the moraine previously described, which stretches from Stark County northward into Geauga County, constitutes a joint intermediate moraine formed between the left-hand margin of the Scioto glacier and the right hand margin of the Grand River glacier. Parting in the north-central part of Stark County from this common range, the moraine proper to the latter glacier curves rapidly eastward, passing by Louisville, and stretching across the northern part of Columbiana County to the east Ohio line. From this point northeastward, across Pennsylvania, I have not followed the course of the moraine, that region being under investigation by the geologists of the Pennsylvania survey, the gravels and moraines being a special subject of study by Prof. H. C. Lewis, assisted by Prof. G. F. Wright. They have traced the moraine that is *marginal to the drift* from the border of Columbiana County, in a general northeasterly course, to Little Valley, Cattaraugus County, New York. In how far this may be the outer member of the range under consideration, and how far an older one formed by the ice of the first glacial epoch, is unknown to me, the details of their results not being at the present writing at command.[2]

If correctly identified, the moraine under consideration enters New York in the southeastern part of Chautauqua County. What is pre-

[1] Vol. II, pp. 10, 11.

[2] I am under obligations to Professor Lewis for informing me of his general results, and the kind assurance of advance proof, but at the date of sending this to press it has not been received. Aside from the great independent importance of his results, a special interest springs from this association with the moraine of the later epoch.

sumed to be the inner of the two principal ranges passes by the southeastern extremity of Chautauqua Lake, appearing at Jamestown, and extending thence northeasterly to Dayton in the northwestern corner of Cattaraugus County, beyond which, taking a somewhat more easterly course, it occupies both sides of Cattaraugus Creek, having here a remarkable development displaying an observed vertical distribution of nearly 600 feet. It extends onward into the central portion of Wyoming County, from which some isolated observations seem to indicate that an intermediate spur is projected northward to the vicinity of Batavia.

This long stretch from Columbiana County, Ohio, to Wyoming County, New York, constitutes the left arm of the Grand River morainic loop, the right arm, in Eastern Ohio, being much shorter, the figure described by the whole being rather that of a giant hook than that of the usual loop.

This singular lobate area has for its topographical axis the Grand River basin of Eastern Ohio extended to the southward by the Upper Mahoning basin, and confluent at the north with the eastern section of the Lake Erie basin. The differentiation of the ice from the common mass occupying Lake Erie was doubtless due to the deep basin formed by these valleys, in connection with the more than usual depth of Lake Erie in the line of their projection. The rim of this basin is formed on the right by the Subcarboniferous promontory of Geauga County, rising about 500 feet to 600 feet above Lake Erie. From thence the elevated margin sweeps curvingly around to the eastward, undulating mainly within a range of 200 feet. It attains its highest elevation south of Alliance, where its height is upward of 700 feet above the lake. From this climax, which lies almost directly in the axis of the trough, it declines in crossing the Mahoning Valley and passes into Pennsylvania with a basal elevation of scarcely 400 feet above Lake Erie, though its summit altitudes approach those attained to the westward.

On the left, or southeastern side, the margin is formed by the highlands of Northwestern Pennsylvania, but the moraine lies somewhat back from the topographical rim.

ICE MOVEMENTS.

Through the axis of this amphitheatral basin a glacial tongue moved south, rising along the slope and spreading laterally until the basin was brimming to its lip, even beginning to overflow. The currents diverged on either hand, as amply shown by the striæ recorded by Mr. M. C. Read, and diagrammatically exhibited in the Ohio report.[1]

Striæ.—The glacial groovings in the axis of the trough in central Trumbull and north Mahoning Counties are there represented as moving directly south; those on the western margin, as running S. 60° W., S. 30° W., S. 40° W., S. 50° W., and S. 40° W., successively in the order

[1]Geol. Surv. of Ohio, vol. I, p. 530.

of position from the glacial axis; those on the southeastern margin, as running S. 40° E., S. 30° E., S. 45° E., S., S. 40° E., S. 20° E., and S. 30° E., respectively in like order.

Prof. I. C. White, of the Pennsylvania Survey, in his report on Crawford and Erie Counties, remarks:

> "The direction of ice grooves which I observed on thirty or forty summits in the two counties has been uniformly about S. 30° E., or south-southeast."

These observations unified form a symmetrical system of radiant divergence from the central axis toward the glacial margin. The phenomenon of divergent flowage is here the more remarkable, because of the steep acclivities which border the basin on every hand, and up which the ice rose, but over which it did not flow beyond the bare overlipping of the rim.

THIS LOOP MARGINAL TO THE DRIFT AREA.

It is an interesting, and, theoretically, an important fact, that the terminal curvature of the loop under consideration is practically marginal to the drift-bearing area. It is scarcely necessary to observe that the course of the moraine to the westward as thus far pursued has lain at considerable, though greatly varying, distances from the drift margin. It here, however, reaches the drift limits. The observations of Dr. Newberry on Columbiana County, and of Prof. J. J. Stevenson on Carroll County,[1] lend this assertion decisive support. The former limits the drift to the northwestern part of Columbiana County, and the latter states that, after diligent examination, no drift was found in Carroll County except a few doubtful specimens in the northeast, and that the boundary line of drift influence lies to the north and northeast of the county.

The outer margin of the moraine, according to my determination, approaches to within less than three miles of the northern line of Carroll County, and I observed no apparent evidence of glaciation south of it. A little farther east, however, drift was observed from three to four miles south of the apparent margin of the moraine. Whether this was formed contemporaneously with the moraine or during the earlier glacial epoch seems to me uncertain, but the general fact that the moraine here reaches the essential limit of the drift-bearing area is satisfactorily determined.[2]

ASSOCIATED DEPOSITS.

The broad, smooth bottom of the central portion of the basin embraced by this morainic loop is overspread by a sheet of pebbly clay—the Erie clay of Logan and Newberry—and regarded by the latter, with corectness, I think, as a deposition from floating ice. At points, this smooth-

[1] Geol. Surv. of Ohio, vol. III, p. 90 and p. 179.

[2] The Bearing of some Recent Determinations on the Correlation of Eastern and Western Terminal Moraines. By the writer. From the Am. Jour. Sci., vol. XXIV, Aug., 1882.

surfaced deposit reaches to the borders of the moraine, and so far as it laps upon it, modifies and subdues its contours in the manner previously remarked, in greater degree, to the west. But for the greater part, the moraine, especially on the southeastern limb, lay beyond, or at least at, the extreme reach of subduing waters, and is bordered by little else than strictly glacial deposits and those inevitable modifications which are their constant attendants. In these portions the formation assumes its own unmodified characteristics, and varies from the type already sufficiently described only in the special phases which its topographical situation, and the character of the indurated formations that furnished its material impressed upon it. Chief among these are the effects produced by the hilliness of the region upon the method of accumulation. The deep, preglacial valleys largely received into themselves the glacial burden of *débris*, leaving a relatively meager proportion on the hilltops. Hence the continuity of the moraine becomes, in some sense, interrupted; not that the marginal accumulation is actually dissevered, but the sharp ridges greatly thinned it while the material swallowed up by the valleys was largely consumed in their partial filling, and hence developed itself less conspicuously, as a range. These effects only reach a partial development in Ohio, but farther eastward, among the stronger hills and ridges of New York, the phenomenon gave to the morainic develment a phase so new and distinctive that a brief digression at this point for its special consideration may not be inappropriate.

DENTATE MARGIN ASSUMED IN THE RIDGED REGIONS.

On entering upon the region of high, elongated, parallel ridges, which characterize the border plateaus and foot-hills of the Appalachian region, especially the southern border belt of New York, the development of the moraine assumes a phase distinctly referable to the topographical circumstances under which it was formed. This I judge to be due, not so much to any unusual heights of hills or depths of valleys—for, although these are very considerable, they are by no means extraordinary—as to their remarkable parallel arrangement and their attitude toward the ice movement. The whole belt may be said to be characterized by linear ridges, rising above the intervening valleys to heights commonly 500 feet to 800 feet, and not infrequently 1,000 to 1,200 feet, or more. While not a universal fact, it is a very general truth that these are arranged in approximately parallel series. Elevated ridges frequently run 10 or 15, and occasionally 20 or 30 miles continuously, in a nearly direct course, accompanied by correspondingly elongated and regular valleys. These lay in the direction of glacial movement (partly because they controlled it, doubtless) and gave to its floor a corrugation of no insignificant proportions. This creasing was, in its grander features, undoubtedly due to preglacial erosion. But within the area which was effectively covered by the intense glaciation of the second epoch, the surface gives unmistakable evidence of having been reduced to a symmetry and smoothness of contour not previously possessed.

But in whatsoever degree due to glacial or to preglacial agencies, the fact remains that the furrowed surface impressed itself upon the relatively thin margin of the ice, and modified its action in the development of the moraine accordingly. The marginal accumulations of the region were gathered in great massiveness into the deep valley troughs, while on the lofty intervening ridges the drift sheet is relatively thin, and the marginal morainic ridge oftimes relatively quite insignificant.

Furthermore the inequalities of surface led to an unequal prolongation of the ice margin. The thickened portions of the sheet, occupying the valleys, thrust themselves forward, while the relatively thin portions of the sheet, lying upon the ridges, were held back by the relatively greater friction, and were sooner wasted by melting and evaporation. Thus the ice-sheet assumed a dentate outline. The extent of the valley prolongation was frequently from 5 to 10 miles, and, unless I misinterpret, occasionally 12 or 15 or even 20 miles. Indeed some morainic accumulations would seem to find their easiest explanation on the assumption of tongues of even greater length. But I hesitate, from conservatism and from theoretical considerations, to so construe the phenomena. If the upward curve of the glacial surface were no more than the observations of Professors Cook and Smock in New Jersey would seem to indicate—34 feet to the mile—then a trough 1,000 feet in depth might give origin to a tongue nearly 30 miles in length; but it may be doubted whether these narrower streams exposed to a friction and wastage relatively greater than that of a massive sheet would be so far prolonged.

Consonant with this digitate outline of the glacier, there was developed not only a digitate morainic outline, but an extraordinary accumulation of morainal matter in the valleys at the extremities of the ice-fingers, and a relative paucity on the retreating loops that spanned the ridges between.

THE QUESTION OF INTERPRETATION.

The foregoing peculiarities introduce somewhat grave difficulties in the tracing, correlation, and interpretation of the moraine. Had we but a single marginal ridge to deal with, the case would be comparatively simple, and involve little more than patient industry in tracing its flexuous course; but, as previously remarked, the morainic belt under study usually embraces two principal ranges (which are in themselves complex), closely attended by one or more minor ones within. The two principal ridges are often considerably divergent, and in this region both were of course affected by the local topographical features, and similarly developed into valley prolongations, connected over the intervening ridges by feeble retreating lines. Being thus closely dependent upon local topography, it is not strange that the two tortuous belts were not strictly parallel, but more or less interlocked, forming a complexity of lines not always easily disentangled. Add to this the massive development of the valley moraines, and the feebleness and ofttimes equivocal character of the connecting lines across the ridges, which are frequently rather shoulders or rude terraces than typical moraines, and some conception of the complexities of the range may be formed.

But a graver difficulty arises from the proximity of the belt to the drift margin, and to the moraines, now referred to the earlier epoch, that characterize it. According to the identifications of Professors Lewis and Wright the moraine which marks the extreme drift limit enters New York near the southwestern corner of Cattaraugus County, and extends thence northeasterly to the vicinity of Little Valley, not quite to the center of the county; where, turning abruptly, it extends southeasterly to Olean, thence into Potter County, Pennsylvania, and onward, in a general east-southeasterly course, across Pennsylvania to the vicinity of Belvidere, N. J., whence it passes across that State, curving considerably to the northward, according to the determinations of Professors Cook and Smock, and strikes the coast at Perth Amboy; thence it crosses Staten Island, Long Island, Block Island, Nantucket, and Martha's Vineyard (King, Upham).

This outer line, it may be observed by reference to the accompanying map, is separated by no great interval from the morainic accumulations of south central New York, and indeed the two are considered coalescent farther east. Herein arises the necessity for discrimination between the two morainic systems, and for distinguishing both from such local developments as may be the result of special circumstances, and hence have no important systemic relations. It will not be matter of surprise or disquietude, therefore, if the correlations here advanced shall be thought to need revision in some respects, as the result of the more critical and complete investigations of the future, but their general correctness is thought to be founded on substantial evidence.

While nothing can replace observed continuity, carefully traced, where the lines are discrete and continuous in the same phase, yet when the lines are subject to alternate coalescence and separation, and the accumulations are seemingly disjunctive, other bases of discrimination and correlation are important aids. Among those found serviceable are the following:

(1.) The moraine under consideration is much more massive and pronounced in development than the moraine referred to the older epoch. This is usually very strikingly true, notwithstanding the fact that the older moraine stands on the edge of the drift, and is thus contrasted with the adjacent driftless surface by which its peculiarities are set forth.

Julius Bien & Co. lith.

T. C. Chamberlin, Geologist.

MAP OF A PORTION OF THE TERMINAL MORAINE OF THE SECOND GLACIAL EPOCH

DRIFT BEARING AREA — STRIAE — MORAINE — GLACIAL MOVEMENTS (GENERALIZED)

(2.) The surface of the younger moraine, is fresher and less subdued by meteoric modifications. This criterion is, however, subject to much qualification arising from the composition, special situations, and conditions of each. Where the moraine is composed very largely of rocky material, especially if it is angular, it is notably less modified by age than when formed of finer material, or of that which is more thoroughly rounded, and this must be taken account of. The influence of lacustrine, fluviatile, or other special agencies, must also be scrupulously eliminated.

(3.) The difference between the character and prevalence of the older and younger drift sheets is usually sufficiently marked to be satisfactorily distinguished. The older sheet is usually thinner and the rock material more angular, less abundantly associated with comminuted products, and spread with less continuity over the rock surface.

(4.) Co-ordinate with this distinction in respect to the drift material is the more available one of surface contour. The double glaciation of the younger surface within the kettle moraine, together with the seemingly more intense action of the second glaciation, produced marked results upon the surface affected. The superficial contours are almost everywhere glacially subdued and softened, and the hills and valleys reduced to a parallelism that usually stands in marked contrast to the less subdued and more irregular contours of the older area. The drainage system of the older drift region is generally well established, having relatively few lakes and undrained marshes. In the hilly regions the drainage streams are rarely different from their preglacial predecessors. In the newer region, on the contrary, the drainage systems are much less perfectly established, and lakes and undrained marshes are prevalent. The drainage courses depart widely from those of the preglacial systems, both in the details of the tributaries and in the general systems of ingathering into great trunks, and also in the direction of ultimate discharge.

These distinctions, while valuable, indeed almost indispensable, as criteria, are not infallible, and must be applied with much circumspection and with a constant regard for special local conditions. At the present stage of investigation these criteria, taken with other considerations, seem to indicate that a part of the moraine traced by the Pennsylvania geologists belongs to the earlier epoch, and it is here so treated, but the correctness of this is held as an open question.

SEPARATION OF THE OLDER FROM THE YOUNGER MORAINE.

The older marginal moraine traced by Messrs. Lewis and Wright must be coincident with or overridden by the later moraine under discussion on the eastern border of Ohio. The two probably part company in northwestern Pennsylvania, but, if so, their courses are only very slightly divergent until the older moraine makes its abrupt turn to the southeast in Cattaraugus County, New York. From this point, while it courses southeasterly across Pennsylvania, the later moraine continues on its northeasterly course to the central portion of Wyoming County, as previously noted. There it turns upon a short curve and runs southeasterly, and, curving across the Genesee Valley in a short loop, swings again to the northward on its east side. Here an intermediate moraine appears to project nearly to Lake Ontario.

Diverging from this in southeastern Livingston County and southwestern Ontario, the main morainic belt sweeps in a broad curve around the extremities of the remarkable group of divergent linear lakes which characterize west central New York, the eastern limb of this arc terminating only a few miles south of Oneida Lake. From this point the course of the belt is easterly, and rudely parallel to the Mohawk, and appears to enter that valley in central and eastern Herkimer County. This seems to mark the eastern limit of the ice movement down the Mohawk and, approximately, the limit of the westerly movement of the ice stream diverging from the Champlain Valley. The moraine marginal to the southwesterly movement from the Champlain-Hudson Valley is illy defined, as might be anticipated from the rugged, mountainous character of the region, and my identification of it is advanced tentatively and alternative views will be presently stated. The morainic accumulations which are regarded as its components stretch from southwestern Herkimer County southward, in an irregular, interrupted manner, which may be best understood by consulting the accompanying map, to a second junction with the marginal moraine.

Glacial lobes in New York.—The moraine across New York is held to mark the limit (1) of a small glacial lobe accompanying the Genesee Valley, (2) of a much broader but less elongate one, covering the territory of the divergent finger lakes, (3) of a less well defined and more unsymmetrical one pushing eastward part way down the Mohawk Valley, where it encounters (4) the western edge of a great irregular lobe occupying the Champlain-Hudson River Valley, and having on the west an irregular sublobate margin.

Such are the irregularities and critical relations of this portion of the morainic course that it seems necessary to here descend more to particulars than heretofore, although no attempt will be made to give anything like the full local details observed.

Morainic spurs in Western New York.—Returning to the moraine in Western New York, it may be remarked that the general line from Jamestown, through Dayton, Protection, and Java Center, to East Gainesville is attended by spurs projecting southward along the valleys, the result, as before indicated, of ice-fingers thrust forward through the deeper surface furrows that lay in the direction of glacial movement. Among the most noteworthy of these spurs is one in the western part of Cattaraugus County that projects from a point a few miles east of Dayton southward through the valley of the south branch of Cattaraugus Creek to the watershed of the Allegheny River, which is formed by a well-developed but not massive moraine heaped up in the usual irregular fashion by the extremity of the ice-tongue. This is but a short distance from Little Valley, where is found the northernmost angle of the marginal moraine of Lewis and Wright.

In the northeastern corner of Cattaraugus County a moraine reaches southward from Yorkshire, past Machias, to the vicinity of Franklinville. It is composed of well-developed morainic hills and ridges which, to the west of Yorkshire, form a high, irregular terrace against the side of the valley. This it follows to Machias Village, in the vicinity of which the moraine is broader and less elevated, and presents a highly characteristic billowy surface. South of this the moraine becomes narrower, assumes the form of a well-defined terrace on the west side of the valley, which gradually becomes smoother, loses all morainic features, and dies away before Franklinville is reached. East of Machias morainic hills rise well up on the slopes of the valley, and a small cluster of low hills and sinks may be seen just over the crest of the ridge. No continuous extension eastward was, however, observed. It may, perhaps, connect with morainic accumulations near Rushford.

Southwest from Machias, in the valley leading down to Ellicottsville, a little moraine occurs, stretching across the valley above Bevereux. A second one below Bevereux is interrupted by the stream, and a third one occurs still farther down, near Ashford, the latter being extended some distance down the right-hand side of the valley as an irregular terrace, which shortly fades out. The valley below this is occupied by a level gravel deposit, such as usually marks valleys on the exterior of the moraine, and is undoubtedly the flood deposit of the escaping glacial waters. These little moraines above and below Bevereux are seemingly older than that at Machias, and yet they are not marginal to the drift, for at Ellicottsville, below them, Archæan bowlders may be seen along the slope up to nearly 400 feet above the valley bottom, and rounded local rock to upwards of 500 feet. In the valley below, at Perth, still farther down, there is a considerable accumulation of drift that has the appearance of an old and modified moraine.

In southwestern Wyoming County there is a third notable morainic projection, extending from the vicinity of Java Center to the southern line of the county, embracing Eagle Village. If the extremity of this spur has any connection east or west it is extremely feeble. One-half mile south of Bliss station a very low, narrow, but still well-characterized morainic ridge was observed along the crest of a rock ridge 165 feet high, and may be a feeble connecting link between the Eagle moraine and one observed eastward at Pike. The range from Eagle to Java is very strongly and characteristically developed, being a sea of tumultuous hills and hollows whose crests and troughs have a vertical range of 200 feet or more.

The main range, of which these may be regarded as the projecting outliers, has its finest development along Cattaraugus Creek on the northern border of the county of the same name. Here, as observed by my assistant, Mr. R. D. Salisbury, the moraine has a vertical range of nearly 600 feet. It occupies both sides of the creek and has a width, at some observed points on the north side, of not less than three miles. Its lateral extent on the south side was not observed except for a short distance east of Gowanda, where its massiveness is scarcely less than that on the other side of the valley. The characteristic morainic features are most strikingly exhibited at a short distance from the stream, where hills and ridges frequently rise from 70 to 90 feet or more above intervening depressions. The strongest observed development of this moraine is at a point about six miles east of Gowanda, near the creek. The irregularities of contour peculiar to the moraine gradually diminish as the slope of the valley is ascended, and do not appear on the high lands above.

Typical section.—The moraine and its associated deposits in Southeastern Erie County may be taken as an illustration of a not uncommon phase of the formation in this hilly region. The summit of the range is crossed by the Buffalo, New York and Philadelphia Railway at Protection, where it is characteristically developed in peaks and tumultuous hills planted on the crest of an elevated rock terrane. To the southeastward the range graduates into a gravel plain, at first marked by occasional sinks, but becoming more smooth as the slope is descended. This is the overwash plain formed on the exterior of the moraine. On the northwest, or interior side, the rocky and gravelly material, which mainly forms the summit of the moraine, graduates into stony clay which prevails in the Cazenove Valley in much force as far north as Holland, in the vicinity of which it thins out and largely disappears. The valley beyond is a straight trough, which, by its smoothed sides and boat-shaped bottom, clearly illustrates the distinction between a glacially fashioned channel and one formed exclusively by drainage erosion, in which case the slopes are creased with side valleys and buttressed by projecting hills. It is presumed that the Cazenove Valley had a preglacial existence, but that it was rewrought and refashioned by glacial action to such a degree as to change its fundamental characteristics. At the time the ice-tongue occupied the valley, and was pushing up the moraine at Protection, the overwash produced the gravel deposits above mentioned, which extend by Sardinia down to the Cattaraugus Valley. As it retreated within the valley the waters derived from its melting formed a foot-lake about its extremity, in which the stony clays were deposited by combined glacial, ice-block, and lacustrine action. This phenomenon is repeated again and again in the elongated valleys of the ridged region of New York.

INTERMEDIATE MORAINE WEST OF THE GENESEE.

The intermediate moraine tentatively mapped as extending northward through the west side of Wyoming County to the vicinity of Batavia, in Genesee County, is based upon testimony to the effect that the moraine above described as extending from Eagle Village to Java continues onward to the vicinity of Attica, and upon some limited personal observation near that point and in the vicinity of Batavia, and upon the harmony of this hypothesis with the topographical and drainage features of the region. Further observation, however, is needed to give much weight to this.

MORAINE OF THE GENESEE GLACIER.

Resuming the consideration of the more pronounced morainic belt in the south central portion of Wyoming County, it may be seen to great advantage in the vicinity of East Gainesville, where it is finely developed and laid open superficially by frequent railway cuts. It is here a broad, massive ridge, with a characteristically roughened surface, composed in part of unsorted drift, and in part of stratified gravel, disposed in kame-like knobs and basins. It here curves to the southward, and reaches the Genesee River at Portageville, its broad development embracing the well-known succession of falls at that point, and extending somewhat south of the village. The river here channels drift to the depth of 150 feet, and the surface rises promptly on either side to about an equal height in addition. To the east the morainic accumulations rise in a high ridge 425 feet above the flood plain of the river at Portageville. As the old buried channel of the Genesee probably lies to the eastward of the present rock channel, it is not improbable that the morainic accumulations in the center of the valley have a depth of 500 or 600 feet. To this massive blocking of the valley by the moraine is due the new course which the postglacial river has assumed, and the consequent succession of falls which have been one source of the celebrity of the Genesee River. The southern side of the moraine presents at some points abrupt southward-facing terraces, which appear to have been formed by waters escaping across the crest of the moraine at the time of its formation. The valley of the Genesee above this point is occupied by a stony clay deposit, which is held to have been formed in an elongated lake that occupied the valley while blocked up by the ice which formed the moraine. This is a deposit of very considerable mass, occupying the valley bottom, and reposing in a thick, inclined sheet against its slopes, the upper edge forming a shoulder or terrace-like bench which was observed to have a height of 300 feet above the valley bottom.

A few miles east of Portageville the moraine is forced against the high hills that lie south of Hunt's and Dalton, and becomes only a great irregular terrace banked against them. East of Dalton it is forced into the deep valley, followed eastward by the railroad—a wide cañon with steep walls, which is apparently filled to a great depth. On the outer (eastern) side the moraine graduates into a gravel plain which stretches onward down the deep narrow Canaseraga Valley.

East of this there is an elevated area whose ridges rise from 600 feet to 1,000 feet above the valleys on either hand. This highland appears to have parted the margin of the glacial sheet, causing one lobe to move around its right flank, forming the accumulations just described, and the other around its left or eastern flank, constituting a tongue which moved southeasterly to a point just beyond, Dansville, where it pushed up a moraine of magnificent proportions, banked at the extremity of the valley to a height of 500 feet, and displaying its characteristic irregularities in great boldness. The marginal line connecting this grand deposit around the nose of the highland on the west to the moraine previously described at Dalton is little more than a terrace-like bench, displaying feeble irregularities, and only here and there there developing into very slight hilliness. Its character is relatively so inconspicuous that it would escape attention not definitely turned to the subject. It is to be observed that this is not strictly a terminal moraine, but rather a lateral one, and that its form and comparative insignificance are such as would naturally be assumed by a quasi lateral moraine in such a situation.[1]

From the east side of Canaseraga Valley, north of Dansville, there rises to a still greater height a north and south ridge, which, in like manner, at the time of formation of the moraine parted the ice margin, and recorded the position of its upper edge along its western side and around its northern extremity, by a similar morainic terrace, occasionally developing a somewhat roughened character. From the height of these lines on either side of the valley it would appear that the ice must have been 600 feet to 800 feet deep.

INTERMEDIATE MORAINE ON THE EAST MARGIN OF THE GENESEE VALLEY.

In eastern Rochester and northwestern Ontario Counties there is a very notable moraine lying on the watershed—probably in reality form-

[1] In referring to the fact that the accumulations under discussion had been previously spoken of by Vanuxem and others purely as valley drift, I, some years since, made the following suggestion concerning the probabilities of such a development, under the given circumstances. Upon testing in the field the suggestion is found to correspond quite closely with the fact. "As these are deep, cañon-like valleys, they would probably modify, in some degree, the comparatively thin margin of the glacier, giving it a somewhat digitate outline, and the greatest accumulations would take place near the extremities of the tongues, in the valleys, so far as drainage permitted, while the connecting chains would form retreating lines and be less conspicuous, and might, therefore, escape observation not definitely turned to the subject."—On the Extent and Significance of the Wisconsin Kettle Moraine, page 26.

ing it—between the Genesee and the peculiar easterly flowing tributaries of the Oswego River. This may be said to have its essential termination at the north, near the little village of Egypt, in the southeastern corner of Monroe County, although some unimportant morainic accumulations are scattered a few miles farther on. Near its termination it rises in hills upwards of 250 feet above its visible base, though it is not improbable that it overlies and conceals a ridge of rock, to which a part of this elevation may be due. From this point its course is southerly and southwesterly, passing just west of Victor, on the Northern Central Railway, and embracing Miller's Corners, on the southern line of the New York Central, in the vicinity of which it is well displayed. From this point it passes south-southwesterly, and rapidly loses its prominence and distinctness. Its connection to the southward has not been traced out, but it is presumed to pass between Hemlock and Conesus Lakes, and to join the marginal line above described.

This appears to constitute an intermediate moraine between the Genesee glacier and the broad lobe that occupied the Finger Lake area. These lobes, however, do not seem to have been as distinctly differentiated as those which have previously been subjects of description, for the glacial movements on either side of this moraine appear to have been southerly, as judged from the prevalent trend of adjacent drift ridges, and, therefore, essentially parallel to the moraine, instead of being at right angles to it, as in the case of a true intermediate moraine.

MORAINE OF THE GLACIER OF THE FINGER LAKE REGION.

The area of the linear lakes of south central New York presents, in its greatest perfection, the parallel ridge-and-valley topographical type, and its influence upon glacial movement and accumulation. The valleys are exceptionally long and deep, and their parallelism very uniformly and definitely developed, though the combined system shows quite a measure of lateral divergence. Correspondent to this uniformity of topographical type, the moraine which skirts the area everywhere developed itself on the same general plan, *i. e.*, that of great accumulations in the valleys, with but comparatively insignificant retreating lines passing over the intervening ridges. Beginning at the west, the little lakes Hemlock, Canadice, and Honeoye, which occupy deep and narrow but not very long nor capacious valleys, are blocked at the south by moraines. That of the first-named lake extends from near Springwater to the vicinity of Wayland, and the others are similarly obstructed at points nearly opposite, the extremities of the moraines reaching to the broad Cohocton Valley east of Wayland. Between Honeoye and Canandaigua Lakes there lies a deep valley similar to the foregoing, save that it is not occupied by water. This is in like manner obstructed at the south.

Canandaigua Lake is the first of the major series, and occupies a beautifully planed valley for a distance of about 14 miles and for a width of from 1 to 2 miles. This, however, is not the full measure of the valley, which projects its low and in part marshy bottom about 5 miles onward from the head of the lake, beyond which point a valley of essentially the same width is blocked by a moraine for a distance of fully 5 miles to its junction with the Cohocton Valley. The height of this moraine above its inner base on the lakeward side is from 500 feet to 600 feet, and the material is cast up in peaks, knobs, and ridges of the most striking and impressive character. The accession of several tributary valleys just south of Naples, where the moraine begins its development, gives to the valley a local expansion, and into this the ice thrust its *débris*, spreading laterally, and giving to the morainic face an amphitheatral aspect. The tendency to lateral divergence is well illustrated by the morainic ridges, and constitutes an instructive phenomenon. It clearly indicates that the ice forming the moraine was a distinctly differentiated valley stream, for if the common sheet had reached this point it could not have deployed in this way in the valley, nor have heaped its drift in the manner observed.

The depth of the morainic accumulation is certainly great. If the valley which connects it with the Cohocton was originally channeled by a stream flowing southward—this part of the valley, at least, is one of erosion and not of glacial production, in all its great essentials—then the depth of the drift is probably considerably more than the measure of the elevation. If the preglacial stream ran in the opposite direction, the drift depth may not be any greater than the visible altitude, but it was probably not much less. With a width of about 2 miles and a length of 5 (really the cross-section of the moraine), this depth indicates a very massive accumulation. Were it heaped upon a plain, its dimensions would be impressive.

At the extremity of Keuka or Crooked Lake a valley of similar proportions is obstructed for about an equal distance, reaching from Bath to within 2 miles of Hammondsport, there being a low, marshy area between the moraine and the lake, undoubtedly a part of the former lacustrine bottom. The height of this moraine above its inner base, according to a not very trustworthy aneroid measurement, is 350 feet.

The sides of the valley rise on either hand from 600 to 1,000 feet above the base of the moraine. Along these slopes the lateral lines of the ice have left their mark in drift benches, whose surface is characterized by low swells and sags. The uppermost of these, near the head of the lake on the north side, lies at an elevation of about 1,000 feet above the lake surface, according to aneroid measurement. This, of course, indicates a somewhat greater depth of ice when the moraine was formed, since the accumulations of the lake bottom are presumably considerable.

This moraine reaches to the Cohocton Valley, and is somewhat thrust into it. The ice, on reaching it, appears to have spread laterally, as did that of the Canandaigua tongue.

The Savona Valley, below, is occupied by a less conspicuous accumulation from its junction with the Cohocton to a point above Bradford, though this long valley train of drift is not characterized throughout by distinctly morainic features.

In the vicinity of Sugar Hill, near the summit of the high ridge that divides Keuka and Seneca Lakes, the connecting moraine is developed more distinctly than observed at most points in similar situations, being here a neat, though small, moraine, banked against a slope, rising to the south of it. Its elevation above Seneca Lake is, roundly, 1,200 feet by aneroid measurement.

Above the head of Seneca Lake, commencing at Havana, 3 miles from its extremity, the valley is choked with morainic hills as far south as Pine Valley, a distance of 9 miles. At this point it graduates into a summit plain—891 feet above mean tide—which extends to Elmira, a distance of 10 miles, and there connects with the Chemung-Susquehanna flats. It reaches its highest elevation, 897 feet above tide, at Horseheads.[1]

This level consists of a broad plain, similar to those almost universally present on the exterior of the moraines in like situations, differing only in somewhat greater length, width, and probable depth, as becomes its central and relatively low position. It is a fine example of an overwash deposit, formed by the glacial waters which there found their escape. Beautifully harmonious with this are the stony clay berg-deposits on the inner flank of the moraine, and along the sides of the Seneca Valley, reaching up to a height of more than 500 feet, the product of a glacial foot-lake.

It has been a somewhat current assumption that this valley, in common with the adjacent ones, is an old river trough that discharged southward through the Susquehanna. If this be true, and no allowance be made, on the one hand, for drift deposits in the bottom of the lake, nor, on the other, for glacial corrasion, the total depth of the drift under the crest of the moraine must exceed 1,000 feet, and this depth, approximately, must continue far down the Chemung-Susquehanna Valley.

This amount of assorted drift represents a much larger quantity of unsorted matter from which it was derived; of which the coarse bowlder element must have been left at the north, and the finer and probably much more abundant product carried down the valley. So great a mass seems out of proportion to the size of the glacier and the amount of drift north of the moraine, and throws doubt upon the correctness of the assumption. It rather favors the more moderate view that the accumulation is of less depth and magnitude, and hence that the glacial corrasion necessary to produce it was less, *but that the glacial excavation in*

[1] Elevations taken from Macfarlane's Geologist's Traveling Hand-book.

the lake bottom was greater than assumed, the action being there most intense. The proposition involved in this statement may not be quite self-evident. The first impression doubtless is to the contrary. But to assume that the rock topography is, in its details, of preglacial erosive origin, and hence to assume that broad, deep cañons, hundreds of miles in length, with all their side valleys—and these must have been many and deep under the assumption made—have been filled up, and in many cases wholly obliterated, to say nothing of the leveling up of the erosion creases of large areas, involves *a magnitude of the mass of drift* and *an amount of glacial corrasion in its production* far greater than the more conservative assumption that the phenomena are due *half to cutting* and *half to filling.*

It is as though a railroad surveyor should establish a grade wholly on the principle of filling, from an indisposition to excavate, overlooking the fact that to obtain the requisite material would really involve several times the amount of excavation required by the common composite method of half-cutting and half-filling. To fill up and smooth out to its present contour a rough preglacial surface, supposed to have been eroded to all the depths now observed and channeled into a consistent system by subaerial drainage, without notable glacial reduction, really involves *indirectly* the assumption of *very great glacial corrasion* to produce the requisite material—the very thing sought to be avoided. The force of this cannot be escaped by assuming that the drift is mainly rearranged disintegrated surface material, for, in the first place, the character of the drift demonstrates that it is of *mechanical* origin. Among other evidence is the prevalence of the carbonates of lime and magnesia in the drift clays, and their almost entire absence from residuary clays. In the second place, the wash from the region during the glacial period may fairly be considered as greater in amount than the residuary material on the surface at its commencement. By a little computation it will be seen that only a very moderate duration of the glacial period would have sufficed to remove the pre-existent surface material on any fair estimate of its amount, and without assuming any specially rapid rate of removal, which might fairly be done, owing (1) to its disturbance by ice, (2) the removal of the protecting vegetation, (3) the possible extra precipitation of the glacial epoch, and (4) the extra amount of water passing over the region, due to the fact that the precipitation of the whole northern region was brought south by the glacial advance, excepting only that lost by evaporation and some possible under-drainage. It would seem that a judicial consideration of the subject would lead to the conclusion that the waste from drainage during the glacial period was *very much* greater than the whole disintegrated material on the surface at its commencement.

It seems to the writer, therefore, quite clear that the assumption that involves the least glacial corrasion is not that which denies to ice any notable action in the modification of the topography of the rock surface, but rather that which assumes that the rock prominences were ground down and some of the great channels of flow excavated, while the remaining depressions were filled with the *debris*. It is manifest that, the known facts being such as they are, the more irregular the rock contour assumed the greater the amount of drift postulated, and, consequently, the greater amount of corrasion involved in its production.

The inner line of the morainic connection from Seneca to Cayuga Valley passes by Odessa, along the foot of Cayuta Lake, and thence by a northerly course over the summit ridge.

At the head of Cayuga Lake, instead of a direct prolongation of the valley, as in the instances previously noted, the valley bifurcates. Both arms are obstructed by moraines, beginning 5 or 6 miles from Ithaca and extending about 6 miles southward, beyond which they give place to gravel valley plains. These moraines, while well developed, are less continuous and massive than those at the extremities of Seneca, Keuka, and Canandaigua Lakes. The crest of the easternmost one rises about 550 feet above Cayuga Lake. Immediately south of Owasco Lake no similar moraine occurs, but a tapering valley leads up to Groton, where a relatively small moraine stretches across it. It is not massive enough to be classed with those above described, the correlative of which is found just over the watershed at Dryden,[1] and reaching thence down to Harford. A fine moraine also runs eastward in the vicinity of the Utica, Ithaca and Elmira Railway, reaching from McLean to within 2 miles of Cortland. South of Skaneateles Lake there is a fine development of moraine hills, which were noted by Vanuxem.[2] Mr. R. D. Salisbury observed a very fine development of the chain in the Tulley Valley. Near Apulia it has a feeble expression.

From this point the morainic belt turns eastward, and, passing to the south and east of Cazenovia Lake, reaches up on the highland in the township of Fenner, Madison County, whence a small, short, intermediate moraine runs northerly and northwesterly, but soon dies away. This is the termination of the morainic loop of the linear lake region. Outside (south) of this there is another belt of valley moraines, whose consideration will, for convenience, be considered later. Concerning some of these accumulations, and some that remain to be considered, Professor Vanuxem, in 1842, made the following observations:

"There is another class of deposits, well defined as to position, but irregular as to composition, which are worthy of note. They occur in the north and south valleys which are on the south of the Mohawk River and the Great Level; or, in other words, the Helderberg range forms generally the dividing line between their north and south waters. These waters anciently flowed in one same direction, through valleys still more ancient than themselves; but they now separate, and flow over double inclined planes in opposite directions.

"The whole of these deposits have a common character. They are in short hills, quite high for their base, and are usually in considerable numbers. None were opened

[1] Prof. F. H. King directed my attention to this deposit several years since.

[2] Nat. Hist. Surv. of N. Y., 3d Dist., p. 219.

and no opportunity offered to ascertain if any defined arrangement of their materials existed or had been made when deposited. They consist of gravel, of stones, also of greater size, sand, and earth.

"The first deposit is on Sauquoit Creek, near the furnace, the hills many and high; the next on the Oriskany, between the falls and Waterville; another is in the valley of Oneida Creek, south of the point where it turns west, being the depression east of the village of Pratt's Hollow. In Onondaga Valley there are two deposits, one on the Indian reservation near the mouth of South Onondaga Valley—there the hills are highest, and the accumulation the greatest, some of the hills appearing to be over 100 feet in height; the other is a lesser deposit and near the head of the valley. A similar but smaller deposit exists at the head of Otisco Valley, near where the road takes a rise into the valley which leads to Homer; also another in the head of the valley which extends south from Skaneateles Lake, in the town of Scott. The last great deposit is in Cayuta Creek, at the head of Cayuta Lake, and extends for miles along the creek.

"Some of these deposits greatly resemble the hills of loose materials which rise in the valley near Fall and Cascadilla Creeks, near Ithaca. The hills appear to have been formed by the waters of the creeks when the lake was at a higher level, for where such substances are deposited in deep and tranquil waters, there is no tendency to diffusion, the head of the lake upon which Ithaca is seated being a perfect flat.

"There are numerous points where the alluvial appears to have been formed over the hillside, besides those near the mouths of the creeks near Ithaca; such is the mass on the west of Onondaga Village, the descent into the valley northwest of Waterville, north of the village of Greene, in the Chenango Valley, &c.

"These deposits of alluvion near the line of dividing waters greatly resemble certain accumulations of similar deposits noticed in the survey of Massachusetts, called *diluvial elevations*."[1]

GLACIAL MOVEMENTS.

After what has been learned of the laws of glacial movement in other lobes, and what has been said of the peculiar topography of this region, it is scarcely necessary to remark that the ice flowed in streams, gently diverging along the courses of the present lake troughs. That these troughs were the preglacial channels of streams does not seem to me to admit of reasonable doubt; but that there was a *selection* and moulding by glacial corrasion seems equally clear, those channels that lay in the directions that would have been pursued had the ice moved on a uniform floor, being ground out wider, deeper, straighter, and smoother, while those in transverse directions were measurably filled and obscured. The whole region shows, in the most beautiful manner, the subduing, softening effects of glacial grinding and deposition, without the obliteration of the bolder features of the preglacial configuration.

Striæ.—Polishing and grooving observed near the head of Canandaigua Lake, on the slopes of its valley, coincide in direction with it, varying from due south to S. 20° W., directions which represent approximately the courses of the valley at the points of observation. At the head of Seneca Lake the same is true, the lines closely corresponding to the local trend of the valley. At Odessa Mr. Salisbury observed two sets, one coursing S. 10° E., and the other S. 40° E., indi-

[1] Nat. Hist. Surv. of N. Y., 3d District, by Lardner Vanuxem, 1842.

cating a lateral divergence from the Seneca Valley. At the head of Cayuga Lake some very interesting observations have been kindly furnished by Prof. H. S. Williams. The general direction of movement he finds to be a few degrees east of south, with interesting deviations in detail. Within the valley, up to a height of 200 feet or thereabouts, the striæ run S. 10° E., crossed by deeper but shorter ones, running more easterly, while there are sometimes others that run due S., or even a few degrees W. of S. A remarkable case of striation is seen on a lateral face of rock on the eastern shore of the lake and about 75 feet to 100 feet above its level, and about a mile north of its extremity. The ledge is scored on the top and side, and somewhat rounded on the angle. The striæ on the upper curving face are more or less nearly horizontal, but on the vertical side the majority of the striæ *dip rapidly to the south*, some of them as much as 25° to 30°. Within the limits of Ithaca, on a ledge 200 feet or so above the lake, striæ run S. 10° E., the secondary ones S. 18° E., and occasional ones S. 8° E. The secondary striæ on the edge of the ledge here appear to incline upward toward the south. On the west side of the valley, 200 feet above the plain, the striæ maintain the same peculiarity, trending S. 10° E., with secondary short but stronger ones, S. 15°–20° E., and an occasional strong groove S. 5° E. At an elevation of 400 feet above the valley, on the east side, which is about the summit average for the neighborhood, the grooves have a stronger easterly trend. The majority, at an exposure on the grounds of Cornell University, 425 feet above the lake, run S. 15°–20° E., while strong secondary grooves run S. 20°–30° E., and a few S. 10° E.

Professor Williams notes some remarkable carvings along the hillside, the blocking out of the ledge by rectangular jointage offering favorable faces and corners for such work. One instance, described from a quarry now cut away and not seen by him, consisted of a deep channel 6 feet or so in depth, with perpendicular walls and rounded upper edges, beautifully striated throughout the surfaces. This was probably produced by tearing up or pushing away the rock between two of the joints, which very markedly characterize the rock here, and which trend about 5°–10° west of north. The ice, by then passing through this, polished and graved its faces. A still more interesting instance is presented by a vertical ledge, whose face is marked by nearly horizontal striæ and a rounded upper angle and polished upper face, striated in the usual direction, S. 10° E. In the face of the wall, however, is a horizontal groove, cut back from the vertical face about 6 inches, and being only about 2 inches deep between its upper and under faces. Within this deep horizontal groove were fine striæ, showing the remarkable adaptive capacity of ice.

Attention is called to the fact that the striæ for the lower 200 feet correspond to the local deflection of the valley westward, while those higher on the slope correspond more nearly to the main valley of the lake, which trends some 10° more easterly.

Mr. Salisbury observed striæ about 3 miles west of Preble, in Cortland County, on the eastern brow of a north and south ridge, their trend being S. 58°E., a direction quite significant of the eastward divergent movement, indicated less definitely by the glaciated valleys and drift accumulations of the region.

MORAINE OF THE MOHAWK VALLEY.

It has been previously remarked that the moraine which marks the margin of the linear lake district curves upon itself on the summit height of Fenner Township, Madison County, and makes connection with an easterly belt, marginal to the Mohawk Valley. This belt descends southeasterly into the valley of Oneida Creek, where a magnificent development is presented, occupying the valley from about Munsville up to and over the Chenango summit to Eton, where, as usual, it graduates into a great train of valley drift. The tumultuous heaping into peaks and hollows is here executed on a grand scale, making it one of the finest among many fine developments of this peculiar formation.

Feebly developed on the intervening heights, the moraine is again finely displayed in the Oriskany Valley, being best characterized about and above the Falls, but having its summit southwest of Salsville. Eastward from this it finds a moderate development in the valley in which Waterville is situated. On reaching the valley of Sauquoit Creek, it again manifests itself in great strength, reaching from Clayville to the Unadilla divide, and rising on the slopes to a height of 700 feet above Clayville. The name of this place is suggestive of, if not derived from, the foot-lake deposit of stony clay that there, as in other similar valleys, characterizes the inner side of the moraine. Between Clayville and Richfield Junction the railway cuts show fine examples of highly inclined, discordant, and curved stratification.

Eastward from this point the development of the moraine is less conspicuous, and the phenomena at the present stage of investigation present some very interesting and partially undecided questions. Directly in the line above delineated, about 12 miles eastward, at Ilion, and above and below in the Mohawk Valley, there is a considerable aggregation of moraine-like drift hills, attended by the usual drift benches on the valley slopes, and by the embankments of stony clay that characterized the inner edge of the moraine in such situations. The drift hills are mainly confined to the south side of the valley, and have their best development just east of Ilion, where there is a considerable cluster of hills from 50 feet to 75 feet or more in height, by estimation. Mounds and ridges of morainic aspect rise on the slope and in the valley of Steele Creek, stretching southward and westward. These seem to be a connecting chain leading back to the moraine on Sauquoit Creek, above described.

The interval, a space of about 10 miles, has not been examined. The line of observation chosen—the only one that limitation of time permitted—lay a little to the south of this, and brought out the interesting fact that, from Cedarville eastward, the trend both of the ridges and of the peculiar fluting of the hillsides that characterizes glacial erosion is notably east-westerly, while to the westward it is as conspicuously north-southerly. On encountering this change in topography search for striæ was not immediately successful, but within a few miles east, between Orendorf Corners and South Columbia, and about 10 miles due south of the moraine at Ilion, are frequent flat exposures of Corniferous limestone, on two of which (about one-fourth mile apart) striæ are still finely preserved. These show, in the one case, a direct westerly movement, and in the other a course S. 80° W. That the movement was *toward* the west was shown both by little projecting knobs of chert, much worn on the "stross side," in whose wakes were conical trains of polished limestone, and by the unequal erosion of the east and west sides of cavities in the surface of the rock. The determination was considered absolutely decisive when made. There are no adjacent topographical influences that could be supposed to make the course here exceptional, the surrounding surface being essentially plane.

The whole region eastward of this on the south side of the Mohawk, at least as far as the topographical axis that joins together the Adirondacks and Catskills, presents phenomena concordant with this, seeming quite clearly to sustain the view of a westerly movement along the plateau south of the Mohawk.

GLACIAL MOVEMENTS IN THE MOHAWK VALLEY.

These facts lead to the broader and very interesting question of the glacial movements in the Mohawk Valley. It seems to have been a currently accepted view that the ice movement was eastward down the Mohawk. The fact just stated suggests that this was true only as far as eastern Herkimer County, and that the easterly moving current was there met by one from the opposite direction moving up the valley. The complete determination of this requires more extended observations than I have yet been able to make, but the following notes may at least assist in setting forth the problem, and in leading on towards its solution.

Returning to a further consideration of the moraine proper to the western Mohawk glacier, it is to be remarked that the valley bottom from Utica eastward is broad and level, as much like a lake bottom as like a fluviatile flat. Its sides slope smoothly up to the highlands on either hand, without massive or distinct benches of drift. To the eastward the valley gradually narrows, and near East Schuyler and Frankfort drift shoulders appear, at first differing little from common river terraces, but soon developing, especially on the south side, into morainic buttresses.

Between Ilion and Mohawk village, the southern portion of the valley bottom is occupied by pronounced drift hills. At Herkimer, on the north side, the drift bench swings around the promontory between the Mohawk and West Canada Creek, and joins similar accumulations in the valley of that tributary. Here they fill a relatively larger proportion of the valley, and are overlain by aqueous and ice-block deposits, which mask the true glacial drift, but the surface contour implies a morainic substratum. On the promontory northwest of Herkimer, morainic benches and embossments rise several hundred feet upon the slope. On the south side of the river, from the village of Mohawk to the vicinity of Little Falls, the valley slope is banked with an unusual amount of drift, the superficial portion of which seems to be a subaqueous deposit, but its contours imply a morainic base. On the heights south of Little Falls are accumulations of semi-morainic aspect. Taken altogether the phenomena of drift accumulation here give the impression of having been formed by an ice tongue that reached down the Mohawk to the vicinity of Little Falls, forming morainic hills and embankments along its margin, and on its retreat permitting the gathering of the glacial waters into a foot-lake in which the clayey deposition of berg till took place, mantling the earlier deposit. Only a portion of these deposits have survived the subsequent waters that swept down this great avenue of discharge.

The general topography of the region accords with this view. It is in this vicinity that the Adirondacks from the north and the Catskills from the south throw out their spurs toward each other and constrict the Mohawk Valley to its narrowest dimensions. It was here, as I think, that a preglacial watershed parted streams that, on the one hand, flowed eastward to the Hudson, and, on the other, westward to the Ontario basin. Neither glacial erosion nor accumulation have here been sufficient to obliterate the main features of the preglacial topography. The watershed may be quite confidently and exactly located near Little Falls. The cutting of the upper and broader rock-gorge of the Mohawk at that point appears to have been the work of the earlier glacial epoch, and of interglacial drainage. It certainly antedated the close of the glacial period, for the ice passed through it, rounding and scoring its ledges, but appears to have in no great degree modified its form or enlarged its capacity. This fact, in some measure, supports the view that the termination of the easterly ice movement was in this vicinity, since in that case little erosion would be here effected; while, on the other hand, if there had passed through the gap a current sufficiently strong and massive to reach down into the Hudson Valley, pushing back the ice that would otherwise have entered from that direction—an ice current which must, therefore, have flowed through the gap for a relatively long period—a much more marked modification of the contour of the gorge should have been accomplished.

A short distance east of this gap there appears in the bottom plain of the valley, its crest rising not more than a dozen feet above the plain deposits, a neat little ridge of very bowldery drift, having the form of a U open westward toward the gap. This may plausibly be regarded as the washed crest of a partially buried moraine, formed by an ice tonguelet thrust through the gap from the west in the last stages of the glaciation and prolonged beyond the common mass that was held back by the transverse ridge through which the gap is excavated. This little supposed moraine is not to be understood as being at all comparable to the great moraine of the epoch, but only one of its smallest, though not least interesting, elements.

Striæ of the Mohawk Valley.—All the glacial gravings west of the longitude of Utica point south, or southerly, coincident with the valleys, and trending directly against the moraine in that region. There are, however, some interesting divergences to the southeastward and southwestward on the slopes of the major valleys, in obedience to the law of divergent flowage. On the western slope of the ridge that stands athwart the valley of the Mohawk at Little Falls are two sets of striæ. The course of the main series is S. 50° E., and of the minor cross-set S. 45° W. North of Little Falls, two-thirds the way up the slope of the valley, the course of striæ is S. 60° E., the movement being apparently from the west. A little farther up the slope, on an eastward inclined rock-surface, the main set runs S. 50°–55° E., crossed by feebler and later ones S. 70° W. Four miles north of Little Falls, a varying group runs S. 18°–28° E., and about 6 miles north S. 37° E.

In the vicinity of Saint Johnsville, 10 miles east of Little Falls, several observations were made. At the saw-mill just north of the village, and near the base of the slope of the valley, striæ trend N. 60° W. (S. 60° E.), the movement seeming to be westerly. Farther up the slope, perhaps a hundred feet higher, the direction is N. 10°–15° W. Here also the movement seemed, at first inspection, to be *toward the north.* There were large semi-cones standing forth on the face of the polished limestone, that, at first glance, seemed to be trains in the lee of harder portions; but, under the influence of the skepticism which so seemingly anomalous a direction called forth, I was led to doubt the evidence of such a movement, as the southward and larger extremities of the low semi-conical projections were not well-polished knobs, such as characterize unequivocal instances of this class. On the ascent northeast of the village, scratches pointing S. 75°–80° E., crossed at some points by a finer set S. 52° W., were observed. About 2 miles to the northeast, the course was N. 12° W. on the surface of a highly silicious rock. The striæ are here attended by rows of minute curved cracks like the imprint of a very large and very thin finger nail, inserted about every quarter-inch. The convexities of these are turned south. I had previously observed a similar phenomenon at Sioux Falls, Dakota, on quartzite, the convexities there being northward. In this case there being no doubt that the movement was southward (S. 20° E.), I had at the time of the observation supposed that this might be a new criterion by which the course of the ice could be determined, and a subsequent observation, coinciding with it, seemed to confirm the idea. This, it will be observed, coincides with the first impressions concerning the striæ above noted.

A little north of the last, just north of the south line of Oppenheim Township, on the more eastern road from Saint Johnsville to Lasselsville, are striæ running N. 15° W. over a planed surface, in a hollow of which scratches run N. 40° to 50° W. Near the point where the above road crosses the line between Oppenheim and Ephratah Townships, south of Lasselsville, striæ on the southeast side of a hill of gneiss run N. 8° W. (S. 8° E.).

At Palatine Bridge striæ were examined at two points, at both of which the course was approximately that of the Mohawk Valley, on the north slope of which they are situated, being N. 50° to 53° W., and N. 55° to 60° W.

Groovings of like trend, and in like conformity to the valley, were noted by Professor Vanuxem, at Speaker's Basin, Amsterdam, and Fort Jackson, Montgomery County.[1]

Passing up out of the immediate valley, the evidence bearing upon the question of glacial movement has been less fully gathered than is needful for a decisive opinion. Between Northville and Hope Falls, in the northeastern corner of Fulton County, and in the very edge of the Adirondacks, I observed scratches pointing S. 7°–8° E., and S. 10° E., but they were on the northeastern sloping base of a mountainous hill, and may have been locally deflected eastward. The linear contours of the drift accumulations from Northville, southwestward toward the Mohawk, give the impression of a glacial movement from the northeast to the southwest.

On the south side of the Mohawk, immediately on rising from the river-trough, in Montgomery County, the surface is characterized by a very notable linear arrangement of ridges and valleys conspicuously parallel to the average trend of the valley, which is a few degrees north of west. Between the northernmost spur of the Catskills, which terminates in the promontory of Mount Independence, near Sharon Springs, and the river, this linear arrangement is very marked, the prevailing trends being about 10° or 15° north of west. At Sharon Springs striation is finely exhibited in one of the quarries within the village, and demonstrates a movement from the northeast (N. 45° to 50° E.). Southward from this, along the mountainous belt leading down to the westerly Catskills, frequent planed and striated surfaces show that the

[1] Nat. Hist. Surv. N. Y., 3d Dist., 1842, p. 245.

movement was nearly due west, ranging from west to W. 10° S., with a single observation of a cross-set W. 20° S. These observations are supported by the testimony of the adjacent topographical contours, and by little morainic loops opposite the gaps in the range, manifestly formed by ice tongues thrust through them, as will be presently noticed.

From the extremity of this mountainous spur, against which the ice impinged from the east and northeast, it is little more than twenty miles westward to the locality near South Columbia, where the movement was westward. Intermediate between these, on a relatively plane surface, northwest of the north end of Otsego Lake, striæ run S. 33° to 50° W. In the northern edge of the village of Cherry Valley two sets were seen, the one S. 24° to 33° W., and the other S. 6° E. Both are in the valley, and subject to local influence. Prof. J. D. Dana, in an article on a Mohawk Glacier, quotes Rev. W. B. Dwight as authority for an additional independent set of striæ seen on Burned Hill, and at a point one-half mile below Cherry Valley, whose course is "east by north."[1] There is no positive statement as to whether the movement was toward the east or west. Taken in connection with associated facts, I entertain little doubt that it was the latter. Such a movement westerly and southwesterly would only continue while the ice retained a thickness upwards of 1,000 feet over the upper plains of the Mohawk. When it thinned below that the mountainous ridges on the east would cut off the flow from that direction, after which a movement down the valley from the north and north-northeast might follow, being a lateral divergence from the main westward current, which would still continue to flow for some time through the valley of the Mohawk.

I hesitate, at this stage of the inquiry, to encourage any confident opinion in regard to the exact history of glacial movements in the Mohawk Valley, further than the general presumption that massive currents having their ulterior channels in the Champlain Valley on the one hand, and the Saint Lawrence on the other, swept around the Adirondacks and entered the Mohawk Valley at either extremity, while a feebler current, at the height of glaciation, probably passed over the Adirondacks and gave to the whole a southerly trend. It should not be overlooked that this valley lies sufficiently back from the average limit of glaciation to afford the presumption that the earlier and later movements may have been quite different. The striation of the immediate Mohawk Valley may be the work of local currents developed on the margin of the retiring glacier. Only a critical survey of the whole region can furnish an adequate basis for a trustworthy conclusion. The facts already gathered are, perhaps, sufficient to determine the more essential questions relating to the marginal moraines under discussion.

[1] On the Existence of a Mohawk Valley Glacier in the Glacial Epoch, by James D. Dana. (Am. Jour. Sci., vol. xxxv, No. 104, March, 1863.)

THE WESTERN MARGINAL MORAINE OF THE HUDSON RIVER GLACIER.

As a result of the westerly and southwesterly movements above indicated, there is a belt of irregularly distributed valley moraines stretching across the hilly plateau on the west of the Catskills and their northwesterly prolongation. These moraines are pre-eminently developed in the valleys, but do not assume precisely the same phase which we have found to characterize in so prominent a degree the region of the finger lakes. Here the original hilliness was clearly developed in much greater boldness, ruggedness, and irregularity, so that instead of presenting a symmetrically grooved floor with ridges lying in positions toward glacial movements favorable for the development of symmetrical ice-fingers, its irregularities and obstructive attitudes seem to have disturbed and greatly enfeebled the movements of the marginal portion of the ice sheet, so that an unusual complexity of accumulation is presented.

As these may fairly, in the present state of our knowledge, be correlated and interpreted somewhat differently, a sketch of their distribution will best precede the general statement.

Distribution.—South of Schuyler Lake, and thrown across the valley through which it discharges its waters, are successive groups of morainic hills, twenty to sixty feet, and occasionally more, in height, mainly composed of assorted material, and presenting the characteristic knob-and-basin topography. In the valley of Otsego Lake morainic side-benches begin at Cooperstown, and, gradually widening, extend across the valley within a mile or two below, in part choking it, and, though not markedly of the rougher moraine type, they yet present characters that clearly differentiate them from simple river terraces and fluviatile accumulations. These gradually die away, and only low undulations of drift continue to near Portlandville, where morainic accumulations reappear in moderate strength, giving place again to undulatory plains of drift, which, near the junction of the valley with the Susquehanna, merge into morainic lateral benches and hills.

In the Susquehanna Valley there is a quite remarkable chain of knobby drift hills; beginning near Richmondville, on the east side of the northerly spur of the Catskills. Morainic hills occupy the valley through which the Albany and Susquehanna Railway finds a passage across the range, from a point a short distance above Richmondville up to the mountain pass. They reach high up on the slopes not only, but on the northern side crown the brow of the ridge and pass over on to the summit toward Seward Valley. Their vertical distribution here is about 500 feet. These accumulations are pushed well up into the mouth of the narrow mountain pass, which is, however, largely free from them. But on emerging into the Susquehanna Valley on the southwest there begins a very notable series of drift hills that recur at short intervals all the way down the valley to the Pennsylvania line. They are best developed about Worcester, Schenevus, and Maryland in the upper part of the valley, and about Nineveh and Lanesboro in the lower part. They are habitually best developed about the mouths of tributary valleys, and are perhaps largely due to conflicting currents, which such situations naturally engendered.

The adjacent Charlotte Valley, a tributary of the Susquehanna, is likewise blocked at intervals from a short distance above Charlotteville down at least as far as Davenport. Above the latter point, along a tributary leading down from North Harpersfield, are similar morainic accumulations thrown across the valley.

At Stamford there is quite a noteworthy little moraine developed on the western side of the mountain range, opposite a gap between Mount Utsayanthe, whose elevation is 3,203 feet,[1] and Bald Mountain, of less height, Stamford being 1,767 feet above the sea. The bottom of the pass, just within the gap, is a smooth, boat-shaped trough, fashioned as if a gigantic keel had grounded in an attempt to force itself through the opening. It is, in truth, beyond doubt, the impression of an ice-keel. Beyond this, encircling it in a rude U-shaped loop, is a moraine, piled into undulatory hills, which reach southward into the valley of one of the sources of the West Delaware. Near Hobart, three miles below, another accumulation of low knobs occurs, and below that others at intervals, as far at least as Bloomville, where a handsomely developed moraine rises to a height of 60 feet, and is so related to the entrance of a tributary from the north as to appear to have been formed by an ice-tongue from that direction. The same is true of others above. From this point to Walton this valley has not been traversed, but at the latter point, leading down to Rock Rift and below, are similar low drift hillocks mainly skirting the eastern side of the valley. It is not improbable that they occur in the unobserved interval.

Like phenomena characterize the headwaters of the East Branch of the Delaware River. The Grand Gorge (Moresville) at its very headwaters is a remarkable natural gap through the northwestern range of the Catskills. Its fluted sides indicate the passage of a powerful ice stream. The gap itself is almost entirely free from drift, but just south, as it widens into the valley, a high massive terrace-like moraine lies along the west side of the valley, extending continuously and in much massiveness five or six miles, beyond which it reaches on in a more interrupted and irregular course for as many miles more. At intervals below this point, irregular drift hills are thrown across the valley as far down as observation was carried (about twenty-five miles from the gap) but with continually decreasing strength. South of Grand Gorge is a small notch lying between Prattsville and Roxbury, on the west side of which near the latter place a morainic terrace is banked against the

[1] Guyot.

valley slope. On the east side of the range below Prattsville there is a fine cluster of morainic hills in the Schoharie Valley, with a train of drift stretching down the valley toward Gilboa, and also in the opposite direction leading up toward the gap westward. Farther up the Schoharie at Red Falls is a moraine, which, for half a mile or more along the valley, presents a very rough knobby surface.

A less massive but sharply defined moraine corresponding more closely to conventional ideas of morainic development crosses the Batavia Kill—a tributary of the Schoharie—just east of East Ashland post-office, or just above the entrance of Lewis Creek. It is a narrow ridge with indented outline, and extends continuously across the valley, save as cut by the stream, which exposes a fresh section of dark dirty-red till. Still above this a similar little moraine crosses the valley at its turn toward the west, just below East Ashland. These moraines, it is to be observed, are in the very heart of the Catskills. The region east of them is notably more glacially worn than that on the west.

In the Esopus Valley, in the southern Catskills, clusters of low drift mounds appear below Big Indian, and extend with interruption to Shandaken, appearing to prefer the east and west portions of the valley and to follow the general rule of largest development opposite tributaries entering in the direction of glacial movement. Morainic heaps occur farther down the valley nearly to the lower land adjacent to the Hudson.

South of the Catskills, the Rondout Valley furnishes an open gateway from the low plateau adjacent to the Hudson to a higher plateau that stretches westward and southward between the Catskills on the north, and the Shawangunk range on the southeast. Into this gateway and across this plateau there was a westerly glacial movement. This will be further considered presently, and is here only referred to for the purpose of giving greater significance to moraines observed in the vicinity of Liberty Falls, Monticello, and Sandburgh, in Sullivan County, which perhaps mark the limit of a glacial lobe occupying the plateau indicated. Its full periphery has not been traced.

On the east side of the Shawangunk Range, at several points from Bloomingburgh to Unionville, near the New Jersey line, morainic ridges have been observed stretching along the eastern base of the range. Following this course onward into New Jersey, it is a noteworthy fact that along it lie the leading points at which "moraines of recession" have been noted by the geologists of New Jersey. Professor Cook's annual report for 1880 gives ampler details, but the following quotation from that of 1878 sets forth more succinctly the prominent facts:

"The drift in the lowlands and valleys is much more uneven, and looks more like that of the frontal moraine. And in some localities there are immense heaps—rising into hills and ridges—of earth, gravel, cobblestones, and bowlders, which mark lines along which the glacier may have halted for a time, or to which it may have again advanced and heaped up the loose materials in front of it. One of the most beautiful of these later moraines is that which stretches across the valley of the Wallkill at Ogdensburg, in Sussex County. In fact, the village is on it. There is a great bank of earth and bowlders, &c., stretching from the gneissic slopes on the east to the white limestone of the Pimple Hills range on the west. This bank or ridge has a convex southward front, showing that it was left here by a glacier which moved southward up the valley of the Wallkill. It is interrupted at the west side of the valley by a gorge or gap through which the kill now flows. It is about 100 feet high above the valley level north of it and above the creek in the gap.

"At Hamburgh there are some very large hills of drift lying near the southern end of Vernon Valley. And these, with others near McAfee Valley, look as if they had been left there by a glacier which moved down, southwestward, through the Vernon Valley. Another well-marked moraine is at the north end of Green Pond, which stretches across what seems to have been the former outlet to that lake.

"In the valley of the Rockaway, near the Sparta Turnpike, there is a group of flat-topped hills, which fill the valley, excepting the narrow depression winding through them, in which the Rockaway finds its way. Similar hills are seen in the same valley farther to the north and near the Pequannock."[1]

In the region west of this the drift is less abundant, and the evidence of glacial wear less marked. In central Morris County this belt reaches the moraine that limits the drift area, joining it at its northern angle, where it is mapped as turning quite abruptly southwestward, and finds its presumptive eastward extension in the morainic range traced in detail by Professors Cook and Smock southeasterly to Perth Amboy, where it bends northeasterly and crosses Staten Island, extending onward, on Long Island, as will be presently noted.

A COLLATERAL BELT OF MORAINES.

The belt now sketched in sinuous course across New York marks the northern or inner border of a wider zone characterized by numerous morainic aggregations. It has been followed to the neglect of the collateral portion, (1) because it is the most strongly characterized, (2) because it lies on the border between the severely glaciated and the feebly subdued drift areas, and seems best to define the limit between the singly and doubly glaciated provinces, and (3) because of the convenience of following a single synchronous range rather than a complex group not strictly contemporaneous. But before gathering the facts into generalizations these collateral deposits need consideration. They consist of groups of rolling drift hills—largely of gravel—heaped in mounds, sharp ridges, and terrace-like benches, accompanied by irregular hollows of circular, elongated, winding, and irregular forms. In other words, they are very similar to the kame-like members of the morainic aggregation already described. They are usually, but not always, less boldly developed than the hills of the inner belt, and are more confined to the valleys, *i. e.*, the connecting links running over the ridges are less con-

[1] Geol. Surv. of N. J., Report of the State Geologist for the year 1878, page 21.

spicuous, and no attempt has been made to trace them out, except in some of the more critical areas in the western part of the State. If they lay on the margin of the drift area, and were not liable to confusion with collateral ridges, it would doubtless be easy to follow them consecutively, but constituting, as they are thought to do, members of a complex, somewhat intertangled series, the distinct delineation of each line is a laborious undertaking, and, for the general results here sought, unimportant, though they will certainly prove very instructive in regard to many phases of special glacial action.

Many of these hills would doubtless be classed by some simply as kames, and referred to torrential action, independently of any special glacial movement. The special phases are undoubtedly due, in an important measure, to the action of water, but the manner in which they are thrown across valleys, or bunched within them, implies as a condition of their formation an advance of the ice.

Distribution.—The general distribution of these collateral deposits may be seen upon the accompanying map, and only a brief enumeration will be here given.

Returning to Western New York, it may be recalled that in Cattaraugus County, several small moraines, thrown across the valleys south of the stronger line, were noted, as those at Ashford and below Bevereux. In south Wyoming and Alleghany Counties, a morainic range extends southward from Pike village along the western side of Pike Valley, and then along the west border of the Genesee to the elbow which it makes just below Caneadea. Here the moraine is protruded westward in a very fine development, nearly to the village of Rushford. The whole of this appears to have been formed by an ice-tongue pushing up the Genesee Valley to the elbow, where, instead of turning with the angle of the valley, it pushed straight onward toward Rushford, forming the moraine mentioned. On the left-hand margin little accumulation of drift occurs, perhaps from the height and smoothness of the bounding ridges on that side. This tongue must have been formed earlier than that which heaped up the much greater moraine across the valley at Portage.

On the eastern border of Alleghany County, at the village of Canaseraga, and stretching in a terrace-like shelf along the western side of the valley leading down to the Canisteo River, is a moraine reaching 200 feet above its base, apparently formed by ice moving up the valley from Dansville. At Arkport, morainic hills rise 300 feet against the eastern slope of the valley. Nearly opposite it, on the west, the lower part of the North Almond Valley is choked up by finely developed moraines, thrown in succession across the valley. Still farther south a yet more finely characterized series of morainic hills occupies the valley through which the Erie Railway reaches the elevated summit between the Alleghany and Canisteo basins. From the point where it joins the Canisteo trough, between Arkport and Hornellsville, up the valley southward by

INNER FACE OF THE MORAINE, NORTH ALMOND VALLEY, N. Y.

Almond and Alfred Station to about a mile beyond the latter place, the valley is occupied by irregularly grouped morainic hills and massive drift benches, banked against the sides of the valley up to a height of 300 feet and to an altitude above the sea level of 1,800 feet.

This very fine display was unquestionably the product of a massive ice-tongue pushed into the valley from its open mouth northward, and is intimately associated with those above mentioned.[1]

In the vicinity of Loon Lake, in the northwest corner of Steuben County, is a very handsomely developed moraine of unusually rapidly undulating surface. It seemed uncertain from the observations made whether this was formed by a protrusion from the Canaseraga Valley, diverging at Dansville, or from that of Hemlock Lake, thrust through the valley leading south from Wayland. The Cohocton Valley at Liberty, just opposite the above, is occupied by a morainic aggregation of drift rising 50 feet or 60 feet above the average level of the valley bottom.

The morainic accumulations to the east of these that seem to fall into the same category are somewhat singularly grouped along the Canisteo, Chemung, Susquehanna, and Chenango Valleys. By reference to a map it will be seen that these streams form a large rude curve approximately concentric with the belt marginal to the linear lakes already described. The valleys of these streams are broad and flat bottomed, and occupied to unknown but probably very considerable depths by gravelly drift, which is, for the most part, undoubtedly the product of the glacial predecessors of the present rivers. At numerous points along almost the entire stretch from Steuben to Madison County the mouths of tributaries from the north are characterized by gravelly hills and hollows, protruding deltas, and undulatory terraces that seem to be the product of the combined action of ice streams and glacial rivers. These are usually much less strongly characterized than the moraine above described. The individual hillocks usually range from 40 feet in height downward, but occasionally reach an altitude of 90 feet, or more, while the clustered masses of hillocks and the terrace-like embankments range from 40 to 100 feet and more. If any of the knob-and-basin accumulations of gravel that in any way imitate the kame-like element of morainic aggregations are formed by the action of water, independently of glacial ice-action, these can most probably be so explained.

Accumulations of this sort have been observed (beginning at the west) at Adrian, Cameron, Cameron Mills, between Painted Post and Corning, just west of Elmira, and on the side of the valley leading north to Horseheads, near Wellsburgh, at Chemung, Waverly, Barton, and at two or three points between that place and Tioga Centre, as

[1] I am under special obligations to Rev. Dr. Maxon and Professor Williams of Alfred University for information and guidance in the study of this moraine and for other kindnesses.

well as at the latter place; at Owego and Campville and between the two, and also east of Campville; at Union and about two miles east of there, at Binghamton and about three miles west of there. In the Chenango Valley moraines occur at Port Crane, and just above Chenango Forks, where the valley is choked to an estimated height of 100 feet with a very noteworthy moraine, having an abrupt northerly face and an extended southerly flood-train of drift. From below Greene almost continuously to Oxford, similar accumulations are developed in considerable strength, as also near North Norwich, and below that place; also east of Earlville, and again at Smith's Valley and below Hamilton, which last brings us into close association with the main belt above described.

Intermediate between this semicircular chain and the more massive one along the extremities of the lakes, similar accumulations have been observed at a number of points along the connecting valleys, as at Lebanon, Erieville, Marathon, Killawog, Lisle, and Rickford. They probably occur at many other points, as the region has not all been examined.

All these accumulations very naturally marshal themselves into a crescentic belt essentially parallel to the more massive one on the north, and may be rationally regarded as the outer member of the composite moraine. That the outer moraine should be, apparently, the feebler does not altogether accord with the general fact elsewhere, but may be due to the roughened character of the original ground on which the margin rested, resulting in a swallowing up by the valleys of a larger proportion of the drift pushed along by the glacier and causing a feebler marginal deposit. Furthermore, the present expression of the moraine may not at all fairly represent its original strength, since it was subsequently subjected alike to erosion and burial through the agency of the drift-burdened waters that escaped while the inner moraine was being formed.

It has been previously remarked that the Susquehanna Valley from its very head is frequently obstructed by morainic aggregations down to the point where it enters Pennsylvania. This, however, is not equally true of the whole distance, the accumulations being most abundant and most conspicuous in the upper fifteen and lower twenty miles of the course. In this lower portion, reaching from about Afton, in south Chenango County, to the villages of Lanesboro and Susquehanna, in Pennsylvania, the accumulations are more notable, and reach up onto the intervening highlands, having a vertical range of nearly 400 feet, and a summit altitude of about 1,400 feet above tide-water. At Medford, in northern Susquehanna County, there is a moraine described by Prof. I. C. White, which probably belongs to this series. The fact that Canadian drift is confined to the northwestern corner of Susquehanna County is worthy of consideration in this connection, as that is the portion of the county which lies northwest of the line of these accumulations.[1]

In the valley of Unadilla River, which is a tributary to the Susquehanna on the north, small moraines occur just above Rockdale; at Upton, where peaks rise more than 100 feet, and near Holmesville, where only moderate strength is developed. Above this the valley is mainly occupied by gravel plains and occasional morainic hills. Along the upper branches of the Delaware similar accumulations have been seen about Walton and below, on the West Branch and at Fish's Eddy and at Hancock on the East Branch. Doubtless they occur at other points not visited.

CORRELATION.

At the present stage of investigation it seems possible to put upon the facts gathered three interpretations, which differ from each other, however, in nothing that essentially affects the general conception of the moraine.

I. *First correlation.*—The first would regard the moraines along and adjacent to the Chenango and Susquehanna Rivers, north of the Great Bend on the Pennsylvania line, and their possible extension into the latter State, as of an intermediate nature, indicating the approximation of two great glacial streams of the earlier epoch, the one having its main channel through the Champlain-Hudson Valley, and the other through the Saint Lawrence Basin. The former stream rose above and flowed over the Catskills, and there was doubtless some flow over the Adirondacks, but not sufficient to prevent the partial differentiation of the two great currents at their margin. This view offers a ready explanation of the fact announced by Prof. I. C. White[2] that metamorphic erratics in Northeastern Pennsylvania are confined to the northwestern corner of Susquehanna County, and are entirely absent from *the remainder* and from the adjacent county of Wayne.

The ice of the second glacial epoch, under this view, passed westerly and southwesterly across the northwestern spur of the Catskills, forming the moraines below Schuyler and Otsego Lakes, those along the upper twenty miles of the Susquehanna Valley and in the Charlotte Valley, those that lie opposite the gaps in the range at Stamford, and at Grand Gorge, and in the valleys below these points. It is believed also that the sheet passed over the northeastern and eastern portions of the main Catskills, but that it did not override with appreciable force, if indeed it surmounted at all, the higher southerly and southwesterly Catskills, the ice being there broken up into valley currents and practically arrested in its progress. To these local currents are referred the minor moraines scattered through the mountain valleys, though some of them may be due to independent local glaciers of later date.

[1] 2d Geol. Surv. Penn. G^5., 1880, p. 26.
[2] Loc. cit.

On the south of the Catskills, however, there entered the gateway between the Catskills and the Shawangunk Mountains a very considerable glacial stream, which spread westward and southwestward, reaching down to the vicinity of the Delaware, but not crossing it. The southeastern flank of this pear-shaped lobe lay against the Shawangunk range, which separated it from the main current passing down the Hudson.

The margin of this lower Hudson lobe had its right flank along the eastern side of the Shawangunk range, but diverged from it near the north line of New Jersey, and below that point, while somewhat interrupted by the mountainous ranges of the region, it swept in a general southerly and southeasterly direction to Staten Island.

The margin thus outlined divides the territory that shows unmistakable evidences of glacial subjugation from that in which the modifying effects of ice action are far less marked and quite subordinate to the preglacial configuration of the surface, the drift being little more than a thin, discontinuous blanket spread over hills and valleys only slightly worn and modified in contour by ice action. This distinction between the two areas obtains throughout the entire glaciated territory traversed by the moraine, and possesses considerable value in discriminating between the earlier and later glacial provinces, but in its application to a region originally so rough as this more or less of doubt attaches to a correlation based upon it.

Striæ.—The general testimony of striation accords with this view. Across the northwestern spur of the Catskills, it is demonstrable that the movement was westerly and southwesterly. The same is true of the northeastern Catskills. The striation in the rear of the Catskills, however, is southerly and southwesterly, as indicated by the following observations:

DELAWARE COUNTY:	
At Hobart	S. 10° E.
Near Bovina	S. 10°–40° W.
The main set being	S. 28°–35° W.
Near Margaretville on a western slope	S. 75°–80° W.

These are in close accord with the observations of the State survey in Northeastern Pennsylvania, which are as follows:

SUSQUEHANNA COUNTY:	
Harford Village	S. 25° W. mag.
North line of Harford Township	S. 30° W. mag.
One mile west of Martin's Creek, Brooklyn Township	S. 30° W. mag.
In Auburn Township	S. 55° W. mag.
WAYNE COUNTY:	
Lebanon Township	S. 5° W. mag.
Salem Township	S. 12° W. mag.
Just east of Nobleville	S. 20° W. mag.

These accord also with those of the adjacent portion of Sullivan County, New York, but in the area of the lobe between the Shawangunk and Catskill Mountains a westerly movement prevailed, with divergence to the south, as shown in the following observations:

"On the highlands west of Shongham, and where there could be no obstruction for 70 or 80 miles, I examined ten or twelve different places in which the furrows were deep and distinct, and found them to run from 10° to 12° north of east, and they continued down the mountain in the same direction a considerable distance. At no great distance to the south, the furrows tended 25° south of east, leading to a low opening in Shongham (Shawangunk) Mountains."[1]

SULLIVAN COUNTY:	
Two and one-half miles below Shin Creek Village	S. 45°–55° W.
One-half mile further south	S. 28° W.
Crest of hill SSE. of Liberty Falls.	S. 35°–50° W.
One and one-half miles SE. of Liberty Falls	S. 50° W.
Crest of hill 2 miles SE. of Liberty Falls, movement from the east	S. 80° W.
One mile farther E	S. 82° W.
One mile N. of the above	S. 78° W.
Two miles N. and one E. of Fallsburg	Due W.
Four miles NNE. from Monticello.	S. 75° W.
Between Monticello and Bridgeville (Mather)	S. 10°–15° W.
Between Monticello and Forrestburg (Mather).	S. 10° W.
On E. declivity of the mountains west of the Mamakating Valley (Thompson)	S. 78°–80° W.
At Mongaup Valley, east slope (R. D. Salisbury)	S. 30° W.
One-half mile W. of White Lake (Salisbury)	S. 20°–28° W.
One-half mile NE. of Fosterdale (Salisbury)	S. 30°–35° W.
One mile further N. (Salisbury), movement from the NE	S. 30°–35° W.

II. *Second correlation.*—The second view would make the upper Susquehanna and adjacent moraines the constituents of the extended Kettle moraine, and presume that they extend into Pennsylvania, and there coalesce with, or perhaps rather constitute, the marginal moraine on the outer edge of the drift area, and after such junction follow eastward the course already determined by the glacialists of Pennsylvania and New Jersey, and as previously sketched briefly. The moraines lying east of this belt, under this view, are attributed to the local influence of the surface irregularities, giving exceptional effect to the oscillations that must have characterized the retiring glacier.

III. *Third correlation.*—The third view combines essentially all of these moraines into the comprehensive Kettle range—the Susquehanna line constituting the outer belt, while the more easterly one forms the equivalent of the range that in the central part of the State lies immediately along the extremities of the linear lakes. The unusually wide divergence of the constituent ranges is, under this view, attributed to the obstruction opposed by the Catskills, which were somewhat readily overflowed by the deeper ice stream of the first stage, but which quite effectively retarded the thinner sheet of the latter. The divergence

[1] Am. Jour. Sci., vol. 23, pp. 243–247. (Thompson.)

of these ranges is less than twice that observed at some other points where the topography is very much less differentially obstructive. Of course the existence of simple obstruction does not necessarily produce divergence, for it might equally well produce coalescence. It is its *differential* effects upon successive advancing sheets, each later one being thinner than the earlier.

The respective merits of these views may be prudently left to the decision of future investigation. The mountainous character of the region raises many special questions which enter into the problem, and which the present stage of investigation scarcely more than lifts into distinct definition. I entertain no doubt that the general principles that controlled glacial movement over the planer surfaces of the interior were dominant here also, but there is a fair presumption that their action was much modified by the special influences that arose from mountainous obstruction. The exact character and measure of this only critical investigation can determine.

It is not impossible that some of the valley aggregations that have here been grouped with the morainic accumulations are due to other causes. The disposition to magnify a favorite method of interpretation—which is, I believe, universal to human nature—may perhaps find an illustration here. It is to be understood that I do not hold that the stratified kame-like knolls and ridges here classed for convenience as morainic phenomena were formed by the direct mechanical action of the ice, but it is my belief that they were due to special aqueous action attending glacial advances in such close relationship that they become distinctive incidental products, and mark the position of halt and retreat as characteristically as the true moraines of mechanical origin themselves, which they so often overlie and conceal. I do not assume that all kame-like clusters, or belts of drift hills, are so formed—certainly not the Åsar ridges that lie in the course of ice movement. There is ground for believing that some such moraine-like but not truly morainic accumulations enter into the drift phenomena of the area under consideration, which have not always been eliminated in the classification of the deposits, as critical study in detail has not been generally possible.

Notwithstanding these and other qualifications that might be pertinent, I think the general fact, essential to our present purpose, viz, that in Eastern New York the morainic belt under consideration turns southward and traverses the mountain and plateau region, forming the Hudson Valley border, to the southern limit of the drift area, where it again becomes the outer marginal moraine, is made fairly certain by the data now at command.

Moraine of the Hudson River glacier.—Assuming the correctness of the foregoing conclusions, the glacial lobe that moved down the valley of the Hudson forced the marginal débris of its right flank up among the mountains and onto the plateaus that border the basin on the west.

In its lower course, the axis of the lobe lay west of the Palisades, and pushed its apex to the southern extremity of Staten Island. The terminal curve on the right, crossing New Jersey, has been traced with admirable precision by Professors Cook and Smock.[1]

Moraine on Long Island.—To the eastward, traversing Long Island, the formation was well-described and mapped by Professor Mather as early as 1842, though he did not recognize its morainic character, the glacial hypothesis, then barely announced by Agassiz, not having been accepted by him.[2] It has more recently been retraced and identified as a moraine by Cook and Smock (1877), and more in detail by Warren Upham (1879).[3]

Concerning this range, and its extension to the islands and mainland eastward, Mr. Upham gives a quite ample and very excellent description, the essential features of which are summarized as follows:

"In the region traversed by the writer for the exploration of these hills, including Long Island, Southern Rhode Island and Block Island, and Southeastern Massachusetts, with the adjacent islands of Martha's Vineyard and Nantucket, both of these terminal moraines are finely developed, lying 5 to 30 miles apart.[4] The New Jersey series, marking the farthest limit reached by the ice sheet, continues across Staten Island to the Narrows, and thence extends in a prominent range through the middle of Long Island and its southern branch to Montauk Point. A second series, probably contemporaneous with that of Wisconsin and Ohio, is found on the north side of this island, from Port Jefferson eastward to Orient Point, the extremity of its north branch, beyond which it forms Plum and Fisher's Islands, and enters the State of Rhode Island at its southwest corner. Thence it is well shown at a distance of 1 or 2 miles north from the shore nearly to Point Judith, where it apparently turns southward into the ocean. Twelve miles to the south the first range is again lifted into view in Block Island, a knot of very irregular drift-hills, which resemble those of Montauk.

"The sea covers the next 30 miles in the line of continuation of these series of hills, beyond which both of them rise above its waves again, the northern forming the line of the Elizabeth Islands, and bending to the northeast and north on the peninsula of Cape Cod to near North Sandwich, where it turns at a right angle, and thence runs along the west-to-east portion of the cape and extends into the ocean at its east shore. The southern moraine forms No Man's Land, the crest of Gay Head, and prominent ranges of hills in the northwest part of Martha's Vineyard, extending northeast nearly to Vineyard Haven. Here this series apparently bends to the southeast, somewhat as the northern range turns at North Sandwich, but it is covered beneath plains or the sea for much of the way beyond this point. It appears unmistakably, however, on Chappaquiddick and Tuckernuck Islands and in Saul's Hills and Sankaty Head on Nantucket.

"The length of the southern moraine in its course from Sankaty Head to No Man's Land is 50 miles, and its whole extent as yet traced to the west line of New Jersey is about 300 miles. That of the northern moraine from the east shore of Cape Cod to the west end of Elizabeth Islands is 67 miles, while its total length to Port Jefferson

[1] Geol. Surv. of N. J., An. Rep. for 1877, 1878, and 1880. George H. Cook, State geologist.

[2] Nat. Hist. Surv. of N. Y., Part IV, Geol. 1st Dist., by W. W. Mather, 1843.

[3] Am. Jour. Sci., Aug. and Sept., 1879, pp. 81-92 and 179-209.

[4] Mr. Upham regards these two moraines as representing the respective margins of the older and later ice sheets, a view from which I take the liberty of dissenting for reasons that follow.

is about 180 miles. The distance between these series at Martha's Vineyard and westward varies from 5 to 15 miles, but increases eastward to 30 miles, where they disappear finally in the Atlantic."

From the completer descriptions of Mather and Upham, it appears that these ranges are bold, massive, and well-characterized expressions of the terminal moraine, coinciding in all essential peculiarities of constitution and contour with the development of the Kettle moraine of the interior. As this is an essentially plane region, the return to identical characters after suffering the modifications imposed by the surface irregularities of the Appalachian range, is quite suggestive of the dependence of such accumulations on topographical conditions, and is, in some measure, indicative of the identity of the two sections.

The correspondence between the eastern and western moraines is not limited to this similarity of contour and constitution. That might be true in moraines similarly formed, but not continuous nor contemporaneous. There are here, as in the interior, two well-defined ranges, separated by an intervening space of from 5 to 30 miles. It is especially to be noted that these two portions, as well indicated by Upham, manifest a disposition to parallelism. It is scarcely credible that this would have been the case had the two been formed by distinct ice sheets belonging to separate glacial epochs. Throughout the interior the course of the Kettle moraine is very notably discordant with the outline of the earlier drift area. It would be very strange, indeed, if the two should fall into such close parallelism as do the moraines of the coast region, especially in the details of angles and curves. It is far more consonant with inherent probability to view these two ranges as the two main constituents of the later or Kettle belt, the outer one the equivalent of the Altamont range, the inner one of the Gary moraine of the *Coteau des Prairies* of Minnesota and Dakota.

Attention may be further called to the sloping sand and gravel plains that flank these moraines upon their southern side, whose character has been well sketched by Upham. These plains are undoubtably due to glacial waters escaping over the moraine during its formation, for they take their origin from the outer side high up toward its crest, and slope thence away to an uncertain outer limit, which is determined by the accident of its situation. These are indented by little bowls, basins, and troughs, and creased by drainage channels, many of which are now dry. In the descriptions of Mr. Upham no distinction of character between the plains attending the outer and inner moraines is discernible. This accords with the view that both were formed in somewhat closely consecutive stages. But if, on the contrary, they were produced in widely different epochs, the outer plains should show very much more markedly the effects of secular drainage erosion. The difference in the erosive modifications of the surfaces of the earlier and later glacial epochs throughout the interior region is so marked as to be a decisive characterizing distinction, so widely applicable as to be highly serviceable in field investigations, as already indicated. So erodable a plain as that flanking the outer moraine of Long Island with a slope of from 50 feet to 150 feet in a distance of from 5 to 10 miles should have manifested its greater age to so practiced an observer as Mr. Upham by the greater erosion it had suffered.

MORAINIC LOOPS OF THE COAST REGION.

In comparing this coast chain with that of the interior, a noteworthy distinction is the absence of those conspicuous loops which form so singular a feature in the latter region. A tendency to a crenate outline is, however, here quite discernible, and, were the chain less broken by the incursion of the sea, this would doubtless be more evident. From the central line of New Jersey the moraine swings southeastward to Staten Island, where it turns toward the northeast, pursuing this course until it approaches the northern shore of Long Island, at a point, it may be noted, which lies in the axis of the highlands rising between the Hudson and Connecticut Valleys. This may be regarded as the terminal loop of the apex of the Hudson glacier. At the locality noted some complexity and confusion in the development of the range is observable, and accumulations are described as lying south of the range and apparently not definitely connected with it. This may possibly be a remnant of the older marginal moraine not here buried.

Morainic curve opposite the Connecticut Valley.—From this locality eastward there are two distinct chains. They trend in an easterly direction until about opposite the axis of the Connecticut Valley, where they curve gently toward the north, and pursue this course until they reach, or somewhat pass, the western watershed of the Narragansett basin, where another turn is taken.

Curve opposite Narragansett Bay.—Here again the inner line, and presumably the outer one, angulates to the southward, and, reappearing on the Elizabeth Isles, recurves and extends northward as far as the inner neck of the Cape Cod peninsula, inclosing Narragansett Bay within the axis.

Curve of Cape Cod Bay.—At the eastern extremity of this curve the moraine again suddenly turns upon itself and extends easterly with a slight northward curvation until it is interrupted by the Atlantic.

The great northward hook of Cape Cod is composed of plains and rolling hills of sand and gravel, which resemble accumulations that often accompany the morainic belt on its interior side, and suggest the thought that the hook may be the modified inner border of the moraine which enters the sea near Orleans, and may be presumed to curve northward concentric with the hook, forming thus a loop inclosing the basin of Cape Cod.

INTERLOBATE MORAINES IN THE COAST REGION.

One of the most striking features of the morainic system of the interior consists of the remarkable intermediate moraines that mark the contact and conflict of adjacent lobes. An abbreviated moraine of this kind, described by Mr. Upham, "is presented in Rocky, Manomet, and Pine Hills, which form a gigantic ridge in the eastern part of Plymouth, four miles long from north to south, with a continuous height 300 to 400 feet above the sea."[1]

Adjoining this range on the west are undulatory sand and gravel plains, such as frequently accompany the inner border of the moraine. The fact that these extend considerably farther along the coast affords ground for the presumption that this intermediate moraine is but the stump of a more extensive one which originally extended northward near the coast line, but has been cut away by the ocean. In this connection may be mentioned the line of gravel hills and ridges described by Rev. G. F. Wright as extending from the vicinity of Marblehead north-northwestward by Andover, and onward across the Merrimac.[2] From the description of this, however, it seems rather to belong to the class of Åsar than to the moraines.

To complete an ideal system there should be an intermediate prolongation from the angle in Western Rhode Island which should lie along the watershed between the Narragansett Bay and the Connecticut River. A few passing observations in that region encourage the feeling that this may not be without support in fact.

Between Slocumsville and Wickford, along the line of the Stonington and Providence Railway, there is a belt of knobs and basins of decidedly morainic aspect. As this lies in the line of Cocoon, Hammond, and Tower Hills, which lead down toward the angle of the moraine described by Upham, northwest of Point Judith, it may be a portion of the hypothetical intermediate moraine. There is, at least, ground for further investigation. Hills of morainic appearance also occur at Shannock Mills. The moraines east of Worcester, Mass. especially at the southern extremity of Quinsigamond Lake, are to be mentioned in this connection.

On the presumption of a Connecticut River glacier, differentiated from that of the Hudson Valley, an intermediate moraine should lie along the highland which separates them. The course of the moraines on Long Island, pointing to such a possible re-entrant spur, has already been alluded to. Professor Mather describes "diluvial hillocks," comparable to those of Long Island, as occurring at several points along the eastern side of the Hudson, but these are *within* the valley rather

[1] *Loc. cit.*, p. 204.

[2] From Proc. of the Boston Soc. of Nat. Hist., Dec. 30, 1876, vol. xix, pp. 47–631.

than upon heights at all comparable to those on which the moraine is developed on the right-hand side of the valley. They appear rather to be scattered valley aggregations.

The general movement on the height between the Hudson and Connecticut—as of New England generally—was southeasterly, according to Percival, Hichcock, Dana, and others, and so unfavorable to the presumption of any important median moraine. But in the New Haven region and northward there was a south-southwesterly movement (Percival, Dana) which may indicate a tendency to minor lobation.

It seems quite manifest, upon consideration of all the data at hand, that no such pronounced system of lobation as that of the interior prevailed in Southern New England. A possible cause of this may be the mountainous barrier along the northern limits of the region, which served to turn the deeper ice-streams down the valleys of the Champlain and Saint Lawrence, and to prevent those deep, strong currents, that were the parents of the lobes, from invading New England, and thus only slight marginal differentiation took place, due simply to the agency of the valleys themselves.

MORAINE OF THE CHIPPEWA VALLEY GLACIER.

Returning from this eastward excursion from the Green Bay morainic loop, which was chosen as a type and starting point, let us follow the course of the great moraine westward.

Crossing the Wisconsin River in northern Lincoln County, within 60 miles of its headwaters, the course of the moraine is west-southwestward to the Chippewa River, which it crosses below the Great Bend, where its tributaries gather into it in a very significant way. It then curves rapidly to the north and follows the western watershed of the Chippewa Basin to the heights that overlook Lake Superior. Here it appears to make a westerly detour (Canaday), and then to curve northward on the heights of the Bayfield Peninsula (Sweet), forming a minor loop embracing the Chaquamegon Basin.[1]

The greater lobe thus formed, it will be observed, embraces the upper portion of the Chippewa Basin, and lies opposite the Keweenaw Bay of Lake Superior. This bay partially occupies a basin broader than itself, bounded on the southwest by the Huronian heights, and on the northwest by a nearly vertical escarpment of Keweenawan strata, 600 feet in height. The basin is prolonged far to the southwestward, gradually ascending the plateau of Northern Wisconsin, which has an elevation of about 1,000 feet above Lake Superior in the line of this valley, beyond which there is a broad descending slope through the Chippewa Valley to the position of the moraine. The Flambeau affluent of the Chippewa

[1] Geol. of Wis., vol. III, p. 384.

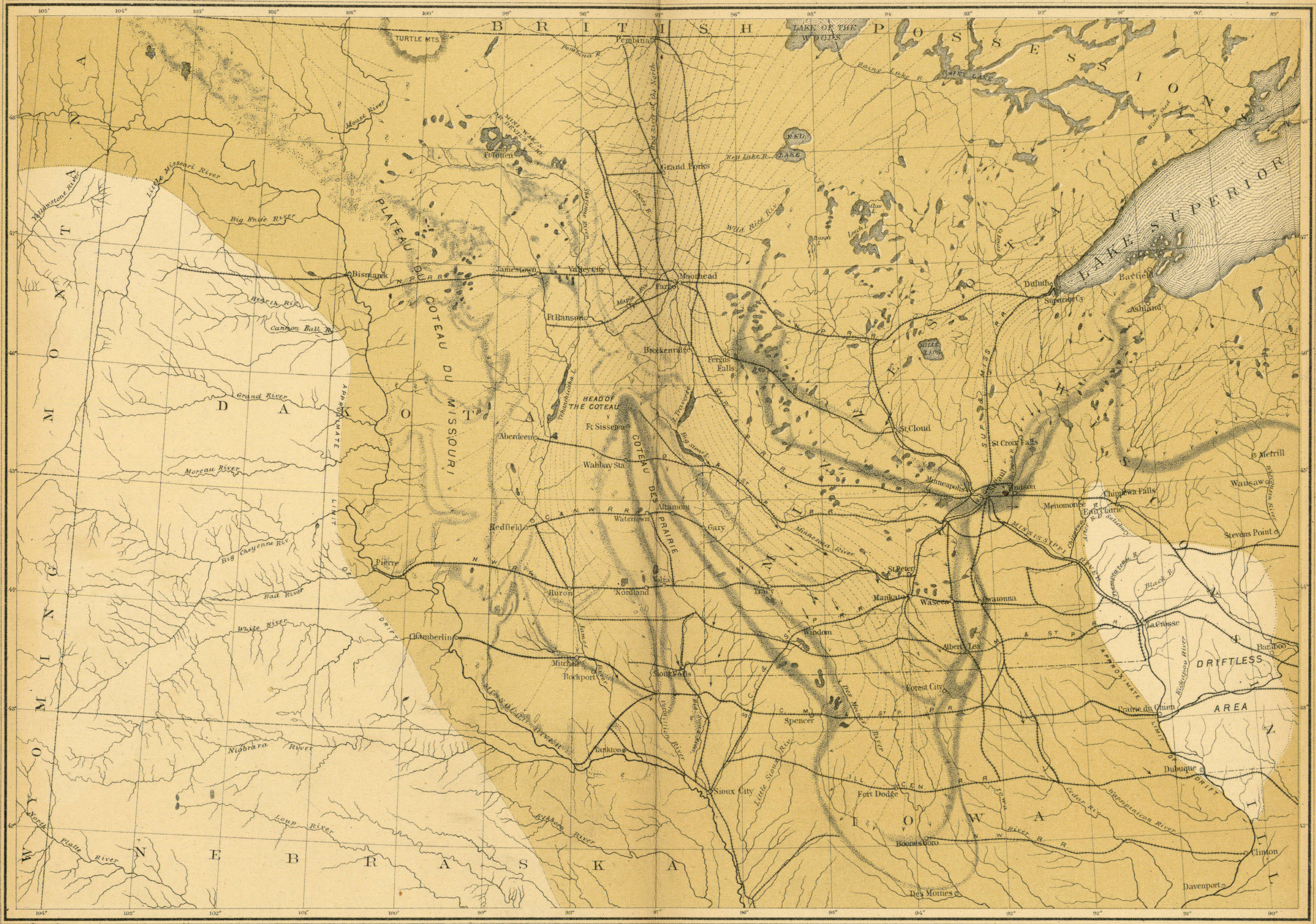
lies in the axis of these joint valleys. The strike of the folded strata lies in the same direction and gives a longitudinal ridging of the rock surface favorable to glacial movement.

To these topographical circumstances the Chippewa glacial lobe appears to owe its origin. Probably the Keweenaw Basin was more efficient than that of the Chippewa, its open mouth gathering and giving direction to a massive current which the latter served to draw out into a lobe when it had passed the intervening heights.

The development of the moraine of this lobe is of the typical character, and, though not ranking among the most massive sections of the range, is yet quite stoutly and finely developed. The material is relatively coarse, rocky, and sandy, and almost exclusively formed from crystalline rock. The copper-bearing series of Lake Superior is well represented on the right-hand wing. The Chaquamegon loop is exceptionally sandy, owing, it would seem, partly to the derivation of material from the Lake Superior sandstone, but more largely, perhaps, to the immense overwash which this portion suffered, as evidenced by the great sand and gravel plains—"The Barrens"—of the Numakagon and Saint Croix Rivers.

MORAINE OF THE LAKE SUPERIOR GLACIER.

The Chippewa, Green Bay, and perhaps a portion of the Lake Michigan glacial lobes received their supplies from the current passing across the eastern portion of Lake Superior; but the great stream that flowed through its longer axis followed its southwesterly projection into Minnesota. The ice of its left-hand margin diverged laterally, and overspread the northwestern corner of Wisconsin. The upper portion of the moraine marking the west margin of the Chippewa glacier and that of the Chaquamegon lobe constitutes an intermediate moraine between these lobes and the one now under consideration as far southward as southeastern Burnett County. Here the frontal moraine of the Lake Superior lobe diverges, and develops into three subordinate ranges whose course is southwesterly across southeastern Burnett County, northeastern Barron County, central Polk County, and Saint Croix County. From the last two counties it crosses the Saint Croix River in a broad belt into Minnesota, the outer range crossing the Mississippi below Saint Paul, and appearing on the heights south of the Mississippi, while the inner belt crosses the river north of Minneapolis, the divergent ranges thus embracing a belt of about 25 miles in width. Singularly enough, the junction of the Minnesota and Mississippi Rivers takes place in the midst of the belt. It is in this vicinity, also, that a morainic belt diverges abruptly southward, which, however, is believed to have been the creation of a different glacial lobe, as will



Julius Bien & Co. lith. Scale 1 Inch = 60 Miles T. C. Chamberlin, Geologist.

MAP OF A PORTION OF THE TERMINAL MORAINE
OF THE SECOND GLACIAL EPOCH

DRIFT BEARING AREA STRIAE MORAINE GLACIAL MOVEMENTS (GENERALIZED) presently appear. It is not so surprising, therefore, that anomalies both of morainic development and of drainage avenues should occur here.

Westward from this interesting junction of moraines and drainage basins, it will be seen by reference to any good map of Minnesota that a remarkable crescentic belt of lakelets extends along the watershed between the Mississippi and the combined Minnesota and Red River Basins. The westward and northward course of the moraine is, in a general way, coincident with the lake belt, or, more rationally speaking, the moraine is to be regarded as the cause of the lake belt, its irregularities entrapping the drainage, and retaining it in lakelets on its bosom. Traced more accurately, however, the moraine is less uniform in direction and development, and less symmetrical in curvature than this lakelet belt. Following mainly the results of the investigations of Upham,[1] the course of the most pronounced morainic line is broadly across Hennepin County and the north central part of Wright County, and thence in a narrow and more definite belt, along the northern border of Meeker County, and somewhat diagonally across northern Kandiyohi and southern Pope Counties.

From the northwestern part of Pope County a most notable ridge runs northerly and northeasterly across Douglas County, and unites with or becomes the Leaf Hills, a very remarkable morainic range running northeast across southeastern Ottertail County, and then deflecting northwesterly, extends to Pine Lake, beyond which it has not been traced. The Leaf Hills constitute the most striking development of the moraine in Minnesota, rising from 200 to 300 feet above their bases, and conspicuously displaying in structure and composition the distinctive characteristics of a massive terminal moraine.

From this there diverges a belt passing northwesterly across the south central part of Ottertail County, encroaching slightly upon the

[1] While there is in general a very gratifying concordance between the results of Mr. Upham's observations and my own, so far as they relate to identical and contiguous regions, some minor differences of views exist at the present stage of our mutual investigations which lead to differences of interpretation and correlation. Mr. Upham's observations in Minnesota have been quite full and specific, while my own have been, partly for this very reason, quite cursory and general. My views are therefore entitled to correspondingly less weight. Nevertheless I have felt under obligations to give expression to such impressions as have arisen from my own observations and the study of those of Mr. Upham, and the earlier views of Professor Winchell, and from comparison with the wide range of study which it has been my privilege to make. The only difference of much consequence springs from certain deposits of stony clay which Mr. Upham regards as till, while I regard them as subaqueous depositions through the agency of floating ice, intimately connected, however, with the glacial retreat. The former interpretation seems to require a northeasterly extension of glacial movement from the Minnesota Valley not necessitated under the other view, and which, for independent reasons, I am not now prepared to accept. The full publication and wide distribution of Mr. Upham's results make it unnecessary to further specify these minor diversities, which are here alluded to only in explanation of slight discrepancies in mapping, though, with the above qualification, I have mainly accepted his conclusions provisionally even when not entirely in accord with my earlier views.

northeastern corner of Grant. In the west central part of the former county this turns northerly into Becker County, and then northeasterly to the vicinity of Rice Lake, in southern Beltrami County, beyond which its course has not been determined. I incline to the view that it is continuous with the Mesabi Range, which occupies the water-shed between the Mississippi and Lake Superior Basins and the Rainy River Valley.[1]

Mr. Upham, however, does not coincide with this view, but correlates the Mesabi Range with the Blue Hills of Southern Manitoba, and refers both to a later epoch.[2]

Inner moraines.—Associated with this main moraine, especially upon its inner side, are subordinate belts of less pronounced development, giving to the whole considerable width, and something of complexity, for the general distribution of which reference is made to the accompanying map. There is ground for difference of opinion as to the extent to which these interior lines are to be regarded as belonging to the morainic group under discussion, and how far to halts, oscillations, or other circumstances attendant upon the glacial retreat.

Interlobate moraine.—The main moraine, as sketched, is conceived as the joint product (1) of a glacial lobe stretching southwesterly from Lake Superior, and (2) of a current descending from the Archæan heights into the Red River Valley, and turning southeasterly down the Minnesota Valley, thus wrapping around the extremity of the Lake Superior lobe.

When glaciation was at its height it seems almost necessary to suppose that these two lobes crowded upon each other with some force, particularly at the most protuberant portion of the Lake Superior tongue. It seems quite possible that the Leaf Hills are the result of this conflict, their course being such as might be produced by the crowding of the Red River glacier against the Lake Superior protrusion. On this hypothesis the morainic belts west of this were accumulated at the second stage (that of the formation of the Gary moraine), when the two currents were withdrawn somewhat from each other, and the Red River stream curved more gradually in its deflection from the Red River to the Minnesota Valley. This view will be readily understood by reference to the accompanying map.

Material of the range.—The material of this range presents some features of special interest. The left or eastern wing of the loop in Wisconsin is composed largely of the débris of the crystalline rocks of Lake Superior, which habitually take the coarser form, bowlders, gravel, and sand, with relatively little clay. Erratics from the Keweenawan or copper-bearing series of Lake Superior form a very notable constituent.

[1] Mesabi Range is briefly mentioned by Col. C. Whittlesey in his paper "On the Fresh Water Glacial Drift of the Northwestern States," Smith. Cont. to Knowledge, 1866.

[2] Geol. Surv. of Minn., Ann. Rep. 1880, pp. 336, 337.

The prevailing color, as the result of this constitution, is reddish, in varying shades. These characteristics remain dominant after the moraine enters Minnesota, as far west as Minneapolis, and somewhat beyond.

Beginning a few miles west of Minneapolis, and extending thence onward, the superficial material of the main range, as above outlined, is composed very largely of clay, with interspersed pebbles and bowlders, and the prevailing color is gray. Coincident with this change of constitution the surface contours become more softened and fluent, and the topographical irregularities less sharply characteristic.

A noteworthy fact is the presence of Silurian limestone, presumed to be derived from the Red River Valley. Were this limestone limited to the moraine, and the region west and south of it in the track of the Red River Valley stream, the occurrence would be interesting and significant, but in no sense puzzling, or possibly misleading. But such limestone has a quite wide distribution over the region about the head of Lake Superior. Blocks and bowlders of it occur in the vicinity of Saint Croix Falls, on the Wisconsin, as well as the Minnesota side, and are quite abundant and widely distributed in the vicinity.

"Dr. Norwood, in Owen's report of 1852, described compact, drab colored limestone erratics, containing Silurian remains, as occurring on the St. Louis River above the entrance of the Swan tributary, and again between the Two Rivers and the Upper Embarrass, the specimens being there large, thin slabs of Silurian limestone; also on the Big Fork River at different points, and again on the Ondodawanonon River, where they are also said to be Silurian; also on the headwaters of the Mississippi. Limestone fragments are also described by Prof. G. M. Dawson as occurring on the southern and western shores of the Lake of the Woods, and as belonging, in part at least, to the Upper Silurian; and the same has been noted by Dr. Bigsby."[1]

So far as I have observed them on the border of Wisconsin, they occur in a deposit of stony clay having a homogeneous constitution and an essentially plane surface, which I refer to subaqueous deposition, and the transportation of these blocks is, in part at least, referred to the agency of floating ice. The same view is entertained as applicable in part to the superficial layer of pebbly and bowldery clay of the more subdued portion of the moraine above instanced, but is not regarded as the whole, and perhaps not the main, cause of the changed characteristics it presents. The subject deserves a broader consideration in connection with the general phenomena of which it forms a part.

General change in the character of the moraine.—The transition above noticed marks a broader and wider distinction. The moraines eastward from the interesting point of union of morainic lines and drainage basins in the vicinity of Saint Paul and Minneapolis, throughout Wisconsin, are generally characterized by (1) a rough surface, (2) heterogeneous constitution, and (3) preponderance of gravelly and coarse material, clearly

[1] Geol. of Wis., Vol. III, p. 388.

the residue of wash. Clay, though commonly present in the massive portions of the range, is less abundant than in the adjacent till, a fact likewise referable to the action of glacial waters. In other words, the moraine is characterized by the unsubdued roughnesses resulting from ice action in some parts, and the assorting modifications of escaping waters in others.

West of the locality indicated, whether we trace the branch above outlined stretching westward, or the limb leading southward and thence by a sinuous course through Dakota, the range presents (1) much more softened and fluent contours, (2) a much more clayey constitution, and (3) a relative absence of the residuum of overwash. This transition is to be attributed in part—probably in the larger part—to the nature of the underlying formations, especially the prevalence of the soft Cretaceous shales within the glacier-ridden area. These would naturally yield to the accumulating débris a large ingredient of clay, while at the same time the shales may have presented a somewhat smoother preglacial surface, over which the ice slid with less interruption or retardation.

This clayey product in its very nature was less susceptible of being heaped by the ice into sharp, rough hills and hummocks, especially in the presence of abundant water, and hence assumed less abrupt contours.

But, measuring as well as may be the effects of these influences, there seems to be a residuum left unexplained. The transition of the underlying formations does not appear to be sufficiently abrupt, nor the predominance of clay in the parent strata so great, as to adequately explain, in itself, the changed character of the formation. This is much more forcibly true of the adjacent sheet of drift than of the moraine, especially that lying within it. It seems to me, as already indicated, necessary to a complete explanation to assume the agency of imperfect peripheral drainage, which the plane character of the region would render inevitable, and which prevails in some degree to the present day. I cannot turn aside here to adequately consider the various circumstances which tended to increase the amount of marginal waters that gathered about the glacier's edge, and I am quite unprepared to draw the line of discrimination between the direct and indirect influences of such imperfect drainage. It is manifest that if a glacier deployed upon a plain that was practically horizontal, or inclined toward it, a frontage of shallower or deeper water was a necessary consequence, and the glacial material would (1) suffer relatively little loss from the washing out of its finer constituents, (2) by being heaped up under such aqueous influences would be subdued in contour, and (3) would be concealed and further rendered flowing in outline by the superposition of aqueous depositions.

The discrimination between the influences of these agencies, and the allotment to each of its respective effects is difficult to the last degree, but I think the agency of each is none the less clearly discernible. It is important to observe that retarded drainage, especially when overburdened with silt, has little or no assorting power. Hence, if we suppose nothing more than that the bordering plains were so nearly level as to prevent free escape of the glacial waters, little coarse, assorted material could result.

Striæ within the area of the Lake Superior lobe.—The observations upon drift grooves and scratches are unfortunately confined to the left half of the area, and are even there not numerous, though they are quite harmonious with each other, and very significant of the movements that characterized the glacial lobe.

The following is the record:

In or near the axis of the lobe—	
Duluth (various observers)	W. SW.
Watab, Benton County (Upham)	S. 15° W.
NE. ¼ sec. 14, T. 44, R. 33 W., Wis. (Strong)	S. 13° W.
Hinckley, Pine County, Minnesota (Upham)	S. 5° W.
On the left of the axis of the lobe—	
Minneapolis, Nicollet Island (Upham)	S. 5° E.
Minneapolis, Hennepin Island (Upham)	S. 22° E.
Minneapolis, quarry opposite University (Upham)	S. 15° E.
NE. ¼ sec. 15, T. 44, R. 9 W., Wis. (Strong)	SE.
Three localities near Clam Falls, T. 37, R. 16 W., Wis. (Chamberlin)	S. 25° E., S. 10° E., and S. 18°–20° E.
S. ½ sec. 28, T. 37, R. 16 W., Wis. (Chamberlin)	S. 20°–27° E.
Sec. 2, T. 36, R. 18 W., Wis. (Chamberlin)	Due S.
SE. ¼ sec. 36, T. 35, R. 19 W., Wis. (Chamberlin)	S. 40° E.
Same locality, fine hair-like lines	Due E.
Near Saint Croix Falls, sec. 29, T. 34, R. 18 W., Wis. (Chamberlin)	S. 45° E.
Glenmont, Saint Croix County, Wisconsin (King)	S. 96° E.

The definite data furnished by these striations are corroborated by the abrasion suffered by the prominences of rock, by the trend of drift ridges and depressions, and by other forms of drift topography, all of which indicate movements in the same direction. Combining these observations into a consistent system, they reiterate the method of movement common to all these lobes. The great axial current moved southwesterly through the trough of Lake Superior, and pushed on southwestward across the Mississippi to its limit on the line marked by the moraine. On the left-hand side, the current diverged curvingly toward the margin. On the right-hand side, no observations have yet been made which positively determine the prevailing course. It seems hard to believe that the currents diverged to the northwest, against the slope and athwart the course of the glacial current from the Archæan heights lying to the north. But such a movement would be little more strange than some whose remarkable courses are fully demonstrated. The prevalence of drift renders the positive determination of the question difficult, while the partially unsettled and largely wooded nature of the country imposes obstacles which time will remove. If the Mesabi Range shall be shown to be directly continuous and contemporaneous with the moraine marginal to this lobe on the west and south, the probabilities will be strong that the law of divergent flow holds sway even here. If that range shall be shown to be later in origin, the presumption will doubtless incline to the view that a somewhat broad ice sheet descended from the Archæan Highlands lying to the northeast, flowing in confluence with the deep stream that issued from Lake Superior, and that there was little northwesterly divergence.

MORAINE OF THE MINNESOTA VALLEY GLACIER.

Branching off from the remarkable intermediate moraine above described, at a point a few miles south of Minneapolis, there extends a double morainic line almost due southward to the center of Iowa, where it curves upon itself and returns to the southern line of Minnesota, whence it bears to the northwest and stretches along the northeastern slope of the Coteau des Prairies, to its head in Dakota, opposite Lake Traverse. The existence of this singular loop was determined by the writer in 1878, but has since been much more amply investigated by Mr. Upham. Throughout the greater part of its course, the two main constituents of the range are distinctly separated by an intervening level, or slightly undulatory plain, and hence set forth this characteristic of the formation in more distinct array than is common to most portions of the belt. From this portion, therefore, distinctive names for the constituent members can perhaps most properly be drawn. The stretch along the east slope of the Coteau des Prairies is best calculated to display this feature of the range, and the moraines that pass through *Altamont*, *Gary*, and the *Antelope Hills* have been selected as denominative portions.

Tracing more in detail, the course of the belt is southerly through eastern Scott, western Dakota, eastern Le Sueur, western and central Rice, eastern Waseca, western and east central Steele, and central Freedom Counties, to the Southern Minnesota line;[1] thence by a westerly deflection diagonally across western Worth, the southeastern corner of Winnebago, western Cerro Gordo, and eastern Hancock Counties, Iowa. Midway the last two counties the course appears to turn again to the south.

Beyond this point the full belt has not been traced in complete detail, but portions of the moraine have been sufficiently followed to make its general position certain, the only remaining doubts relating to the exact positions and connections of the constituent ranges. Mr. Upham regards the outer member as extending southward through western Franklin, Hardin, Story, and Polk Counties, crossing the Des Moines

[1] Most of the details of distribution are derived from Mr. Upham's report, Geol. Surv. of Minn., 1880.

River a little below the capital city, where he supposes it to curve promptly upon itself, and to stretch northwesterly along the middle Raccoon River, diagonally through northeastern Guthrie and central Carroll into Sac County, where it turns more northerly and extends to the southern part of Buena Vista County. Here it makes a strange easterly detour, passing curvingly through eastern Clay, central Dickinson, and northeastern Osceola Counties, Iowa.

The southern extremity of this loop has not, however, been traced from Hardin County around the curve indicated to Guthrie County. The inner line is held by Upham to run from Hancock County south through eastern Wright and Hamilton Counties. Near the southeast corner of the latter it curves rapidly to the west, and joining Mineral Ridge, well described by Dr. C. A. White a dozen years since, and regarded by him as morainic,[1] it crosses the northern point of Boone County, and then is presumed to extend northwesterly to Palo Alto County, where it coalesces for a few miles with the outer range; but again separating, it passes north through the western edge of Emmet County to the Minnesota line.

On entering Minnesota, the outer moraine runs northwesterly diagonally through eastern Noble County, southwestern Murray, the northeastern corner of Pipestone, and the southwestern part of Lincoln Counties, passing into Dakota across the northeast corner of Brookings County, whence it continues its course across the center of Deuel, the southwestern corner of Grant, the northeastern portion of Codington, and onward through the western part of the Sisseton and Wahpeton Reservations to the head of the Coteau des Prairies.

The inner line pursues a nearly parallel course through central Jackson, southwestern Cottonwood, northeastern Murray, southwestern Lyon, northeastern Lincoln, and the extreme southwestern portion of Yellow Medicine County, in Minnesota, whence it passes around into Dakota through northeastern Deuel, southwestern Grant and the reservation, to a junction with the outer moraine on the head of the Coteau.

Course of the Ice Tongue.—This is one of the most remarkable loops of the whole series. Taking its differential origin in the Red River Valley, the ice tongue that produced it seems to have moved southward over the slight upward incline of that valley, then across the very low watershed into the Minnesota Valley, whose southeasterly course it followed to the point where the Minnesota River makes its abrupt turn to the northward, an eccentricity the stiff ice tongue declined to follow, but pushed right on over the more considerable watershed between the affluents of the Minnesota and the Des Moines Rivers into the valley of the latter, which it descended until stayed in its course by the increased waste of the warmer climate into which it penetrated.

The topographical features of this pathway afford some interesting and significant facts. The Coteau des Prairie, the most prominent

[1] Geol. of Iowa, 1870, p. 99.

feature of the region, consists of a Λ-shaped plateau, the apex of which lies about 40 miles west of Lake Traverse, and attains a maximum elevation of a little over 2,000 feet above the sea level. This promontory stands boldly forth 600 to 800 feet above the plains which skirt it on the east, north, and west. From this apex the eastern area stretches away south-southeasterly, broadening and flattening until it imperceptibly dies away in Southwestern Minnesota. The western branch bears southerly, presenting an abrupt westerly face for more than 100 miles, beyond which it grades down into the undulatory plains of Southeastern Dakota. The Sioux Valley lies between the arms of this topographical Λ, though its depression is not equal to that of the greater valleys on the exterior.

The trough pursued by the glacier takes its distinct origin where the head of the Coteau divides the great plain of Northwestern Minnesota and Northeastern Dakota. The western margin of the basin is 2,000 feet, roundly speaking, above the ocean, while its opposite side is formed by the relatively low watershed between the Red River and the Mississippi, whose average heights are from 300 to 600 feet lower. The bed of the valley is a broad smooth plain, rising gradually toward its lateral margins. Its axis is, in round numbers, 1,000 feet above the sea, at the watershed between the Red and Minnesota Rivers. The glacial course was southeasterly down this broad boat-bottomed trough, as far as the elbow of the Minnesota River.

Throughout this course both the eastern and western margins decline in altitude faster than the bottom of the valley, and the whole becomes broader and more nearly approximate to a plain. The strange fact here is that the current did not move directly on its course into the Mississippi Valley. In the present position of the surface its lowest avenue would have been found by curving to the left instead of the right. Even if it had pursued a direct course, it would have encountered but slightly greater elevation than that which it actually passed over. Instead of this, however, its course was, singularly enough, deflected to the right, and it passed through a broad shallow depression across the watershed that lies near the southern limit of Minnesota, the lowest point of which is about 300 feet higher than the Minnesota Valley, exclusive of the immediate channel of the river. Its course in Iowa is less striking but almost equally singular. Instead of moving southeasterly along the general slope, or at least keeping straight onward in its course, it even turned slightly to the west, somewhat against the present slope.

Vertical relations of the moraines.—A comparison of the general altitudes of the moraines on the opposite sides of the lobe presents quite as remarkable facts. At the neck of the lobe, opposite the head of the Coteau, the moraine upon its right hand or westerly side is, roundly stated, from 300 to 600 feet higher than that on the opposite side, the distance between the two being about 80 miles; measured at the point where it turns southward, its right-hand side is about 500 feet higher than the moraine at the crossing of the Minnesota River, which is the lowest point of its course. In the vicinity of the southern line of Minnesota, the difference in altitude between the inner moraines is about 200 feet, and between the outer ones about 400 feet. Towards the extremity of the lobe in Iowa the outer eastern moraine is still 150 to 200 feet lower than the outermost western one. These general truths are sustained, whether we compare the elevation of railroad grades crossing the moraines, which may be assumed to represent the lower altitudes available for the several lines, or the more general altitudes of the moraine as determined by barometrical observations.[1]

It is, therefore, a very conspicuous and suggestive fact that throughout its entire course the left-hand moraine lies very considerably lower than the right-hand in the present position of the surface. That this was true at the time when the glacier pursued its peculiar course, is scarcely credible. The two margins of the glacial stream flowing over a broadly open, almost plane country, like that of Southern Minnesota and Northern Iowa, should attain, at its opposite points, essentially the same altitude, neglecting, of course, local irregularities to which so stiff a stream could not readily conform. These remarkable facts strongly suggest that at the time of this glacial movement the relative altitudes were different to the extent of their present discrepancy. This may have been due to a relative depression on the southwest. This hypothesis would account for the deflection of the current in that direction, and would assist in explaining (1) the immunity of the driftless region from glaciation, (2) the singular termination of the drift sheet along the border slope of the Mississippi in Eastern Minnesota and Iowa, (3) the abundant evidence of imperfect drainage of glacial foot-lakes over the wide area presumed to be affected by such a depression, and (4) the distribution of loess on the hypothesis of its aqueous origin.

In connection with these facts, attention may be directed to the similar phenomenon already noted, that the Green Bay glacier passed southward into the Rock River Valley over a watershed 300 feet above Lake Michigan, instead of continuing in an equally direct course southwesterly into the lower Wisconsin Valley, whose watershed is 100 feet lower. This might be accounted for in part at least if the intervening driftless area were relatively elevated or the Lake Michigan Basin relatively depressed. I have elsewhere called attention to independent data indicating that such changed altitude was an historical fact.[2]

If we could allow ourselves a wider latitude, a broad field of similar facts, partially gathered, but largely yet awaiting harvest, would open before us in this direction, all significant of possible slightly changed surface attitudes during the glacial period. The facts now cited are sufficient to indicate the significant data bearing upon such collateral

[1] Compare altitudes given by Upham, Geol. Surv. of Minn., 1880, p. 355.
[2] An. Rep. Wis. Geol. Surv., 1878, pp. 331, 332.

questions which will arise from the definite mapping of this great moraine.

Character of the moraine.—As has been before implied in generalized statements, this moraine presents a surface contour less rough and rugged than that which characterizes its equivalent in Wisconsin. This is more especially true of that portion which lies upon the plains of Iowa and Eastern Minnesota. On the highland margin of the Coteau it has a rough development, and its knobs are conspicuously strong, but even there in general the acclivities are less steep, and the bowls and irregular hollows less deeply impressed.

The predominance of the clayey constituent is very marked in comparison with the typical moraines of Wisconsin, Michigan, New York, and the coast region. The more stoutly developed and sharply elevated peaks and ridges are composed usually of a bowldery clay, though superficially this is very much exaggerated by wash. While in the lower swells of the range stony material abounds, its relative proportion is not conspicuously large, though it usually exceeds very much that of the clayey drift occupying the adjacent plains. As before remarked, these characteristics are probably due mainly to the influence of the Cretaceous shales which overspread a large part of the glacial track, but partly to the relative inefficiency of drainage, and locally to aqueous depositions.

GLACIAL MOVEMENTS.

For convenience the general course of the glacial stream has already been indicated. It remains to present the definite data which sustain the statement made. The following is the record of observations on striation:

Granite Falls, on the Minnesota River (Upham)	S. 45°–50° E.
Fort Ridgely, on the Minnesota River (Upham)	S. 60° E.
Beaver Falls, on the Minnesota River (Upham)	S. 60° E.
Redstone, near New Ulm (Upham)	S. 25° E.
Jordan, on the Minnesota River (Upham)	SE.
Posen, Yellow Medicine County, Minnesota (Upham)	S. 50° E.
Echo, Yellow Medicine County, Minnesota (Upham)	S. 50°–55 E.
T. III, R. 38, Redwood County, Minnesota (Upham)	S. 50°–60° E.
Stately, Brown County, Minnesota (Upham)	S. 50°–55° E.
Germantown, Cottonwood County, Minnesota (Upham)	S. 30° E. and S. 70° E.
Dale, Cottonwood County, Minnesota (Upham)	S. 20°–35 E.
Amboy, Cottonwood County, Minnesota (Upham)	S. 35°–70° E.
Selma, Cottonwood County, Minnesota (Upham)	S. 18°–22° E.
Delton, Cottonwood County, Minnesota (Upham)	S. 15°–80 E.
Adrian, Watonwan County, Minnesota (Upham)	S. 20°–30° E.

Adjacent to the moraine on the outside:

Pipestone quarry, Pipestone County, Minnesota (Upham)	S. 20°–30° W.
Mound, Rock County, Minnesota (Upham)	S. 25°–35° W.
One and one-half miles northwest from the last (Upham)	S. and S. 35° W.
Northwest corner of Iowa (White)	S. and S. 8° E.
Sioux Falls, Dakota (Chamberlin)	S. 20° E.
Three miles west of Sioux Falls (Chamberlin)	S. 22° E.

These, when correlated, indicate a southeasterly movement along the axis of the Minnesota River, with some tendency to lateral divergence. In addition to these data, Mr. Upham makes the significant observation that the quartzites which appear at New Ulm, in the axis of the lobe, and occupy a wide surface area southwest of that, are abundantly distributed along the southwestern arm of the loop, but are only sparsely found in the eastern one. Other facts of distribution of similar but less definite import are observable. These sufficiently indicate that the general law of axial protrusion and lateral divergence prevails here as elsewhere.

SUBORDINATE MEMBERS.

The constituent members of the range are here displayed with exceptional distinctness. The high, smooth slope of the eastern face of the Coteau des Prairies was exceptionally favorable for their distinct development. Along its whole course the outer moraine, as well shown by Upham, is separated from its inner neighbor by a space of five or six miles, usually occupied by a smoother tract composed of the usual drift of the adjacent plain, or an overwash deposit sloping from the inner moraine. Within these, at a distance twice as great or more, is a third feebler range. The first or outermost moraine is well displayed at Altamont, Deuel County, Dakota, and may fittingly be known as the *Altamont* moraine. The next inner one is well shown in the vicinity of Gary, southeast of this on the Minnesota line, and may be denominated the *Gary* range. The innermost line is locally known as the Antelope Hills, which furnishes a suitable designation for it. There is little difference in the massiveness, breadth, height, complexity, or constitution of the Altamont and Gary moraines. In general they are very strikingly similar. Locally the one or the other predominates. These observations hold true in general in the wider extension of the terms to their supposed equivalents at distant points. This equality of character may therefore fairly be regarded as indicative of equivalence in conditions of formation, and may, to that extent, be helpful in ultimately arriving at just views of the ulterior causes of the formation.

MORAINE OF THE DAKOTA VALLEY GLACIER.

Topography of Eastern Dakota.—The newness of the region, the unsettled character of a portion, the rapidity of change to which political boundaries are here subject, and the defects of maps accessible to the general reader render it expedient to give special prominence to topographical features in our outline of the distribution of this moraine, the more so because the topography is in itself an influential condition of morainic development. A brief sketch of the surface relief of the territory east of the Missouri River, with which alone we have to deal, is therefore here introduced.

Bordering the Missouri River on the east, from the extreme northwestern corner of the territory almost to its southern limit, a distance of nearly 400 miles, is the remarkable elongated plateau known as the Coteau du Missouri, whose width ranges from 20 to 50 miles miles, and whose elevation may be roundly stated at 2,000 feet above the sea, though it rises considerably above this at the north, and falls much below it and dies away at the south. The eastern face of the plateau presents a somewhat firm, unbroken front, but the western is much skeletonized by erosion, which has carved out valleys, ridges, and buttes, and has broken down the face of the plateau. The eastern frontage was doubtless originally similar to the western, but has been trimmed off and plastered up by drift agencies.

This plateau overlooks on the east, from a height of 400 to 800 feet or more, a broad valley plain, of which three sections may be recognized. The first is the great plain of the Souris, lying mainly in the British Possessions, but reaching down 70 miles into Dakota. Across this to the east, on the boundary, lies the Turtle Mountain, a somewhat isolated and elevated promontory on the margin of a plateau or prairie-steppe that stretches thence east to Pembina Mountain, which forms its eastern edge, and overlooks the valley of the famous Red River of the North, the great plain of the ancient Lake Winnepeg.

The second section is the somewhat elevated and roughened plain in which lie the upper courses of the James and Cheyenne Rivers. This is confluent with the prairie-steppe east of Turtle Mountain, and, like it, is terminated by a more or less abrupt terrace-like face at the east on the border of the Red River plain, above which it rises to the north 400 feet or more, but gradually declines to a common level at the south, the Red River plain slowly rising to meet it, so that at the head of the Coteau a common plain, scarcely interrupted, stretches from the foot of the Coteau du Missouri to the moraine hills of Minnesota.

The third section consists of the lower valley of the Dakota or James River—the Jacque of the early explorers, and the "Jim" in present local parlance. This is a broad (60 miles) smooth-bottomed valley plain, bordered on the east by the Coteau des Prairies and on the west by the Coteau du Missouri, lying from 400 to 600 feet below them. As the coteaus die away to the south the limits of the valley fade into the gradual slopes of the uplands, and the sharp definition of the basin ceases.

COURSE OF THE DAKOTA MORAINE.

Starting from the union with the range of Southwestern Minnesota on the head of the Coteau des Prairies, it follows the plateau in a southerly and slightly southeasterly direction until the highland grades away into the common plains of Southern Dakota. The outer moraine was pushed well across the western limb of the Λ-shaped plateau, and lies near its eastern margin next the Sioux Valley, which occupies the interval between the arms. Its general course may be staked off as follows: From the head of the Coteau it runs southwestward, passing east of Fort Sisseton to Wabay Station, Day County, on the east side of which it passes, and is finely and roughly developed. Thence it runs centrally through Codington County, embracing Lake Kampeska, thence still a little east of south across central Hamlin County and western Brookings, passing between Volga and Nordland; thence southward across eastern Lake County, encroaching somewhat upon western Moody, across western Minnehaha, embracing Wall Lake, into the northwestern corner of Lincoln County. Here its development upon the smooth plains becomes obscure, and it manifests itself only in a broad, low swell, characterized by low mounds and swales, whose vertical undulations are commonly only 12 or 15 feet. Its course from this point, as identified by Professor Todd, who has studied this region more than myself, bears eastward to the vicinity of the Big Sioux River, and thence follows the hilly tract bordering its west side southward into Union County. He calls attention to the fact that the hills on the east side of the Big Sioux River are covered with loess, while those on the west, though they have similar and even lower heights, are free from it. All observations thus far made by Professor Todd and myself unite in testifying that the loess does nor cover the newer drift, a very significant fact if fully sustained.

Concerning the southern curve of the loop, a final opinion is not now offered. Professor Todd identifies as a morainic tract a ridged belt starting near the southern extremity of the Big Sioux Hills and extending northwesterly between the Vermillion and James Rivers. He classifies in a similar category a nearly parallel belt on the west side of the latter river. On the south side of the Missouri River he finds a curved belt of hills swinging from a point a little below the mouth of the James River westerly to near the mouth of the Niobrara. This he inclines to regard as the outer moraine of the later epoch, but reserves judgment in view of the importance of the determination and the critical relations of the later drift to the loess.

Inner moraine.—Before attempting to follow the formation along the Missouri Coteau, it may be most convenient to make brief reference to the course and character of the inner moraine adjacent to the course of the outer range just outlined, along the Prairie Coteau. This moraine is less uniformly and definitely developed than its correlative member on the eastern face of the Coteau. It is not difficult to find a reason for this. On the east side the moraines were formed on a smooth ascending plain, an attitude favorable to the reception of distinct embankments, marking the two stages of ice encroachment. On the west side the edge of the Coteau rises quite abruptly to nearly its maximum height, and then retreats, at a general level, sometimes even descending eastward. The ice of the first stage surmounted this in sufficient depth to push across the upper face of the plateau for a distance of 25 or 30 miles. The ice of the second stage, however, rising less high, appears to have pushed out upon this upper plain only a relatively thin and inefficient sheet, whose periodic oscillations—upon which we conceive the strength and complexity of the moraine to depend—were less concentrated in space, and less effective because of the thinness of the ice and the unfavorable attitude of the surface.

The whole western edge of the Coteau is marked by irregular heaps of stony drift, clearly referable to the mechanical action of the ice. How far this may be due to the resistance imposed by the abrupt front of the plateau, and how far to its marking the limit of a general advance, it is difficult to determine. The rolling belt lying along this edge and on the upper face of the Coteau adjacent to it is probably due to the frontal action of the glacier in the second stage. These topographical conditions appear to have influenced in a similar but less marked degree the action of the ice margin in the earlier stage, so that its moraine is more widely and less sharply displayed than is usual. It results that the two belts grade away toward each other, and the intervening smooth gravel plain so often present elsewhere is largely wanting here. The whole western upper face of the plateau for a width of about 30 miles, usually, is more or less markedly undulatory, of the semi-morainic type. The accompanying map exhibits the belt which appears to represent the more forcible marginal action of the ice in the second stage. It is only on the eastern slope of the East Vermillion Valley that I have observed a pronounced display of typically morainic peaks and indentures. Here, it will be observed, the topographical attitude is favorable, in that it presents a moderate slope opposed to the impinging of the ice.

MORAINES OF THE MISSOURI COTEAU.

Character of the Coteau.—To prevent possible misunderstanding, it may be distinctly and quite positively asserted that this great Coteau is not mainly a drift accumulation, but a pre-existent plateau of chiefly Cretaceous rock, which was carved into all its grander features in preglacial times by drainage erosion. The effect of glaciation has been to grind off something of the roughness of its exposed faces, to fill up its creases, and to heap upon it, in an irregular, bunchy manner, the glacial *débris*, in the form of morainic hills. These hills, while very notable objects in themselves, owe their general elevation and much of their individual prominence to the concealed Cretaceous terrane beneath. The prominence which the old underlying plateau, with its preglacial inequalities, gives to certain portions of the drift, and the influence exerted by it in effecting exceptional local accumulation, resulted in special moraine-like aggregations that are to be discriminated from those which mark the extreme edge of the ice and constitute the true terminal moraine. The whole eastern face of the great Coteau, so far as seen, is more or less marked by such massive drift aggregations, but it seems quite clear that the ice pushed out on the plateau much beyond this. While the region has been reconnoitered sufficiently to determine the leading facts, sufficient detailed work has not been done to permit a very close delineation of the course or character of the moraine, or enough to justify a final opinion concerning some interesting minor questions that arise in connection with it.

Starting with the outer moraine opposite the mouth of the Niobrara, its course, as traced by Professor Todd, lies northwesterly, immediately adjacent to the Missouri River, to about the meridian of 99°, where the main belt strikes northward to the Wessington Hills, where it has a conspicuous development. From these westward, an interrupted chain of accumulations leads across a generally plane country to the Ree Hills. From these a feebly undulatory tract stretches northward curvingly across the Great Ree Valley to the Bald Mountains, in Faulk County. But westward of this detached hills and an extraordinary accumulation of bowlders seem to mark an outer line which follows somewhat closely the Missouri River. From the Bald Mountains the morainic course, as traced by Professor Todd, is first westward and then northward to northeastern Walworth County, where, recurving upon itself, it reaches to the Missouri River, which, he thinks, it crosses as indicated upon the accompanying map; but it was impracticable to demonstrate this by a visitation at the time. Its course from its reappearance on the east side of the river to the eastern portion of the Coteau, where it again develops strongly, is only provisionally mapped. From the latter point it pursues a sinuous course northerly to the vicinity of the Northern Pacific Railway, for the details of which reference may be made to the accompanying map.

Turning now to the inner moraine, it is mapped by Professor Todd as crossing the Vermillion River in northeastern Turner County, and thence, curving around to the northwest, it crosses the James River in southern Hanson County and passes diagonally across Davidson County, south of Mitchell, and, following the course of the Firesteel River, passes east of the Wessington Hills, extending northward to Redfield. The latter portion of this is regarded as an interlobate moraine, lying between the main ice tongue which passed down the James Valley and a minor lobe occupying the Turtle. Departing from this intermediate moraine, a little north of the Chicago and Northwestern Railway, Professor Todd identifies a feeble morainic belt sweeping around to the west and then to the north, and pursuing a northerly course to the vicinity of the Northern Pacific Railway. Throughout this course it lies near the foot, or on the lower face, of the Missouri Coteau. Some features of the foregoing mapping are to be held as in some measure tentative, since they have been taken directly from the field reports of Professor Todd without opportunity for reconsideration or the revisitation of doubtful points. Some portions of the Coteau are difficultly accessible, and an absolutely continuous tracing of the moraine is at present impracticable.

The disposition of the moraine to assume new phases with every distinctly new situation is here exemplified. The southern portion has not the definite plateau character of the northern, but consists rather of an upward swelling plain arching from the James River on the east to the Missouri on the west. On this there stand forth abrupt prominences. These all undoubtedly have a core of Cretaceous rock, but on the exterior they bear massive heaps of bowlder-drift, which give to the whole the appearance of enormous morainic masses. On the adjacent plains the drift is more evenly spread and the peripheral belts give but the barest relief. The result is that undue prominence is given to the aggregations on the heights, while those on the plains are shadowed into inexpressiveness.

Farther to the north, in the vicinity of the *Maison du Chien*, or the Dog's Den, and southward and eastward, Prof. F. H. King made, under my direction, a partial examination of the moraines of the Coteau in connection with those of the plains eastward and southward. He there finds the eastern edge of the Coteau characterized by strongly developed and very stony moraines.

In connection with the British Boundary Commission, Mr. G. M. Dawson some years since examined the formation on our northern border and beyond, and as he did not conceive it to be a moraine, and was not therefore influenced by any possible morainic bias, his description at this, the present known extremity of the long chain, possesses peculiar interest, and is here introduced:

"The Missouri Coteau is one of the most important features of the western plains, and is certainly the most remarkable monument of the Glacial period now existing there. I have had the opportunity of examining more or less carefully that portion of it which crosses the forty-ninth parallel northwestward for a length of about 100 miles. On the parallel, the breadth of the Coteau, measured at right angles to its general course, is about 30 miles, and it widens somewhat northward.

"On approaching its base, which is always well defined at a distance, a gradual ascent is made, amounting, in a distance of 25 miles, to over 150 feet. The surface at the same time becomes more markedly undulating, as on nearing Turtle Mountain from the east, till, almost before one is aware of the change, the trail is winding among a confusion of abruptly rounded and tumultuous hills. They consist entirely of drift material, and many of them seem to be formed almost altogether of bowlders and gravel, the finer matter having been, to a great extent, washed down into the hollows and basin-like valleys without outlets with which this district abounds. The ridges and valleys have in general no very determined direction, but a slight tendency to arrangement in north and south lines was observable in some places.

"The bowlders and gravel of the Coteau are chiefly of Laurentian origin, with, however, a good deal of the usual white limestone and a slight admixture of the quartzite drift. The whole of the Coteau belt is characterized by the absence of drainage valleys, and in consequence its pools and lakes are often charged with salts, of which sulphates of soda and magnesia are the most abundant. The saline lakes frequently dry up completely towards the end of the summer, and present wide expanses of white efflorescent crystals, which contrast in color with the crimson *Salicornia* with which they are often fringed.

"Taking the difference of level between the last Tertiary rocks seen near the eastern base of the Coteau, and those first found on its western side, a distance of about 70 miles, we find a rise of 600 feet. The slope of the surface of the underlying rocks is, therefore, assuming it to be uniform, a little less than 10 feet per mile. On and against this gently inclined plane the immense drift deposits of the Coteau hills are piled."[1]

EVIDENCES OF DRIFT MOVEMENT.

It cannot have escaped the notice of the discriminative reader that one of the great pillars of evidence constantly relied upon to support the conclusions arrived at has been the positive and inferential testimony of the areas embraced in the morainic loops as to the drift movements that passed over them. In most cases this has been, if not ample, at least clear and forcible. In its cumulative strength, when the full array drawn from all the long chain is massed, its force is overwhelming. In Dakota, unfortunately, the evidence is meager. Almost the entire area is occupied by Cretaceous shales, whose soft and perishable nature led (1) to their being extensively ground down and almost universally covered with drift, and (2) to the subsequent obliteration of such markings as they may have been competent to receive from the ice. The general worthlessness of the rock for constructive purposes and the newness of the country have been unfavorable to those artificial exposures of the buried rock surface that may at length yield valuable evidence.

Striæ.—Within the large area but a single locality has yet revealed distinct striation. That is the quartzite exposure in the valley of Wolf or Black Earth Creek, southwest of Bridgewater, in the Southern Dakota Valley (S. side Sec. 21, T. 101, R. 56). The main set of scratches here point southeast by south, while a few run south-southeast (mag.). *Roches moutonnées* are also here finely exposed, and have their southeast sides broken off along transverse jointage lines (Todd). Though a lone witness, the testimony of this striation accords perfectly with theory. A few observations just over the moraine on the outside harmonize with and strengthen this one. They are as follows:

At Sioux Falls, on Huronian quartzite	S. 20° E.
At Sioux Falls, on Huronian quartzite, doubtful	S. 40° to 45° E.
About 3 miles west of Sioux Falls, on Huronian quartzite	S. 22° E.

[1] On the Superficial Geology of the Central Region of North America. By George M. Dawson. Quar. Journal Geol. Soc., Nov., 1875, p. 614.

Disposal of bowlders and drift.—The dearth of evidence from rock grooving and the abrasion of domes of obdurate rock is paralleled in meagerness by that derivable from transportation. The almost universal prevalence of a single soft formation afforded little opportunity for a distinctive distribution of erratics. Nearly all bowlders were derived from the remote north—the Archæan highlands or the Silurian belt at its base—and hence have too wide and common dispersal to be very significant, while the contribution of the soft shales is too narrowly local or too indecisive to determine any general question. The main dependence for internal evidence is therefore essentially narrowed to that offered by the attitudes assumed by the drift accumulations themselves, a class of evidence whose force depends much on the multiplicity of the observations and the circumspection of the observer. A large measure of the work in Dakota, after the preliminary reconnoissances had determined the general distribution of the moraine, was devoted to observations on the drift of the included area, particularly to some very interesting and not a little puzzling moraines that lie in the embraced territory. In these observations I think I have secured an important advantage in the association with myself of two independent observers, Professors Todd and King, who, on separate examination of identical phenomena, have usually arrived at conclusions identical with my own.

The most satisfactory evidence of this class consists (1) of the disposal of the minor peripheral moraines formed at intervals during the general retreat of the ice ("moraines of recession") in the form of small arcs, concave towards the ice, of whose crenate margin they are the mold, and (2) of overwash plains, channels, and similar phenomena on the exterior of such later moraines. A discussion of this evidence in detail would transcend the limits of this report.

A special group of morainic lines, stretching from near the head of the Coteau des Prairies to Minne'Waukon, or Devil's Lake, and beyond, merits fuller consideration than can be given it, because of its close relationship to the older moraines in the former region, and because of its very strong development in the latter.[1]

The distribution of these moraines, so far as now traced, may be seen by reference to the accompanying map. Their special discussion is reserved for the future. It is sufficient here to remark that they were all formed by glacial movements from the northeast and north, and are not true intermediate moraines, though occupying a seemingly mediate position.

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[1]These have been studied in considerable detail, though not to completeness of delineation, between the head of the Coteau and the Northern Pacific Railway, by Prof. J. E. Todd, under my direction. They have been traced from the latter line northward to Devil's Lake, and westward, by Prof. F. H. King. I have studied them at a few points, and more cursorily examined them in reconnoissances at the distant points named, and at some intermediate localities.

POSSIBLE COURSE OF THE MORAINE BEYOND PRESENT EXPLORATION.

That a moraine which has held its course with such strength and consistency of characters for 3,000 miles, reaching two-thirds the way across the continent, should terminate where present knowledge leaves it, is wholly improbable. Its cause must be some widely prevalent combination of conditions that must, presumably, have affected the entire ice-field. The moraine is, therefore, rationally presumed to be coextensive with the limit of the great ice sheet at the epoch of its formation, and its complete delineation will afford evidence of the origin and dispersal of ice accumulation on the continent of no insignificant importance. That delineation leads, however, into distant and difficult, possibly into inhospitable, regions. Present data afford ground for at least three possible conjectures as to its further extension, which may do good service as tentative working hypotheses, if restrained within the limits of their proper use.

I. Broadly viewed, the section of the moraine now known stands in a suggestive concentric relationship to three great features of the northeastern portion of the continent: 1st, the Great Lake system; 2d, the Great Archæan axis; and 3d, the present glacial area of the continent. The first hypothesis is built upon the presumption that it will continue to sustain this relationship, in which case its course might be expected to be northwesterly over the northern plains, and skirting on the west the great chain of lakes to the Arctic Ocean, the Mackenzie River perhaps lying along the outer border, somewhat as the Missouri and Ohio do in lower latitudes. A study of the northeastern part of the continent develops many facts that readily fall into beautiful consonance with this conjecture.

This hypothesis is another form of postulation of a great area of dispersion in the northeastern part of the continent. It assumes that the glaciation of northwestern America was subordinate to such a degree as not to interfere with the radial dispersion of the northeastern sheet.

II. *The second hypothesis* departs from this in respect to the last particular. While postulating a vastly predominant ice expansion from the northeastern center, it assumes also a dispersion from the axis of the northern Rocky Mountain range of sufficient magnitude to encroach upon and interfere with the free overflow from the northeastern field, giving rise to an intermediate moraine along the line of conflict, whose general position may not be widely different from that assumed in the preceding case, but whose special course and characteristics would be quite different. This junction and welding, so to speak, of the Kettle Moraine with the contemporaneous terminal moraine of the mountain ice-field, would give an actual connection and correlation with the presumably complex morainic systems of the mountains, and through them complete the chain to the Pacific.

III. *The third hypothesis* goes a step further and postulates a broader northern ice-field, spanning the continent and moving southward to various latitudes, according to the balance between accumulation and facility of flow on the one hand and waste on the other. In this view, the presumption would be that at no great distance beyond the limits of its present known extent the moraine recurves to the southward and passes in tortuous course across the mountain belt to the Pacific.

It is no part of my purpose to discuss these hypotheses. I have even hesitated to express them, so great, and in large measure so just, is the prejudice against hypothetical projections; but it is important that observation be definitely trained to the determination of specific and pregnant problems. Enough has been wasted in desultory unsystematic work. The line of investigation to which this paper is a contribution proposes, with a fair probability of success, a definite solution of these great problems and of others dependent upon them. As remarked some years since, the extent of the range is likely to prove too great for the immediate time and means of a single observer.[1] And in this there is a sufficient sanction for so much of theoretical forecast as shall be suggestive of problems to be solved, and of specific methods for their solution.

[1] Proc. Wis. Acad. Sci., 1878. "On the Extent and Significance of the Wisconsin Kettle Moraine."

A REVIEW

OF THE

NON-MARINE FOSSIL MOLLUSCA

OF

NORTH AMERICA.

BY

C. A. WHITE, M. D.

LETTER OF TRANSMITTAL.

SIR: In accordance with your request that I should prepare an article for your annual report upon a subject which has for some years been engaging my attention, I have the honor to submit herewith the following, which I have entitled "A Review of the Non-Marine Fossil Mollusca of North America."

In the preparation of this article I have endeavored as fully as practicable to follow your suggestion, that it should be as free from technical forms and methods as the nature of the subject will allow. I have therefore endeavored to address the general reader rather than the special investigator; but I have given copious references in the form of foot-notes, so that those who wish to pursue the subject further may readily refer to nearly all that has been published upon it in America.

Your recognition of the fact that there is a natural and growing desire on the part of intelligent readers to know something of the geological history of the predecessors of the animals with which they are more or less familiar, or which are frequently referred to in the books they read, would be expected by those who are familiar with the graphic style of your own writings; and your wish to gratify that desire is too obviously correct to make any explanation or apology proper on the part of a specialist who may be called upon to communicate with the public in the form proposed by you.

In the selection of a subject, I have chosen one which, although primarily based upon molluscan species which are all extinct, embraces the consideration of, or reference to, living forms, congeners of those which have ceased to exist, that are scattered over all parts of the country. It is, therefore, a subject which a far greater number of persons will find of ready application within their every day experience than many others which the wide range of paleontology might furnish. In illustrating this subject on the accompanying plates, I have in each case selected such figures (which are in part copies of illustrations already published by various authors, but largely newly drawn from the type-specimens of the various species) as would exhibit the form, and such features of the objects, respectively, as strike the eye of the ordinary observer, omitting, in many cases at least, those details of structure which more especially engage the attention of the special investigator.

While the material upon which the present statements and discussions are based is in many respects very incomplete, it is nevertheless extremely suggestive and instructive, and a knowledge of it is sure to awaken a strong interest in future labors in the same field that has been fruitful of these results.

A majority of the illustrations accompanying this article have been drawn directly from specimens in the United States National Museum, permission having been kindly given to do so by Professor Spencer F. Baird, the Director of the museum. A large part of the specimens thus used are the original types of the species which are illustrated.

The drawings have been made with pen and ink by Dr. J. C. McConnell, of Washington, and they have been reproduced by the photo-engraving process.

Very respectfully,

C. A. WHITE.

Hon. JOHN W. POWELL,
Director of the United States Geological Survey.

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ILLUSTRATIONS.

A REVIEW OF THE NON-MARINE FOSSIL MOLLUSCA OF NORTH AMERICA.

By C. A. White, M. D.

INTRODUCTORY REMARKS.

In this article I propose to review the principal known facts concerning the fossil fresh-water, brackish-water, and land mollusca of North America, taking up each family in the order of systematic classification, and tracing the history of its occurrence, so far as it has been learned, from the earliest known appearance of any of its species within the present limits of North America until the present time; and to follow the same with some general discussion of certain questions that are suggested by the facts thus set forth. For the purpose of giving an approximately chronological view of the different faunæ the figures are arranged on the plates under headings that indicate the successive geological periods to which they belong. The plan proposed involves at least brief mention of every species of non-marine fossil mollusca yet discovered in North America, and the illustration of nearly all of them by figures, which show their external form and leading features, so far as they are known. To avoid frequent repetition, it is mentioned here that all statements made in this article in regard to the range of families and genera in time, must be understood as applying to North America alone, unless it is otherwise expressly stated.

The scope of this article, as indicated by the title and foregoing remarks, is a very wide one; and the presentation of such a title would seem to imply the known existence of much material upon which to base a discussion of the subject. Lest I should seem to assume greater knowledge of this subject than the facts will warrant, it may be stated that while the material upon which our present knowledge of it is based is really considerable and very important, it is nevertheless true that as regards a continuous history of the faunæ herein discussed, and the geological epoch in which our most common living molluscan types really originated, our knowledge is very imperfect. Enough material, however, has been collected to throw much light upon the character of the ancestral representatives of many of the families which are herein mentioned. It is proposed to go so far only in the discussion of these fossil forms as we are warranted in doing by the well-ascertained character of the evidence adduced.

As to the scope of the general subject, although it embraces the three categories of non-marine mollusca, namely, those of brackish-water, fresh-water, and land habitat, it is still small as compared with that of the great mass of that portion of the molluscan subkingdom which is embraced by the marine mollusca. Not only is the diversity within the three categories of molluscan forms which are herein discussed almost incomparably less than that which obtains among marine mollusca, but a greater proportion of the remains of formerly existing non-marine than of marine mollusca, have almost certainly been destroyed as the result of geological changes and other causes which will be suggested, or they have failed to be preserved in an available condition for study. Therefore the record furnished by the fossil non-marine mollusca is much more imperfect than it is in the case of the marine mollusca. Still, the scope of this subject is a very broad one, even with our present incomplete knowledge of its details, and the discussion of many interesting points pertaining to it must be deferred to other occasions.

Again, while the three non-marine categories of mollusca, especially the first two, in the order in which they have been named, may be defined from each other with a good degree of accuracy in the case of their living representatives, yet it has not always been found easy to say whether some of those fossil forms whose nearest living congeners are found exclusively in perfectly fresh-water may not have lived in waters which contained at least a small proportion of salt; but this subject will be further referred to on subsequent pages. Neither are we positive in all cases that those species which we refer to a land habitat were really land pulmonate mollusks, or that they may not have been in some cases palustral pulmonates, or, possibly, gill-bearing mollusks. But generally these determinations are made with much confidence, based upon the known correlation of shell characteristics with the soft parts of the living mollusks which formed them.

The more indefinite boundary of the scope of the present article is that which I have drawn between the brackish-water and marine forms. The difficulty of drawing such a line arises largely from the fact that some of the genera which have more or less abundant representatives in brackish waters have also representatives in marine waters; but I have regarded those strata as of brackish-water origin, which have been found to contain by natural deposition forms whose living congeners are found in brackish waters, even though such fossil forms are found associated with those on the one hand whose living congeners are sometimes, but not not always, found in marine waters; or, on the other hand, with those whose living representatives are known only in fresh waters. Such a commingling of forms as is here indicated really occurs in numerous instances, especially in the strata of the Laramie group. Thus the association in one and the same stratum of *Corbicula*, *Corbula*, *Neritina*,

&c., is held to indicate a brackish-water origin for such a stratum, even though it holds, associated with those shells, such forms as *Unio*, *Viviparus*, *Goniobasis*, &c., especially if such strata alternate (as is often the case in the Laramie Group) with strata which contain on the one hand only such fresh-water forms as *Unio*, *Viviparus*, &c., and on the other hand such saline-water forms as *Ostrea*, *Anomia*, &c. This view is also confirmed by the fact that in the Laramie Group *Corbicula*, *Corbula*, and *Neritina* are frequently found so associated with *Ostrea* and *Anomia* as to plainly indicate that they all lived together. It is thus clearly shown that a part of the forms discussed in this article have near allies in strata of marine origin, and also many near allies now living in truly marine waters, and none in fresh waters; but the commingling of these fossil species of undoubted saline habitat with others which clearly indicate that they lived in water of far less than marine saltness, makes it necessary to regard the former as members of a brackish-water fauna, and, therefore, as coming within the scope of this article.

In some cases the brackish waters that, by the presence in the deposits they have left of such fossils as have been referred to, are indicated as having then prevailed, were plainly those of estuaries, which indented the coasts of formerly existing seas at the mouths of then existing rivers. But the greater part of the species enumerated in this article, which are regarded as having had a brackish-water habitat, come from strata (namely, those of the Laramie Group) which bear evidence of having been deposited in a great inland sea, in parts of which sea brackish waters alternated with fresh, or nearly fresh-waters. The facts upon which this conclusion is based have been presented in other publications, and are repeated to some extent upon following pages in this article.

Before proceeding with the enumeration of the specific forms of non-marine mollusca which have been discovered in North American strata, and the geological position which each fauna represented by them respectively occupies, it is necessary to present a brief tabular statement of the arrangement or order of the geological formations, beginning not with the earliest known fossiliferous rocks in the geological series, but with the formation which has furnished the earliest known molluscan forms that come within the scope of this article, namley, Devonian.

This tabular view of the formations has been made with especial reference to those which have been recognized in Western North America, because it is there that the greater part of the fossils have been collected which are discussed in the following pages.

It may not be entirely unnecessary to state that, although the terms group and formation are somewhat variously used by different writers, the strata that were formed in a period or epoch of geological time are usually and properly referred to by the same name as that of the period or epoch in which they were formed. Thus, the following table of geological time is really a table of the formations that were produced dur ing that time.

Subdivisions of geological time.

Time.	Ages.	Periods.	Epochs.
Cenozoic or Mammalian	Cenozoic	Post-tertiary	Recent. Quarternary.
		Tertiary	Pliocene. Miocene. Eocene.
		Laramie.	
Mesozoic or Reptilian	Mesozoic	Cretaceous. Jurassic. Triassic.	
Paleozoic	Carboniferous	Permian. Coal-Measures. Lower Carboniferous.	
	Devonian	* * * * * * *	

No special explanation of the terms or names used in this table, with perhaps the exception of Laramie, is deemed necessary, because they are to be found in all text-books of geology now in use; but some supplementary explanation of the terms that, in connection with those which have become so commonly known, have been used by the various geologists who have made original investigations in Western North America is necessary to enable the general reader to understand clearly the use of them that is made in the following pages.

The term Laramie Group, although it is unknown except in the geology of Western North America, will be mentioned oftener perhaps in this article than the name of any other formation; because a greater number of the species herein mentioned come from that group of strata than from any other. This name is applied to a large and very important formation which, in the western part of the continent, comes between the well-recognized marine Cretaceous strata below, and the equally well-recognized Tertiary strata above. Geologists are not agreed as to whether this great group should be referred to the Tertiary or Cretaceous period, some contending for the former and some for the latter reference. The truth appears to lie between the two opinions, and I have elsewhere presented reasons for regarding this group as occupying a transitional position between the Cretaceous and Tertiary.* Neither the Laramie Group nor any true geological equivalent of it is at present known anywhere except in Western North America. It there occupies or is found at various localities within a large region, the present known limits of which may be roughly stated as extending from Northern New Mexico on the south to the British possessions on the north, and from the vicinity of Great Salt Lake on the west to a present known distance out upon the Great Plains of more than 200 miles from the eastern base of the Rocky Mountains. It has been traced within the western boundary of both Kansas and Nebraska.

In the course of the earlier geological investigations which were made in the west, the strata of this great group, which represents a distinct

*An. Rep. U. S. Geol. Sur. Ter. for 1877, pp. 259–265. *Ib.* for 1878, part I, pp. 51, 52.

period in the geological history of North America, were studied independently by different investigators, at various more or less widely-separated localities within the region that has just been indicated, which resulted in the strata of that group receiving different names in different regions. Thus, Meek & Hayden gave the name "Judith River Group" to those strata in the valley of the Upper Missouri, near the mouth of Judith River, which were found tocontain brackish-water fossils. They gave the name "Fort Union Group" to strata of similar faunal character near Fort Union, also in the valley of the Upper Missouri, but at a considerable distance to the eastward of the Judith River region. They also gave the name "Lignitic Group" to those strata in Colorado east of the Rocky Mountains which were found to contain a similar fauna. Professor Powell, studying the strata in Wyoming and Utah, gave the name "Point of Rocks Group" to a series which agrees mainly with that which is now called Laramie, and which had been referred to by Meek & Hayden as the "Bitter Creek Coal series." The strata which are herein called the Bear River Laramie beds of Southwestern Wyoming and the adjacent parts of Utah were by Meek and Hayden generally referred to as the "Bear River Estuary beds." Mr. King was the first to place all these local groups together (except those of the Upper Missouri River region) under the general and comprehensive name of Laramie Group. I subsequently showed that the Judith River, Fort Union, Lignitic, and Point of Rocks groups are all connected together by specfiic identity of fossils in their respective strata.* I have therefore treated the strata of all those different regions respectively as only local development of parts of one great group; but I have retained the local names which they originally received from different authors, only substituting the word "beds" in most of those cases for that of "group," using the latter term in the more comprehensive sense. Thus, I speak of the Judith River beds, Fort Union beds, Bear River beds, &c., while referring them all to the great Laramie Group.

A similar duplication of names, arising from similar circumstances, also exists in reference to the earlier or earlist members of the purely fresh-water Eocene series, which immediately succeeds the Laramie Group. Thus, the names "Wahsatch Group" of Hayden, "Vermilion Creek Group" of King, and "Bitter Creek Group" of Powell are regarded as substantially equivalent, or as representing one and the same division of the Eocene epoch.

To aid the reader, who may be assumed to be unfamiliar with the details of western geology and with the names which the different series of strata in the West that are necessarily often referred to in this article have received from different investigators, the following summary of facts and opinion is given:

1. The "Judith River Group," "Fort Union Group," "Lignitic Group,"

*An. Rep. U. S. Geol. Sur. Terr. for 1877, pp. 252–265.

"Bitter Creek Coal series," "Point of Rocks Group," and "Bear River Estuary beds"* are all parts of the great Laramie Group.

2. The Laramie Group is regarded as a transitional group between the Cretaceous and Tertiary series, and therefore as representing a period partaking of both the Mesozoic and Cenozoic ages.

3. The "Wahsatch Group," "Vermilion Creek Group," and "Bitter Creek Group" are regarded as at least approximately equivalent strata, constituting the oldest member of the purely fresh-water Eocene Tertiary series of deposits in the West.

4. The Green River and Bridger Groups are respectively the second and third members of that fresh-water Eocene series.

5. The Wind River Group of Wyoming is regarded as of Eocene age.

6. The White River Group of Dakota is regarded as of Miocene age.

7. The fresh-water deposit of the Kawsoh Mountains, in Northern Nevada, and its equivalent in Southern Idaho, called by King the Truckee Group, are regarded as of Miocene age.

8. No strata of Pliocene age are referred to in this article except those of Cache Valley, in Northern Utah, because with that exception no non-marine mollusca are known to have been obtained from any North American strata which may be referred to that epoch; unless certain forms of *Physa* be also excepted, which have been found in the Brown's Park Group of Powell, in Southern Wyoming.

Our knowledge of the various geological formations which are found within the limits of North America enables us to trace with a good degree of satisfaction the history of the evolution of the continent or the progressive steps by which it was elevated above the level of the sea. A brief outline, or at least a statement of some of the phases of this history, as it is understood by geologists, is necessary to a proper understanding of the facts which are presented in the following pages. Without going into the details of investigations by which geologists have arrived at their conclusions, it may be stated that the continent in its present shape has been produced by the coalescence of two or more principal portions which were elevated above the level of the sea in the earlier geographical ages in consequence of the progressive elevation of the continental area. The two principal portions of the continent previous to the Cretaceous period were an eastern and western one respectively, and before the close of that period they were separated by a broad stretch of open sea. By the continued slow rise of the whole continental area this broad stretch of open sea became land-locked at the close of the

* It should be remarked here that the molluscan species of the Bear River beds and their equivalents are all different from those of the Laramie Group elsewhere; but those strata are referred to the Laramie Group because they hold the same stratigraphical relation to the Cretaceous below and the Tertiary above that the typical Laramie strata do in other regions, and also because they contain a brackish-water fauna. Whether this difference in the faunæ is due to difference in age, contemporaneous isolation of waters as separate seas during the Laramie period, or to some other cause, is not yet known.

Cretaceous period and beginning of the Laramie, changing the area thus inclosed to a brackish-water sea, in which the strata that we now call the Laramie Group were deposited. By the continued elevation of the continental area that sea became much reduced in size and entirely fresh at the close of the Laramie period.

During the immediately succeeding Eocene Tertiary epoch at least, the great fresh-water lakes that were thus formed prevailed over a large part of that area which in the Laramie period had been occupied by brackish, and previously by marine, waters. Then began the series of movements in the earth's crust which resulted in the elevation of the plateaus and the great systems of mountains of Western North America, into the structure of which these Laramie and Eocene strata enter. Some portions of the western part of the continent continued to be occupied by fresh-water lakes of the kind last referred to, during the middle and latter portions of the Tertiary period; but they were much less in size than those which previously existed. They also gradually became smaller, and finally disappeared by being drained of their waters; or remnants of them remained to become the salt-water lakes of to-day.

The incompleteness of that portion of the geological record which is furnished by the fossil remains of the three categories of mollusks, which form the subject of this article, has already been referred to, and the causes of it are very apparent when it is remembered how small a proportion the non-marine have always borne to the marine mollusca; and also how small a proportion of fresh and brackish water deposits there must always have been in comparison with marine deposits.

The extensive fresh and brackish water deposits of Western North America are remarkable exceptions to the general rule, that extensive geological formations are of marine, or open sea, origin; and we have therefore in that region, and for the epochs which those formations represent, an unusually full record of non-marine and terrestrial life; for it must be remembered that those formations contain many remains of terrestrial vertebrates, and an abundant flora, as well as of fresh-water and land mollusca. This statement of facts naturally leads to a brief consideration of the conditions which prevailed in former geological periods, and which conduced to the preservation of the molluscan forms herein discussed, when so large a proportion of their kinds in other parts of the world were destroyed.

While the remains of aqueous mollusca were readily entombed and preserved in the sedimentary deposits of the waters in which they lived (which deposits afterward became rocky strata), those of land mollusca must have been transported from the land into such waters, where alone they could have been preserved, and where in fact they did receive the same entombment with those that had lived there. This transportation of the shells of land mollusca was doubtless in most cases effected by the currents of rivers near the banks of which the mollusks lived, and into the waters of which they were swept in time of flood. And yet an unexpectedly large proportion of the known fossil pulmonate mollusca are those whose habitat was constantly upon the land. The conditions, however, which prevailed during the Coalmeasure period of the Carboniferous age, and under which the immense quantities of vegetable material that we now know as coal were preserved, were necessarily somewhat favorable to the preservation of such land mollusca as may have found a habitat among that vegetation. The paucity of the remains of such mollusca that have yet been discovered in the extensive coal-bearing strata of that early period seems to prove that they could not then have been very abundant; but the discoveries of Dawson, Bradley, and Whitfield show conclusively that a well-developed and widely differentiated land moluscan fauna existed at least as early as the middle of the Carboniferous age, and probably much earlier.

From the Coalmeasure period until that of the Laramie the few remains of non-marine mollusca that have been found in North American strata present indications that the layers in which they were discovered were deposited under estuary, palustral, or limited lacustrine conditions, reference to which will be made in connection with the separate mention of the species on following pages. The conditions which prevailed in Western North America during the Laramie and Eocene periods have already been indicated, and for fuller details the reader is referred to the works before cited.

Although there are really many facts now known which throw light upon the physical conditions that prevailed, and the molluscan faunæ which lived in Western North America during the various geological periods from the later Paleozoic to the present time, a part of which have been referred to, the following counter-facts should also be mentioned, because they show how far from perfect or continuous the geological record really is, in relation especially to the non-marine mollusca.

Rivers, ponds, and marshes have necessarily existed ever since any considerable portion of the continent rose above the sea, and those rivers and ponds, without doubt, all had their own molluscan faunæ ever since the later portion of Paleozoic time, if not from a still earlier date, and yet no trace of any river deposits, except those of estuaries (and few of these are known), has yet been discovered which pertain to any geological epoch except that of the Post-Tertiary. The same can hardly be said of palustral deposits, because much, if not all, of the coal must have been produced under palustral conditions; and yet it is a noteworthy fact that the greater part of the known fossil palustral mollusca have been found preserved in lacustrine deposits together with mollusks of lacustrine origin, and very few in true palustral deposits.

Although it is only in the eastern half of the continent that any remains of non-marine mollusca have been found in strata of Paleozoic age, the remains of such mollusca as have been found there in strata of any of the periods between that of the Coalmeasures and the Post-Tertiary are few and unimportant.*

* See remarks on a following page on spurious and doubtful species.

The same might also be said of that portion of the continent which borders upon the Pacific Ocean, and for the same periods, but for the very few Unione forms which the Cretaceous deposits have furnished there, and which have special interest in connection with other fossil Unionidæ mentioned in this article. Therefore, almost the whole of our present knowledge of the character of the non-marine molluscan types which existed during the whole of Mesozoic and Tertiary time and of the order of their succession has been derived from discoveries of their remains which have been made in the interior region of the western half of the continent, mainly in connection with the surveys that have been prosecuted under the auspices of the government. Moreover, the discoveries that have been made in North America up to the present time give us very little information of any molluscan fauna, except the marine, for the Miocene epoch, and still less for the Pliocene. Therefore this review of the non-marine molluscan faunæ of the continent, although it is intended as a synopsis of all the species that are at present known, is something like a chapter, or parts of chapters, taken at random from a book; but these selections are of such a character as to give us a very good indication of what the whole book, figuratively speaking, must be. This indication is all the more clear because of the fact that while every species that is discussed in this article, from whatever formation it comes, is regarded as extinct, the great majority of the genera, and even the sections or subdivisions of the genera, are precisely the same as those which we find represented by living forms. In the case of many of the fossil forms, so clearly are these familiar generic and subordinate types expressed, that the fossil species are often found to resemble those now living so closely as to require careful scrutiny to discover wherein they differ. This persistence through long periods of geological time, of even the simpler types of non-marine mollusks, after they were once established, is a remarkable and interesting fact. Individuals, generations, and species died, as the epochs succeeded each other, but the types* have remained to this day.

*The word "type," as used by different authors, has often necessarily a somewhat indefinite meaning; but as used in this article it may be defined as an ideal representation of the essential characteristics of a group of species, usually applied to a group which may embrace a genus, or only a subordinate division of a genus. In the latter case, I use the designation subordinate type. I do not use the term type in any case as interchangeable with any of the names that are used in systematic classification, such as species, genus, family, &c.; but sometimes it may be equivalent in scope with any of them; as, for example, when only a single species of a subgenus, genus, or family is known.

Thus, although types may have no material existence in one sense, they are found to have been more persistent in time or duration than specific forms; for we find that many of the types, as above defined, which now exist among living mollusca also existed in various geological epochs as far back as Mesozoic, or even earlier, time; but every known fossil species in which those types have been expressed have successively become extinct.

ANNOTATED AND ILLUSTRATED CATALOGUE.

CONCHIFERA.

The families of the Conchifera, which are represented by the fossil species discussed in this article, are those only which are represented among the living non-marine mollusca; because, so far as we now know, there is not a single representative of an extinct family among all those species. Moreover, the principal genera are the same among both the fossil and recent forms, and in only a few cases at most is there a subgeneric difference, or even a difference in the subordinate types into which certain of the genera may be divided; although all the species are regarded as extinct.

It should be understood that this article is a review, and not a revision, of published species. Therefore, the genuineness of the different species which have been published by various authors is seldom called in question, even when it is doubted, as it is in a number of instances. It is thought best on this occasion to present the subject somewhat historically, and defer a critical revision of the species to another time.

OSTREIDÆ.

Although the Ostreidæ of the present time are much less frequently found living in the waters of the open sea than in those of bays and estuaries, the fossil shells of all the various generic groups of that family are often found quite abundantly associated with those of such molluscan forms as must be regarded as having been denizens of the open sea. Indeed, both the Mesozoic genera *Gryphæa* and *Exogyra* seem to have been invariably of open-sea habitat; while *Ostrea* proper has, in all the Mesozoic and Cenozoic epochs, existed in both marine and brackish waters; but the last-named genus seems to have always been in past times the only representative of the Ostreidæ that has lived in brackish waters, while none of the family have probably ever lived in perfectly fresh waters.

The most noteworthy examples of the fossil brackish-water Ostreidæ of North America, namely, those of the Laramie Group, occur in strata that contain no truly marine forms, but which are frequently found to closely alternate with other strata in which fresh-water and land mollusca prevail; and, indeed, there are often found associated with these shells of *Ostrea* those of species whose living representatives exist only in fresh waters. But as it is my intention to prepare a separate essay for a future report on all the fossil Ostreidæ of North America, little more than incidental reference will be made to this family in this article—even to those species of *Ostrea* which constitute parts of the brackish-water fauna herein discussed. Since, however, the molluscan fauna of the great inland brackish-water sea which existed during the Laramie period will be necessarily somewhat frequently referred to and briefly discussed on following pages, it is thought best to make the series of its illustrations the more complete by presenting a few figures of the more characteristic forms of its Ostreidæ, which will be found on Plates 9, 10, 11, and 12.

Five species of *Ostrea** have been described and published by various authors from strata which are now regarded as belonging to the Laramie Group; but in view of the known wide range of variation among the species of this genus, and the actual discovery of many intermediate forms which connect at least a part of those supposed species together, it is now thought that the strictly specific forms of *Ostrea* which have been discovered in the Laramie Group do not number more than two or three at most.†

It is interesting to note how closely some of these ancient species of *Ostrea* are allied to living forms, a good example of which is afforded by *O. wyomingensis*, as may be seen by comparing the figures of it on Plates 10, 11, and 12, with the shells of the common *Ostrea virginica*, now living so abundantly upon our Atlantic coast. So closely, indeed, are some of the fossil specimens like living ones that, but for their partially mineralized condition, the former might easily be taken for damaged examples of the living species.

While the Ostreidæ have formed a more or less prominent feature of all the molluscan faunæ whose remains are found in all the marine deposits from the Jurassic period to the present time, we have yet discovered no remains of the family in any North American strata of any of the epochs between the close of the Laramie period and the beginning of the Post Tertiary which can be properly referred to a brackish water origin. Therefore the consideration of this family as contributing any of its species to non-marine molluscan faunæ must cease in this article with the references that are made to the fauna of the Laramie Group.

Precisely similar remarks may be made concerning the genera *Anomia*, *Corbicula*, *Corbula*, and *Neritina* so far as regards the extinction of all the species of those genera in the waters of the Laramie Sea as a consequence of their becoming completely freshened at the close of that period; and, also, because of the non-discovery of any brackish water deposits of a later date than that period in which such remains may have been deposited.

ANOMIIDÆ.

Since among fossil faunæ *Anomia* is an almost constant associate and sometimes, as, for example, in many of the layers of the Laramie Group,

* These were named, respectively, *Ostrea subtrigonalis* Evans & Shumard; *O. glabra* Meek & Hayden; *O. arcuatilis* Meek; *O. insecuris* White; and *O. wyomingensis* Meek. Examples of all these forms are figured on the plates accompanying this article.

† See remarks on this subject in An. Rep. U. S. Geol. Sur. Terr. for 1877, p. 162. Also, *ib.* for 1878, Part I, p. 56.

apparently the only immediate associate of *Ostrea*, the same general remarks may be made concerning the Anomiidæ that have just been made concerning the Ostreidæ so far as they are applicable to the subject of this article. The earliest known North American species of *Anomia* have been found in Cretaceous strata, the greater part of them having by the different authors who have described them been reported as associated with forms that must be regarded as of marine origin, but some of them are known to have existed in the estuaries that indented the sea coasts of the Cretaceous period.

One estuary species, *A. propatoris*, White, was discovered by Mr. Meek in an interesting estuary deposit of Cretaceous age at Coalville, Northern Utah, where it was found associated with *Cyrena*, *Unio*, *Valvata*, *Melampus? Physa*, and also with some marine forms. It is represented on Plate 5. In the marine Cretaceous strata of the same neighborhood some imperfect examples of *Anomia* have been found which seem to be specifically identical with *Anomia propatoris*. If this identification is correct it seems to prove that the species in question ranged from marine to brackish waters. This supposition is a plausible one, because certain living species of mollusks are known to have a similar range of habitat.

Anomia propatoris is very closely like some of the various forms of *A. micronema* presently to be mentioned, and the former not improbably represents the latter species ancestrally.*

Two other species of *Anomia* only are known, which come within the scope of this article, both of which are found in the strata of the Laramie Group in Colorado and Wyoming; although it is by no means unlikely that other species existed in the brackish waters of all the epochs that have passed since the family was first established. These two species are *A. micronema* and *A. gryphorhynchus*, Meek. They are both represented on Plate 12. Both are from the Laramie Group, and although in the same neighborhood they are seldom found associated in one and the same layer.

It has been the subject of frequent remark that not a single example of the under valve of either of the three species of *Anomia* herein noticed has ever been discovered, although hundreds of examples of the upper valves of at least two of the species has been obtained, at many different localities, in a good state of preservation. I was lately so fortunate however as to find in the Laramie strata of Northeastern Colorado several examples of the under valve of *A. micronema*, one of which is illustrated by Fig. 11, on Plate 12. That the under, or byssus-bearing, valves of *A. micronema* at least have been so generally destroyed is due to the fact, first, of their extreme thinness, and, secondly, to the fact that, with the exception of a thin, porcelanous layer in the middle portion, the whole valve is composed of a prismatic layer, like

* See remarks in An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 14, pl. 12, fig. 15.

the shell of *Pinna;* the pearly layer, which gives such strength to the upper valve, being apparently entirely wanting in the lower. This prismatic layer breaks up into its component prisms with great facility. The characteristics of the under valve of *A. micronema*, as well as those of the upper valve, show it to be a true *Anomia;* thus presenting evidence of the great antiquity of the genus just as it exists to-day.

MYTILIDÆ.

This family is very sparingly represented in the brackish water strata of North America, and not at all, so far as is now known, in either any existing fresh waters, or in any strata of purely fresh-water origin; yet the family has representatives in some of the strata of all the geological ages, from the Paleozoic to the present time. The only genus of this family which has been recognized among the fossil collections from our brackish water strata is *Volsella* Scopoli; and all the examples of it that have been discovered in those strata are apparently referable to the subgenus *Brachydontes* Swainson.

Two species have been described from the Laramie Group of Wyoming and Colorado, namely *Volsella* (*Brachydontes*) *regularis* and *V.* (*B.*) *laticostata* White;* both of which are represented on Plate 13.

An undescribed form of this genus is also known to exist in the Bear River Laramie beds of Southwestern Wyoming. At least one species, which is closely allied with those just mentioned as coming from the brackish-water strata, is known to exist in the marine Cretaceous strata of the same region in which those Laramie species occur, and it is not improbable that they are genetically related with each other.

The genus *Dreissena* Van Beneden, a living species of which is so common in certain of the rivers of Europe and Western Asia, and which genus is so abundantly and variously represented in the fresh-water Tertiary deposits of Eastern Europe, is not known to be represented in North America by a single species, either living or fossil. Neither is *Adacna* Eichwald known in North America, either fossil or recent, although so common in Eastern Europe and Western Asia, in brackish waters and brackish-water formations.

The genus *Mytilus*, although it is recognized by Meek in the marine Cretaceous strata of the epoch which immediately preceded the Laramie period, seems not to have survived in the brackish waters of that period as did *Ostrea*, *Anomia*, and *Volsella.*

In the foregoing discussion of the three families Ostreidæ, Anomiidæ, and Mytilidæ, representatives of which are now so abundant upon our marine coasts, it will be seen that especial reference has been had to the faunæ of the Laramie and other great groups of strata in the western portion of the continent. This arises from the fact which has already been stated or alluded to, that in the epochs represented by those groups, the conditions were, in that region, widely extended and

* An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 58, 59, pl. 25, figs. 3 & 4.

very favorable for the developement of brackish and fresh-water faunæ; while whatever of estuary deposits may have been made during the periods that have elapsed since paleozoic time in those regions which now constitute other portions of the continent, have been nearly or quite destroyed by the geological changes that have occurred, or they have hitherto escaped discovery. Consequently, as has already been remarked in relation to the Ostreidæ, discussion of not only the brackish-water representatives of these three families, but of all brackish-water forms will cease in this article with the references that are made to the fauna of the Laramie period. Discussion of the fresh-water and land mollusca will be continued to a much later epoch by references to their fossil remains, because favorable and extensive fresh water conditions continued in Western North America long after the wide-spread brackish waters of the Laramie period had ceased there.

But even as regards these purely fresh-water and land molluscan families, few of their remains have yet been discovered which are referable to the epochs which passed between the Eocene and the present time. These deficiencies of the geological record and their zoölogical bearing will be made apparent as the different known faunæ are presented in their order on the following pages.

UNIONIDÆ.

For various reasons, no family of non-marine fossil mollusca is of greater interest than the Unionidæ, especially since the discovery of the large number of species in the Mesozoic and Cenozoic strata of Western North America, and of the rich Unione fauna of the Tertiary deposits of Eastern Europe.

Although certain shells found in the Carboniferous and Devonian strata of Europe and America have been referred to the Unionidæ by different authors, the accuracy of such reference has been by others seriously questioned; and American paleontologists at least have of late years not generally recognized as belonging to that famliy any shells found in strata of earlier than Mesozoic time.* Prof. James Hall has, however, recently expressed the opinion † that the two bivalve species, which were named by Vanuxem *Cypricardites cattskillensis* and *C. angustata*, respectively,‡ belong to the genus *Anodonta;* and that the Montrose and Oneonta sandstones (later Devonian) in which those species occur, were "deposited under estuary and fresh-water conditions."

Aside from the apparent Unione characteristics of these shells, and the other facts upon which Professor Hall bases the opinion he has expressed, the wide differentiation, which is now known to have become fully established among the Unionidæ, at least as early as the later portion of Mesozoic age, points to a very early period for the origin of the family.

* See remarks on a following page on spurious and doubtful species.

† See "Science" for December, 1880.

‡ Vanuxem's Rep. Geol., 3d District, New York, p. 186.

It is not improbable, therefore, that representatives of the Unionidæ existed as early as the later Devonian, as has been suggested by Professor Hall. This opinion, furthermore, is all the more probably correct, because of the known fact that a well developed land-molluscan fauna existed during the Coalmeasure period, and apparently also in the Devonian, all the known species of which are mentioned on the following pages and figured on accompanying plates. Although it may not be regarded as certain that the *Cypricardites cattskillensis* and *C. angustata* of Vanuxem really belong to the genus *Anodonta*, copies of Vanuxem's original figures are given on Plate 1, for the purpose of comparison.

Dr. J. W. Dawson, in his Acadian Geology, second edition, describes seven species of edentulous bivalves from the Coalmeasure strata of Nova Scotia, under the generic name of *Naiadites*. He states his belief that they are the shells of brackish-water or fresh-water mollusks "allied to the Mytilidæ or Unionidæ." The shell structure, as given by Dr. Dawson, is like that of the Unionidæ and unlike that of the Mytilidæ. It seems, therefore, not improbable that at least a part of his species really belong to the Unionidæ. Three of those species, namely, *Naiadites carbonaria*, *N. elongata*, and *N. lævis*, are represented on Plate 2, the figures being copies of Dr. Dawson's original illustrations in the work referred to.

If these Devonian and Carboniferous shells do not really belong to the Unionidæ, the earliest known members of that family now known to exist in North American strata are two or three species, specimens of which were collected by Prof. E. D. Cope in the valley of Gallinas Creek, New Mexico, from strata which he regarded as of Triassic age.* These shells belong unquestionably to the genus *Unio* proper, as is shown by the character of the hinge and the muscular markings. The outer prismatic layer of the shell which characterizes the Unionidæ is also well preserved on some of the specimens. One of these forms, which is figured on Plate 3, was described by Mr. Meek,† under the name of *U. cristonensis*, and specific names were also proposed for the two other forms, the specimens of which he deemed to be too imperfect for characterization.‡ There are some reasons for regarding the strata from which these shells were obtained as of Jurassic instead of Triassic age, but further investigation is needed before such an opinion can be confidently expressed. The figure of *U. cristonensis* is drawn from one of the best of Mr. Meek's type specimens, but which is nevertheless very imperfect. The species has never before been figured.

While *U. cristonensis* is probably the most ancient published North American species of *Unio*, this portion of the subject ought not to be

*An. Rep. Expl. and Sur. west of the 100th meridian, for 1875, p. 81.

†An. Rep. Expl. and Sur. west of the 100th meridian, for 1875, p. 83.

‡These two names are respectively *Unio gallinensis* and *U. terræ-rubræ*; but the specimens to which they are applied are really too imperfect to justify the application of any specific names.

passed over here without reference to the fact that Dr. S. G. Morton, Mr. T. A. Conrad, and Dr. Isaac Lea have all described fossil species which they regarded as belonging to the Unionidæ. They were, however, either incorrectly referred to that family, or the formations from which they were respectively obtained are incorrectly stated; and they are, therefore, enumerated under the head of spurious and doubtful species on following pages.

That the Unionidæ existed within the area that now constitutes Western North America in the Jurassic period, and that the genus *Unio* of Retzius had then not only become established, but had reached a good degree of differentiation as regards the establishment of subordinate groups of forms within that great genus, is apparently beyond reasonable doubt; and in this article the question is treated as affirmatively settled. At the same time it should be stated that in the case of at least a majority of the alleged discoveries of fresh-water molluscan species in Jurassic strata, some doubt has been thrown upon the genuineness of the fresh-water origin of the strata in which they were deposited, or upon the actual Jurassic age of those strata.

The first discovery in North American Jurassic strata of shells which are referable to the Unionidæ was announced by Meek & Hayden in connection with the publication of *Unio nucalis*,* which is figured on Plate 3. Those authors, however, expressed a remote doubt as to whether the strata in question, which occur in the vicinity of the Black Hills, are really of Jurassic age. No other examples of this species besides the type specimens have ever been discovered. They are shown to be those of true *Unio* by the hinge characters observable upon one of the specimens; and the outer prismatic shell-layer is observable on all of them. They were found associated with shells, which Meek & Hayden referred to the genera *Planorbis*, *Valvata*, *Viviparus*, *Neritella*, and *Lioplacodes* respectively.

Another Jurassic species referable to this family is *Unio stewardi*, White, which was described from some imperfect specimens that were collected from Jurassic strata by Mr. J. F. Steward in Northern Utah.†

Fig. 1, on Plate 3, is an outline illustration of this species which has been made up by help of several fragments, no perfect example having ever been discovered. It is believed to represent closely the outline and general aspect which the species presented while living. It is an interesting form, because it illustrates the fact that at least one of the subordinate types of *Unio* that now exists among the living species of the Mississippi River system was established at that early epoch.

The next known member of the Unionidæ, the appearance of which is to be mentioned in the order of geological time, is an interesting form

* Paleontology of the Upper Missouri, p. 92, pl. iii, fig. 13.

† Powell's Report, Geology of the Uinta Mountains, p. 110.

which was described by Meek & Hayden,* from Southeastern Dakota, under the name *Margaritana nebrascensis.* It was obtained from the Dakota Group, which is the earliest group of the Cretaceous strata in the North American series; and it was found associated with *Cyrena dakotensis* and *Pharella? dakotensis* of the same authors. These forms indicate a brackish-water, probably estuary, origin for at least the layers in which those fossils occur, although the remains of marine mollusca are found in other parts of the same group. *Margaritana nebrascensis* is represented by two figures on Plate 4, which figures are drawn from the principal type specimen.

In shape and general aspect this shell resembles some of the living forms of *Margaritana,* but it is of a somewhat different type from any known living species of that genus. It differs still more from any of the other known fossil Unionidæ, except the form which was described by Gabb † from the Cretaceous strata of Vancouver's Island under the name of *U. hubbardi.* This suggestion of congeneric relationship is based upon the external characteristics alone which both present, because nothing is yet known of the character of the hinge of *U. hubbardi.* The hinge of *M. nebrascensis,* as ascertained by Meek, seems to warrant its reference to the genus *Margaritana,* and if this reference is correct, that species is, with the probable exception of the *U. hubbardi* of Gabb, the only known North American fossil form which can be properly referred to *Margaritana.* But, as before intimated, it probably belongs to a subordinate type of that genus which early became extinct. *Unio hubbardi* is represented by copies of Mr. Gabb's figures on Plate 5.

Mr. Gabb also described and figured ‡ another species, a strange bialate form from the Cretaceous strata of California, under the name of *Unio penultimus,* of which he seems to have had very imperfect specimens. Figure 1, on Plate 5, is a copy of Mr. Gabb's original figure of this form. He expressed no doubt of the correctness of his reference of that species to the genus *Unio,* and, notwithstanding its unusual form, there appears to be no reason to suppose that it may not belong at least to the Unionidæ. If it really is a member of this family it presents an interesting example of a subordinate type which has become extinct, while many co-ordinate types which existed contemporaneously with, or shortly after it, have come down to the present time unchanged. It is a significant and interesting fact, especially in connection with the reference of his Coalmeasure genus *Naiadites* to the Unionidæ by Dawson, that both of the Uniones which were described by Gabb from the Cretaceous strata of the Pacific coast were found in strata associated with the coal beds of that period.

The three last-mentioned species of the Unionidæ are, with one exception, all that are at present known to have existed within the area which

* U. S. Geol. Sur. Terr., vol. ix, p. 114, pl. i, fig. 5.

† Paleontology of California, vol. ii, p. 190, pl. 30, fig. 86.

‡ Paleontology of California, vol. i, p. 182, plate 24, fig. 164.

is now occupied by the North American continent during the epochs that all geologists agree in referring to the Cretaceous period. It cannot be doubted, however, that many representatives of the family really lived during that period, the remains of most of which are probably forever lost, but some of which we may yet hope to discover. The exception that has been referred to is a species, the only known remains of which consist of a few fragments, too imperfect for specific characterization, which were found in the Estuary deposit at Coalville, Utah, which has already been referred to as furnishing *Anomia propatoris*, and is yet to be mentioned in connection with certain other species.

The cause of the apparent paucity of Unione and other non-marine molluscan remains in strata of Cretaceous age, is not, probably, that such mollusca did not then exist in very many places in greater or less abundance; but it is probably due to the fact that few of the non-marine deposits of those epochs have escaped destruction.

We come now to the consideration of a geological period, namely, the Laramie (which is also a remarkable period of time in the evolutional history of the Unionidæ), in which the physical conditions within the area now occupied by the North American continent were exceedingly favorable to the existence and development of non-marine mollusca. The chief of these conditions was the wide prevalence of brackish and fresh waters during the whole of that period. During the Laramie period there existed a Unione fauna that, for differentiation into a great variety of subordinate types, is truly remarkable when we remember that it occurred at a time so remote.

It is also a remarkable fact that a large proportion of these types are precisely those which now characterize the peculiar and rich Unione fauna of the Mississippi drainage system. A part only, and apparently an unimportant part, of those subordinate types that existed during the Laramie period appear to have become extinct.

In tracing the evolutional history of any family of mollusca we should, in a general way at least, expect to find that the simplest forms were the first to appear in the order of time; and although simplicity of form of the shell is not by any means a necessary correlative of simplicity of structure in the mollusk which produced it, we nevertheless naturally inquire whether the simple shells of *Anodonta* did not precede in geological time the more complicated shells of *Unio*. This may or may not have been the case; for the difference in actual zoölogical rank between the two genera is at best measured only in part by the differences in the shells of each genus.

If, however, Professor Hall's suggestion is correct, that the two Devonian forms that have already been referred to, belong to the genus *Anodonta;* and if Dr. Dawson is correct in referring his Carboniferous genus *Naiadites* to the Unionidæ, the evidence seems to be strongly in favor of the opinion that *Unio* was actually preceded in geological time by *Anodonta* and other edentulous Unionidæ.

On the other hand, if those two Devonian species are rejected as not being members of the Unionidæ, the earliest species of *Anodonta* that are yet known in North American strata have been obtained from the Laramie Group, although, as we have seen, diverse and characteristic forms of true *Unio* existed as early at least as the Jurassic period; and *Margaritana* appears also to have existed in the earliest epoch of the known North American Cretaceous.

One of the two species of *Anodonta*, which have been discovered in the Laramie Group, namely, *A. propatoris* White, from the Judith River beds of the Upper Missouri River region,* is represented on Plate 19. In form and general aspect it is exceedingly like certain species which are now living in North American waters. The example represented by Figs. 7 and 8, on Plate 19, is not of fully adult size, as is shown by an accompanying figure of another, but less perfect example; but it serves to illustrate the form of the species with considerable accuracy. Fragments found associated with them show the characteristic edentulous hinge of *Anodonta*, one of which is represented on that plate. Indeed there can be no reasonable doubt that both *Unio* and *Anodonta* have come down from at least the close of Mesozoic time, wholly unchanged, not in generic characters only, but in those characteristics also which separate subordinate types within those genera from each other.

The other Laramie species of *Anodonta*, namely, *A. parallela* White,† was obtained from the valley of Crow Creek, Northern Colorado; but only fragments of the shell have yet been discovered, Fig. 5, on Plate 19, being a restoration of the form, which has been prepared by aid of those fragments. It is an unusually elongate form, but it is apparently a true *Anodonta*.

At the present time lacustrine waters appear to form a more congenial habitat for *Anodonta* than fluvatile waters do, although various species of that genus occur in both; but notwithstanding this fact, no specimens of *Anodonta* have been discovered in any of the great lacustrine deposits of Tertiary age which succeeded those of the Laramie Sea in Western North America, although several species of true *Unio*, as well as other fresh-water molluscan forms, are frequently found in those deposits. Notwithstanding the fact that so few of the remains of *Anodonta* have been discovered, it cannot be doubted that it was continuously represented by different species from at least as early a period as the Laramie down to the present time.‡

Returning again to the genus *Unio*, we find it remarkably well represented in the strata of the Laramie Group and those of the immediately succeeding fresh-water Eocene Tertiary groups.

That division of the Laramie Group which is known as the Bear River

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*An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 62, pl. 24, fig. 2.

† An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 62, pl. 24, fig. 3.

‡See reference to *Anodonta decurtata*, Conrad, under the head of spurious and doubtful species.

beds, and which is better known in Southwestern Wyoming and the adjacent parts of Utah than elsewhere, is probably somewhat earlier in its origin than those divisions of the group which occur in other portions of that great western region.* Therefore the two species of *Unio* which those strata have furnished may be properly first considered.

One of these species, which is represented on Plate 6, is interesting as the type of what was regarded by Mr. Meek, who described the species under the name of *Unio belliplicatus*,† as a distinct subordinate type of *Unio*, to which he subsequently gave the subgeneric name of *Loxopleurus*.‡ As this species has the true hinge structure, pallial and muscular markings, and ordinary external form of *Unio*, its assumed type characteristics consist only of its peculiar style of surface plication. It may well be questioned whether this feature is sufficient to base a subgeneric distinction upon, especially as the bent plications seem to consist essentially of a blending of small concentric folds, which are developed only near the beaks, with radiating folds, both of which are respectively found upon various other species of *Unio*.

The other species which has been referred to as occurring in the Bear River Laramie beds, and with which *U. belliplicatus* is usually associated, is *Unio vetustus* Meek,§ which is figured upon Plate 7. This species has an external form somewhat similar to that of *U. belliplicatus*, but its surface is plain, except that a few more or less distinct concentric wrinkles are usually observable upon the beaks; and sometimes one or two faint radiating raised lines appear upon each side of the postero-dorsal portion. Both species have all the characteristics of true *Unio* well developed, and both have the front shorter than is usual among living species of that genus which have a like transversely oval outline. In the latter feature they agree with other fossil species, which are presently to be noticed.

Those strata belonging to the great Laramie group, which are somewhat extensively developed in the Upper Missiouri River region, and which have become generally known as the Judith River beds, have furnished a considerable number of species of *Unio*, besides one species of *Anodonta*, which has already been mentioned.

All the species of *Unio* noticed in this article, especially those of the Laramie and fresh-water Eocene groups, may be divided into several natural sections, each section representing a subordinate type of *Unio*, which, with one doubtful exception presently to be noticed, has repre-

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* This suggestion that the Bear River beds are older than the other portions of the Laramie Group is not made with entire confidence. It is based wholly upon the greater dissimilarity that appears between the fauna of the former than that of the latter when both are compared with living mollusca. This dissimilarity may, of course, be due to other causes than the supposed greater length of time since the existence of the Bear River fauna than has passed since that of the other portions of the Laramie group was living.

† Geol. Sur. 40th Parallel, Vol. iv, p. 165, pl. xvi, fig. 4.

‡ See U. S. Geol. Sur. Terr., Vol. ix, p. 515.

§ Geol. Sur. 40th Parallel, Vol. iv, p. 164, pl. XVI, fig. 5.

sentatives now living in the waters of the Mississippi drainage system. These types of living Uniones, which have such well-defined representatives among the fossil species of the Laramie Group, are among those which, being characteristic of the molluscan fauna of the Mississippi drainage system, have come to be generally known as "North American types of Unio." So unmistakable is their relationship that no reasonable doubt can be entertained that the fossil, represent the living forms ancestrally.

In only one particular, if we except the peculiar plication of *U. belliplicatus*, do any of the fossil species of *Unio* of Laramie or Tertiary age assume a characteristic which is either not present or not clearly recognizable in any living species among North American Uniones. This excepted characteristic consists in the extreme shortening of the shell in front of the beaks in certain of the species which have also a considerable transverse elongation and an approximately oval outline; that is, instead of having the beaks situated near, or only a little in advance of, the mid-length of the dorsal border, as they are in all the living oval and some of the shorter forms, the beaks in the case of the fossil forms in question are placed very near to the front. Short forms of *Unio*, of living as well as fossil species, have their beaks placed thus far forward, but attention is called to the fact that it is only in the fossil species that this peculiarity has been observed in connection with such shells as are much elongated transversely. A living species, which perhaps more nearly than any other approaches in this respect the fossil species referred to, is *U. clavus* Lamarck, which is a common shell in the Ohio River and its tributaries. But this species is, in reality, only one of the short subtriangular forms, which is a little more than usually elongate.

The *Unio subspatulatus* of Meek & Hayden,* from the Judith River beds, which is illustrated on Plate 14, may be taken as an example of an elongate shell with a shortened front, such as has been referred to. In this case, however, there is an unusual narrowing of the shell posteriorly.

Associated with *U. subspatulatus*, and closely related to it, is another form which was described by the same authors under the name of *Unio danæ*,† and which is represented on Plate 17. This species has also been somewhat doubtfully identified in the Laramie strata of Southern Wyoming, further mention of which fact is made on a following page

Two other species have been obtained from the Judith River beds, namely, *Unio deweyanus* Meek & Hayden,‡ and *U. cryptorhynchus* White,§ both of which possess the shortened front in connection with a transversely oval outline, which features have already been discussed.

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* U. S. Geol. Sur. Terr., vol. ix, p. 518, pl. 41, fig. 1.

† U. S. Geol. Sur. Terr., vol. ix, p. 517, pl. 41, fig. 3.

‡ U. S. Geol. Sur. Terr., vol. ix, p. 519, pl. 41, fig. 2.

§ An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 68, pl. 24, fig. 1.

These two species are represented on Plates 17 and 14 respectively. Some imperfect specimens of a form that seems to be specifically identical with *U. cryptorhynchus* have also been discovered in the Laramie strata at Black Buttes station. The correctness of this identification is rendered the more probable, because of similar identification of other molluscan species in both regions, one of which has already been mentioned.

Of the Uniones that are yet known from the Judith River beds, two species remain to be noticed namely, *U. primævus* and *U. senectus* White,* which are represented on plates 14 and 19 respectively.

These two species differ much in external form, but both are marked by small rugose plications upon the postero-dorsal portion of the surface, a feature which is not unusual among living North American species of Unio, but which is possessed by few of the known fossil species.

The aspect of these shells is so suggestive of certain features presented by some of the living forms of *Unio* just referred to, that it is only their fossilized condition which at first view conveys to the mind an impression of their great antiquity.

One other species, *Unio priscus* Meek & Hayden,† has also been obtained from the Laramie strata of the Upper Missouri River region; but this one is from the Fort Union beds which occur in a part of that great region which lies far to the eastward of that in which the Judith River beds are found. This species is of an ordinary oval outline, with a moderately short front, but without any noteworthy peculiarities. It is represented on Plate 14 by a copy of Mr. Meek's original figure.

In a single stratum of the Laramie Group at Black Buttes station, in Southern Wyoming, nearly a dozen species of *Unio* have been found, among which are some of the most interesting fossil forms of that genus that have ever been discovered. Some of these species have the peculiarly shortened front, together with a transversely oval form, of which mention has already been made; but in their general characteristics others of them are peculiarly like certain forms that are now living in the waters of the Mississippi drainage system.

Among these species from the Black Buttes locality is *Unio couesii*, White,‡ the largest species of that genus which has ever been found in North American strata. It is represented on Plate 16. Its large size, massive test, and general aspect strongly recall certain of the large Uniones that are found living in the waters of the Wabash and other rivers of the Mississippi drainage system.

Associated with *U. couesii* is another species, which is nearly as large, but of different form, namely, *U. endlichi* White, § which is represented on Plate 15.

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* An. Rep. Sur. Terr. for 1878, Part I, pp. 69, 70, pl. 29, fig. 3, and pl. 28, fig. 1.

† U. S. Geol. Sur. Terr., vol. ix, p. 516, pl. 43, fig. 8.

‡ An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 64, pl. 27, fig. 1.

§ An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 66, pl. 26, fig. 1.

The shells of both these large species are strong and massive, and both have strong and well developed cardinal and lateral teeth, such as are observable upon the shells of the large living river Uniones.

The other species of *Unio* that have been obtained from the Black Buttes locality have all been described by me under the following names respectively: *Unio propheticus*, *U. brachyopisthus*, *U. proavitus*, *U. aldrichi*, *U. goniambonatus*, *U. holmesianus*, and a form which I have doubtfully referred to the *U. danæ* of Meek & Hayden * has also been obtained there. These seven species are represented by appropriate figures upon Plates 13, 15, 16, and 19. They cannot fail to be especially interesting to those who are familiar with the Unione fauna of the Mississippi drainage system.

The form which is represented by figures 1 and 2, on Plate 18, has already been referred to as having been doubtfully identified with *Unio danæ*, the type specimens of which species were obtained by Meek & Hayden from the Judith River beds of the Upper Missouri River region. It is not improbable that further comparison will make it necessary to regard the Black Buttes form as a distinct species.

In some respects, at least, the most interesting of these fossil species of *Unio* is *U. holmesianus* White. It is especially noteworthy as indicating, in connection with its associates, the wide diversity of subordinate types that the genus *Unio* had attained in the Laramie period, and also as affording a fine fossil example of one of the most characteristic subordinate types of *Unio* that are now peculiar to North American fluvatile waters.

Unio gonionotus White† is illustrated on Plate 13. It was discovered, by Professor Powell, in the Laramie strata of Southern Utah, where alone any specimens of the species have yet been found. It is an interesting form, especially because of the strong plications which it bears, and which are similar to those that characterize various living species, and also because it possesses the excessively shortened front which has before been noticed as characterizing other fossil Uniones.

Only one other species of *Unio*, which is referred to the Laramie Group, remains to be noticed by name in this article; but, judging from various fragments that have been found at different localities, it is quite certain that several, perhaps many, other species exist there. Indeed, the known wide diversity of type that the genus *Unio* had attained during the Laramie period seems necessarily to imply that a greater number of specific forms then existed than have yet been discovered.

The species last referred to, and which is illustrated on Plate 18, I have described under the name of *Unio mendax*.‡ Specimens of it

* For original descriptions and figures of these seven forms see An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 62–68, pl. 22, 26, 27, and 29.

† An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 71, pl. 26, fig. 2.

‡ Bull. U. S. Geol. Sur. Terr., vol. iii, p. 605.

have been collected, by Professor Powell, from certain strata in the Cañon of Desolation, and others, by one of the parties under Lieutenant Wheeler, from the coal-bearing strata at Wales, Utah, all of which probably belong to the upper portion of the Laramie Group. The specimens obtained at Wales were erroneously referred by me to *U. vetustus* Meek,* which species *U. mendax* resembles in certain particulars.

In the Eocene fresh-water deposits, which immediately succeeded the Laramie, several species of *Unio* have been found; and it is a noteworthy fact that while there was great diversity of form and considerable diversity of surface ornamentation among the species of *Unio* that existed in the Laramie period, all the species of that genus which have yet been found in the purely fresh-water Eocene deposits have a transversely oval form and plain surface; that is, there are among the latter no short forms, like several of those of the Laramie Group and many among living species, and none of them have the surface marked by plications, rugæ, or pustules; nor are they marked in any other manner except by the ordinary concentric lines of growth. Most of these oval shells also have the beaks placed at least a moderate distance from the front, as is usual in the case of living species of oval form; but one of them at least possesses a shortened front, like that of several of the Uniones of the Laramie Group which have already been noticed.

The species referred to is *Unio clinopisthus* White, which is described and figured for the first time, as follows: *Unio clinopisthus* (sp. nov.), Plate 28, Figs. 1 and 2. Shell transversely elongate, short in front of the beaks, elongate and narrowing behind them to the posterior end; basal margin having a gentle sinuosity, there being a slight emargination just behind the midlength; front margin regularly rounded; dorsal margin proper rather short; postero-dorsal margin forming a long, convex, downward slope from the dorsal to the postero-basal margin, which latter margin is narrowly rounded; beaks depressed and placed near the front of the shell. A somewhat prominent, but not sharply defined, umbonal ridge extends from the beak of each valve to the postero-basal margin, giving a flattened space at the postero-dorsal portion of each valve. Surface marked only by concentric lines of growth.

Length, 63 millimeters; height, 30 millimeters; thickness, both valves together, 23 millimeters.

This species was collected by Dr. Hayden from the fresh-water Eocene strata, near Washakie Station, in Southern Wyoming.

Another species, quite a large one, to which I have given the name of *Unio Meekii*, changing it from *U. leai* Meek, which name was preoccupied, was obtained by Dr. Hayden from the Bridger Group of Southern Wyoming. This form is yet known only by fragments and natural casts of the interior; but it is known to have been a large, plain shell

*Expl. and Sur. West of the 100th Merid., vol. iv, p. 206, pl. XXII, fig. 12, a, b, c, and d.

of transversely oval outline, and having the anterior portion rather short in front of the beaks.*

The remaining three species of *Unio* yet to be noticed are all of the simple elongate, or transversely oval form, so common among living representatives of the genus.

The first is *U. shoshonensis* White,† which is figured on Plate 28. Specimens of it have been found at various localities in Southern Wyoming and the adjacent parts of Colorado and Utah, in the Wahsatch Group of fresh-water Eocene strata there.

The next is *U. washakiensis* Meek,‡ which is figured on Plate 28, and which has a similar geographical range and geological position. It seems also to range upward into the Bridger Group.

The third and last is *U. haydeni* Meek,§ which is represented on Plate 28. This species closely resembles *U. shoshonensis* in external form, but it is a thinner and more delicate shell, with a more slender hinge. It also comes from a different group of strata. It is not improbable that *U. haydeni* is identical with the species that was described by Hall under the name of *Mya tellinoides*.‖ For purposes of comparison Professor Hall's principal figure of that form is copied on Plate 28.

Although there are fresh-water deposits of considerable extent in Western North America of later date than the Eocene Tertiary epoch which have furnished numerous vertebrate, and a few molluscan remains, no Uniones, and only a few other bivalve species, which are referred to *Sphærium*, have been found in any of them. In a few instances, some Uniones have been discovered in certain Post-Tertiary deposits, but as they have all been referred to living species, they do not come within the scope of this article.¶

CYRENIDÆ.

The geological history of the Cyrenidæ of North America, as it is at present known, begins with the earliest epoch of the Cretaceous; but it was no doubt actually introduced much earlier.

The family has apparently never formed a very prominent feature of any molluscan fauna, either marine or non-marine, in any of the geological periods, except that of the Laramie, since its introduction. In this period there was so extraordinary a development of the genus *Cor-*

* This species is described, and a cast of one valve figured in An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 43, pl. 19, fig. 1. Owing to the imperfection of all the specimens of this species that have yet been discovered, no figure of it is given in this article.

† An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 41, pl. 19, fig. 2.

‡ An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 42, pl. 19, fig. 3.

§ Simpson's Report Great Basin of Utah, p. 364, pl. 5, fig. 11.

‖ Fremont's Rep. Oregon and N. California, p. 307, pl. iii, figs. 1 and 2.

¶ For an interesting discovery of this kind, by Prof. John Collett, in Indiana, see 7th An. Report Geol. Sur. Indiana, p. 246. See also, on a following page, remarks on spurious and doubtful species.

bicula as to give an impression to the casual observer that the family then reached a culmination, but it was in reality a culmination of the genus *Corbicula* only.

In the Cretaceous strata of the western part of the continent several species belonging to the Cyrenidæ have been discovered, all of which are referred to the genus *Cyrena* as distinguished from *Corbicula*.* Only two of these species, however, are regarded as coming within the scope of this article, because all the others are found to be associated with such forms as are regarded as indicating a marine habitat, while those two species are associated with non-marine forms. Although in the Cretacious period the genus *Cyrena* was established with all its distinctive characteristics, as they are at present known, and was represented by several known species in the southern portion of North America, with one or two exceptions the genus has not been recognized in strata of any geological period since the Cretaceous.

And again, although the genus *Corbicula* formed so conspicuous a feature of the fauna of the Laramie period, it is at present not known to occur in any North American strata of either earlier or later date than that period; if we except the *C. truncata* of Prime, which is understood to be of doubtful authenticity. These facts are significant as regards the genetic history of the family, and show, among other things, that our knowledge of that history is far from complete.

The earlier of the two non-marine fossil species of *Cyrena* that have just been referred to, is *C. dakotensis* Meek & Hayden,† which has already been mentioned on a previous page as an associate of *Margaritana nebrascensis* in strata of the Dakota Group in Southeastern Dakota. It is represented on Plate 4 by copies of Mr. Meek's original figures.

The other species is *Cyrena carletoni* Meek,‡ which is represented on Plate 5, and which was discovered by Mr. Meek in the Cretaceous estuary deposit at Coalville, Utah, which has already been mentioned in connection with remarks upon *Anomia propatoris*. The only examples of this species that have been discovered are small and delicate, and it is probable that they are all young shells.

Although the family Cyrenidæ has evidently become well established in the estuary and marine waters of the Cretaceous period, at least by its typical genus *Cyrena*, it is in the strata of the Laramie Group, as before stated, that we find evidence of its greatest development, especially as regards the genus *Corbicula*. Among the fossil forms of that genus which the Laramie Group has furnished, three sections or subgenera are recognized, two of which have become extinct.

Beginning with the Bear River beds of the Laramie Group, which are perhaps somewhat earlier than the other known portions of the group,

* For remarks on these genera, by Mr. Meek, see U. S. Geol. Sur. Terr., vol. ix, p. 157.

† U. S. Geol. Sur. Terr., vol. ix, p. 159, pl. I, fig. 1.

‡ An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 20, pl. 12, fig. 16.

we find in Southwestern Wyoming, and the adjacent parts of Utah, one species of *Corbicula* which is interesting as being the type of a section of that genus for which Mr. Meek proposed the subgeneric name of *Veloritina.** This species, which he described under the name of *Corbicula (Veloritina) durkeei,*† is represented on Plate 8.

Two species of *Corbicula* were described by Meek & Hayden from the Judith River beds of the Upper Missouri River region, under the names respectively of *C. cytheriformis* and *C. occidentalis,*‡ which are represented on Plates 22 and 23 respectively. The first-named species is referred to the typical section of the genus; but the latter approaches in form the type of the subgenus *Veloritina.* Both these species have also been obtained from Laramie strata of Bitter Creek Valley in Southern Wyoming.

The form which was described by Meek from that region, under the name of *C. bannisteri,* is regarded as identical with *C. occidentalis.*§ This form is represented on Plate 17.

Two other Laramie species of *Corbicula* were described by Meek & Hayden, from the Upper Missouri River region, both of which are, however, from the Fort Union beds. They are respectively *C. nebrascensis* and *C. subelliptica,* both of which are represented on Plate 20. The latter has been recognized in the Laramie strata of Colorado east of the Rocky Mountains. It was referred by Mr. Meek to his subgenus *Leptesthes.*‖

It seems not improbable that *C. nebrascensis* is only a young example of *C. cytheriformis,* but as that question is not yet settled, the former is here treated as a distinct species as well as the latter.

The Laramie strata east of the Rocky Mountains in Colorado, which were by Dr. Hayden designated as the Lignitic Group, have been found in several localities to be especially rich in *Corbicula.* A part of these species are referable to the typical section of the genus and a part to the subgenus *Leptesthes.* To the latter subgenus belong *C. subelliptica* Meek & Hayden, *C. macropistha* White, *C. planumbona* Meek, and *C. cardiniæformis* White;¶ all of which are figured on Plates 21 and 22.

Since the last-named form was published numerous other examples have been discovered which make it probable that it should be regarded as a variety of *C. fracta* Meek.

Other published species found in the valley of South Platte, and its tributaries in Colorado, are *C. cleburni* and *C. obesa* White,** which are figured on Plates 20 and 23 respectively.

* See U. S. Geol. Sur. Terr., Vol. ix, p. 161, for a diagnosis of this subgenus.

† U. S. Geol. Sur. 40th parallel, vol. iv, p. 167, pl. lvi, fig. 6.

‡ U. S. Geol. Terr., vol. ix, pp. 520, 521, pl. 40, figs. 5 and 6. Also, An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 74, 75, pl. 21.

§ See An. Rep. U. S. Geol. Sur. Ter. for 1878, Part I, p. 75.

‖ For diagnosis of this subgenus, see U. S. Geol. Sur. Terr., vol. ix., p. 161.

¶ These species are described and figured in the An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I. References are also given there to original descriptions.

** See An. Rep. U. S. Geol. Sur. Terr. for 1878, part I, pp. 73, 73, pl. 23.

In addition to the six species last-mentioned, the three which are described in the following paragraphs for the first time, have been discovered in the Laramie strata of South Platte Valey, Colorado, since the former were published.

Corbicula berthoudi (sp. nov.), Plate 21, figs. 1, 2, and 3.—Shell very large, subtrigonal in marginal outline, moderately gibbous; front concave immediately in front of the beaks; front margin regularly rounded; basal margin broadly rounded; postero-basal margin abruptly rounded up to the postero-dorsal margin, which latter margin slopes obliquely downward with a gentle convexity from between the beaks; hinge strong; all the teeth well developed, the lateral ones especially being long and large and crenulated upon their edges, as is usual with all the known species of *Corbicula* of the Laramie Group; muscular and pallial impressions having the usual characteristics; surface marked with the usual concentric lines.

Length of one of the largest examples in the collections, 62 millimeters; height from base to umbo, 54 millimeters; thickness, both valves together, 44 millimeters.

This fine large species, the largest yet known in North America, has been found only in the Laramie strata east of the Rocky Mountains in Colorado. It is named in honor of Capt. E. L. Berthoud, the first discoverer of the rich shell deposits of the Laramie Group in that region.

Corbicula augheyi (sp. nov.), Plate 21, figs. 4, 5, and 6.—Shell moderately large, sub-tetrahedral in marginal outline, postero-dorsal region not flattened, as in *C. berthoudi;* umbones full, rounded, considerably elevated above the hinge-line, front regularly rounded; basal margin broadly convex; posterior end truncated, the direction of the truncated margin usually a little backward of a line drawn perpendicularly with the base of the shell; postero-dorsal margin a little convex; hinge well developed; muscular and pallial markings of the usual character; surface marked by the usual concentric lines of growth, and usually by very faint umbonal ridges extending from the umbo to the postero-dorsal and postero-basal margins respectively upon each valve.

Length of an adult example, 46 millimeters; height from base to umbones, 38 millimeters; thickness, both valves together, 30 millimeters.

This species has yet been found only in the valley of South Platte River, in Northern Colorado, east of the Rocky Mountains. It is named in honor of Prof. Samuel Aughey, of Nebraska State University, who assisted me in the collection of the type specimens.

*Corbicula umbonella** Meek; Plate 21, Figs. 7, 8, 9, and 10.—Shell resembling *C. obesa* White, in most respects, but it is proportionally longer, the umbones are fuller and more elevated, and upon the posterior portion there are upon each valve two or three indistinct radiating rugæ. Upon other parts the surface is more than usually smooth.

*See Bull. U. S. Geol. Sur. Terr., Sec. Ser., No. 1, p. 44, where this species is named but not described.

Length, 39 millimeters; height from base to umbones, 34 millimeters; thickness, both valves together, 26 millimeters.

The large series of examples of all the described species of *Corbicula* that have been obtained from the Laramie strata east of the Rocky Mountains in Colorado give unmistakable indications of genetic relationship between them. It has already been stated that *C. cardiniæformis* is perhaps only a variety of *C. fracta;* and it may be remarked that *C. obesa*, *C. umbonella*, and *C. augheyi* hold similar relations to each other. It is not unlikely that when all the Corbiculæ of the Laramie Group come to be fully studied, some of the species heretofore described must be abandoned; but in an article like this, it is thought best to make mention of, and to figure, all the forms that have been published by any author, as he has published them.

The species which Mr. Meek adopted as the type of his subgenus *Leptesthes*, namely, *C. (L.) fracta** Meek, has been found in considerable abundance at Black Buttes station, in Southern Wyoming, and sparingly also at other localities on both sides of the Rocky Mountains. It is figured on Plate 20.

This is the largest species of the subgenus *Leptesthes* yet known, and with the exception of *C. berthoudi*, herein described, the largest species of *Corbicula* that has ever been discovered in North American strata. The figures that are here given show it to be a very variable species as regards external form. Fig. 1, on Plate 20, is a copy of Mr. Meek's drawing from his type specimen. The partial truncation of the posterior border is a slight deformity of that specimen, and is not common to the species. The dimensions of that figure are also somewhat less than the average for adult shells. Figs. 4 and 5, on Plate 20, represent two views of a young example of ordinary form, but some examples of this species are more elongate transversely.

No examples of the genus *Sphærium* have been found in any North American strata of older date than the Laramie Group, and none have been published from that group except the four species which were obtained by Meek & Hayden from the Upper Missouri River region, and described by them respectively under the names *Sphærium planum*, *S. recticardinale*, *S. formosum*, and *S. subellipticum*.† These four species are all represented on Plate 17 by copies of Mr. Meek's original figures. The two first-named species are from the Judith River beds, and the other two from the Fort Union beds. Some fragments of a species of *Sphærium*, which is perhaps different from either of the four species above referred to, have been discovered in the coal-bearing beds at Evanston, Wyoming, which beds seem to belong to the upper part of the Laramie Group.

A few imperfect examples, too imperfect for specific characterization, but evidently belonging to one or more species of the genus *Sphærium*,

* See U. S, Geol. Sur. Terr., vol. ix, p. 161.

† See U. S. Geol. Sur. Terr., vol. ix, pp. 526, 527, pl. 43.

have been found in the Eocene fresh-water deposits of Southern Wyoming, which are, like those of the Laramie Group, so similar to certain living species as to call for no distinguishing remarks.

We yet know nothing of the existence of *Sphærium* in North America between the close of the Eocene epoch and the Post-Tertiary except the two species which were respectively described by Meek under the names *Sphærium rugosum* and *S. idahoense*, both of which are represented on Plate 32 by copies of his original figures. The types of these two species were obtained from the fresh-water deposit of the Kawsoh Mountains of Northern Nevada, which is regarded as of Miocene age by parties connected with the United States Geological Survey of the 40th parallel.* We do not yet know even so much as this of the history of the Unionidæ between the close of the Eocene epoch and the beginning of the Post-Tertiary; † yet we cannot doubt that both *Unio* and *Sphærium* flourished together somewhere during all that time.

PISIDIIDÆ.

Of the genus *Pisidium*, only one fossil species, namely *P. saginatum* White, has yet been discovered.‡ Its form is represented by figures 14 and 15, on Plate 20, and it is by its outward features alone that it is referred to *Pisidium*, the interior markings of the shell having never been ascertained. It was obtained from the series of coal-bearing strata near Evanston, Wyoming, which are at present understood as belonging to the upper part of the Laramie Group.

While it seems to be unquestionable that the living Unionidæ of the Mississippi drainage system are generically descended from those species which, as we have seen, existed during the Laramie period, and from their associates which yet remain to be discovered, no descendants of the Cyrenidæ which then existed seem to have survived the close of the Laramie period, except those of the genera *Sphærium* and *Pisidium*. In fact, all three of the sections of the genus *Corbicula*, which have been mentioned as having lived during the Laramie period, seem to have required the same conditions of habitat that the contemporaneous *Ostrea* and *Anomia* did. When, therefore, at the close of the Laramie period, the waters of the interior region of North America became entirely fresh, all the forms of *Corbicula* which had flourished throughout that great region ceased to exist; while *Sphærium* and *Pisidium*, whose habitat is in fresh water only, survived to the present time, doubtless in company with representatives of the Unionidæ, and with many freshwater gasteropods. This opinion of course implies not only the belief that while the living Uniones of the Mississippi drainage system are, either wholly or in part, directly descended from those whose remains

* U. S. Geol. Sur. 40th parallel, vol. iv, pp. 182, 183, pl. xvi, figs. 1 and 2.

† That is, if we omit all those which are mentioned on following pages under the head of spurious and doubtful species.

‡ Powell's Report Geology of the Uinta Mountains, p. 128.

we find in the strata of the Laramie Group, but also the belief that the brackish water Cyrenidæ which existed contemporaneously with them in the Laramie period are not thus ancestrally related to the living species of *Cyrena* and *Corbicula* of North America, but that the latter have come down by some other lines of descent which are not yet known.

CORBULIDÆ.

The genus *Corbula* is represented by several species in the Cretaceous strata of North America; but all the species that are yet known from strata of that period are found associated with marine forms; and, as they no doubt lived in marine waters, they do not fall within the scope of this article. Three or four species are known to have lived during the Laramie period, the faunal associates of which indicate a brackish water habitat; and as no other fossil species of this genus have been discovered under such circumstances as to make it probable that they lived in other than marine waters, we shall have only those Laramie forms to discuss at the present time.

Nine species of *Corbula* have been described and named by different authors, from strata which have been studied at different localities, all of which strata are now referred to the Laramie Group; but at present I am disposed to regard less than half of them as distinct species, the remainder being regarded as at least no more than varieties of those species, respectively.

Mr. Meek regarded all the Laramie species of *Corbula* as not belonging to the typical section of the genus; and he referred one of them to the proposed subgenus *Anisorhynchus* of Conrad, and the others to *Pachyodon* Gabb. In this article, however, I shall treat all the species herein discussed as true *Corbula*, without expressing an opinion as to the sections of the genus proposed by Conrad and Gabb; but it is proper to call attention to the fact that the first two mentioned of the following species present a facies or type which is quite different from that of any living North American species of *Corbula*. Indeed, we may regard these Laramie forms as representing extinct lines of descent, for it is practically certain that the line of descent of none of the living species of *Corbula* has come down through any of those of the Laramie period as represented by the strata which we now know as the Laramie Group.

The reasons for this opinion are expressed in the remarks that have been made in relation to the Cyrenidæ of the Laramie Group, and the subject is further discussed in the remarks which close this article.

Since the Bear River beds are hypothetically regarded as the earlier portion of the Laramie Group, the first of the species of *Corbula* to be mentioned is *C. pyriformis* Meek,* which has been found only in those beds, and their equivalents in Southwestern Wyoming and the adjacent

* See Simpson's Rep. Great Basin Utah, p. 361, pl. v, figs. 9 and 10. Also U. S. Geol. Sur. 40th Parallel, vol. iv, p. 170, pl. xvii, fig. 2.

parts of Utah. It is represented on Plate 8. Mr. Meek described another form in connection with this under the name of *C. englemanni*, but the numerous examples that have been collected from those strata show such a degree of variation as to make it very doubtful whether the difference between the two forms is anything more than individual variation. *C. englemanni* is therefore regarded as a synonym of *C. pyriformis*.

An interesting species, which occurs in the valleys of Bitter Creek, Southern Wyoming, and Yampa River, Northwestern Colorado, was described by Mr. Meek under the name of *Corbula undifera*, which is illustrated on Plate 18. A variety of this species, which also occurs in the valley of Bitter Creek, but at a higher horizon in the Laramie Group by several hundred feet, was described by me under the name of *C. subundifera*.* Although the latter is now regarded as only a variety of the former, yet the variation is quite constant and readily recognizable, as may be seen by comparing the figures of the variety with those of the typical form on Plate 18.

Two species were described by Meek & Hayden from the Judith River beds of the Upper Missouri River region, under the names respectively of *Corbula subtrigonalis* and *C. perundata*, both of which I regard as belonging to one and the same species. Furthermore, the two species which were described by Meek from the Laramie strata of the valley of Bitter Creek, Southern Wyoming, under the names respectively of *C. tropidophora* and *C. crassatelliformis*, I regard as also belonging to that species, making three synonyms of *C. subtrigonalis*.† Figures of these forms may be seen on Plate 19.

One other published form of *Corbula* only remains to be noticed in this article, namely, *C. mactriformis*,‡ which was described by Meek & Hayden from the Fort Union beds of the Upper Missouri River region, and which has hitherto been found nowhere else. It is represented on Plate 18.

The non-marine bivalve mollusca that have been noticed on the preceding pages comprise only six families, while, as we shall see, their associated gasteropod families were more than double that number. This numerical proportion of the families pertaining to the Conchifera and Gasteropoda, respectively, may be taken as about the same as that which obtains in those two classes among living non-marine mollusca. Indeed, the families which have been recognized among these fossil forms are no other than those under which we group their living representatives.

* For descriptions and figures of both these forms see An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 80, 81, pl. 29.

† For descriptions and figures of these forms and remarks upon them see U. S. Geol. Sur. Terr., vol. ix, pp. 529, 530, pl. 40; An. Rep. U. S. Geol. Sur. Terr. for 1870, p. 315; *ib.* for 1872, p. 514; *ib.* for 1878, Part I, pp. 80, 81, pl. 25.

‡ U. S. Geol. Sur. Terr., vol. ix, p. 528, pl. 42, fig. 7.

Moreover, the majority of the genera, and many of the subordinate divisions of those genera, possess no recognizable variation from those under which we are accustomed to range the living species. We have, however, seen that a small number of those subordinate types among the Conchifers have become extinct; and we shall see that still more of them among the Gasteropoda, together with a few of that class that we regard as full genera, have also become extinct; but yet the fact remains that these ancient non-marine mollusca, as a whole, are wonderfully like their living representatives.*

GASTEROPODA.

Although, in zoölogical rank, the gasteropoda are so much in advance of the Conchifera, the various families of the former seem to have been developed as early in geological time as those of the latter; and so far as we are now acquainted with the history of the fossil non-marine mollusca of North America, it appears that highly organized land pulmonate gasteropods were introduced quite as early as any of the Conchifers. Indeed, from present indications, we are led to believe that the relations of the different classes of non-marine mollusca to each other were much the same in all geological epochs as they are to-day.

AURICULIDÆ.

Three or four species of gasteropods have been discovered in the Cretaceous estuary deposits, and those of Bear River, Laramie series, which are regarded as belonging to the family Auriculidæ; and these are the only members of that family which have been discovered in North American strata, and the only ones that come within the scope of this article.

One of these species was discovered by Mr. Meek in the Cretaceous estuary deposit at Coalville, Utah,† which has already been mentioned

* There have been found in the Laramie Group two Conchifers and one Gasteropod, which, so far as is now known, have living allies only in marine waters, and they are therefore not enumerated in this article, although they seem to have survived in the brackish water Laramie Sea from the time when it was an open sea of marine saltness. They are respectively *Nuculana inclara*, *Axinæa holmesiana* and *Odontobasis buccinoides* White. With these exceptions, all the known molluscan species of the Laramie Group are such as we should naturally refer to some non-marine habitat. It is not at all improbable that these species of genera which are usually characteristic of open-sea waters survived the land-locking of the Laramie Sea, and did not yield up their existence until the complete freshening of the waters took place, when their associates *Corbicula*, *Corbula*, *Neritina*, &c., also ceased to exist. The species which was described by me as *Odontobasis? formosa* probably belongs to some genus of the Ceriphasiidæ. For remarks upon the species referred to in this note, with descriptions and figures, see An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 59, 60, 102, and 103; plates 20, 25, and 28.

† An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 23, pl. 12, fig. 11.

in connection with *Anomia propatoris* and *Cyrena carletoni.* It was originally described by Meek under the name of *Melampus? antiquus*, but it is quite certain that it does not strictly belong to that genus. It is illustrated by several figures on Plate 5.

An imperfect example of a similar and apparently congeneric form, which is represented by Fig. 17 on Plate 5 was found in the same neighborhood among the remains of marine Cretaceous mollusca, as was also an imperfect example of *Physa;* both of which specimens were no doubt drifted from the then adjacent shore, and sunk among the shells of marine mollusks that then lived there.*

In the Bear River Laramie beds in Southwestern Wyoming there have been found two species closely related to the two that are referred to *Melampus?*, which, from their characteristics as well as their brackish-water faunal associations are referred to the Auriculidæ. They have considerable resemblance to *Melampus? antiquus*, and are possibly congeneric with it; but Mr. Meek proposed for them the generic name of *Rhytophorus.*†

The first of these two species was discovered by Mr. Meek, and described by him under the name of *Rhytophorus priscus*;‡ and the second was described by myself under the name of *R. meekii.*§ Both these forms are illustrated by figures on Plate 8.

These three or four species constitute the only representatives of the Auriculidæ that have yet been obtained from North American non-marine strata, and they are so remotely allied with living representatives of that family that we cannot regard them as holding such ancestral relation to any of the living North American Auriculidæ as the fossil Unionidæ and some other families herein discussed, evidently hold to the living representatives of those families respectively. Indeed, for reasons already stated, it is practically certain that the lines of descent from such of the mollusca of the Laramie period as required a saline habitat were necessarily broken at the close of that period, when the waters of that sea became wholly fresh and greatly reduced in extent.

LIMNÆIDÆ.

The earliest North American strata in which remains of the Limnæidæ have been discovered are those of the Laramie Group; if we except the Jurassic form, which was described by Meek & Hayden under the name of *Planorbis veternus*, and which is presently to be further mentioned. In the Laramie Group, however, we find the family represented by all the principal genera that are known among the living Limnæidæ, as well as the greater part of the subordinate sections of the

* See An. Rep. U. S. Geol. Sur. Terr. for 1878., Part I, p. 25. *Ib.* for 1877, p. 307.

† For diagnosis of this genus see U. S. Geol. Sur. 40th Parallel, vol. iv, p. 175.

‡ U. S. Geol. Sur. 40th Parallel, vol. iv. p. 175, pl. xvii, fig. 6. Also Simpson's Rep. Great Basin, Utah, p. 364, pl. v, fig. 4.

§ See An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 82, pl. 30, fig. 8.

genera which constitute that family. These facts necessarily point back to a period much more remote than the Laramie, for the origin of the family, and although we lack the positive evidence of the fact, we cannot doubt that it not only had its origin as early as the beginning of Mesozoic time, but that it had then become well established.

The earliest known species belonging to the genus *Limnœa* is *L. nitidula* Meek,* which is found in the Bear River Laramie strata of Southwestern Wyoming. It is represented on Plate 6. It is referred to the subgenus *Limnophysa* Fitzinger. Among its faunal associates is a minute form, which I have described under the name of *Acella haldemani*,† which is represented by enlarged figures on Plate 6.

Associated with these is also a small *Planorbis*, belonging to the subgenus *Gyraulus* Agassiz.

It is a fact which doubtless indicates the imperfection of our present knowledge that, while those two widely differentiated members of the Limnæidæ are found in what are regarded as probably the earlier strata of the Laramie Group, the only other species which is referable to the subfamily Limnæinæ that has been found in any part of that group is a form, which was described by Meek & Hayden, from the Fort Union beds, under the name of *Limnœa tenuicostata*.‡ Mr. Meek proposed for this form the subgeneric name of *Pleurolimnœa*, but it might probably be referred to *Acella* with equal propriety. It is represented by a copy of Mr. Meek's figure on Plate 23. Although a greater number of the Planorbinæ than of the Limnæinæ have been discovered in the Laramie Group, the apparent absence of the latter from most of the fossiliferous strata of that group, even those which contain other palustral pulmonates, such as *Physa* and *Bulinus*, is unexpected, and, as before intimated, it is probably not because they did not exist, but because they have not been discovered.

Mr. Meek described a species under the name of *Limnœa* (*Limnophysa?*) *compactilis*,§ from Separation Station in Southern Wyoming, which was obtained from strata that he regarded as Tertiary, but which doubtless belongs to the Laramie Group. It probably belongs to the genus *Thaumastus*, and not to *Limnœa*. It is represented on Plate 26 by figures of Mr. Meek's type specimen.

Mr. Meek described two species of *Limnœa*, which he stated were discovered in the Bridger Group of Eocene fresh-water strata in Southern Wyoming. He named them respectively *L. vetusta* and *L. similis*.‖ Both these forms are represented by copies of Mr. Meek's figures on Plate 29.

From the Green River Eocene Group of Southern Wyoming I have

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* U. S. Geol. Sur. 40th Parallel, vol. iv, p. 181, pl. xvii, fig. 5.

† An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 84, pl. 30, fig. 9.

‡ See U. S. Geol. Sur. Terr., vol. ix, p. 534, pl. 44, fig. 13.

§ An. Rep. U. S. Geol. Sur. Terr. for 1872, p. 517.

‖ U. S. Geol. Sur. 40th Parallel, vol. iv, p. 191, pl. xvii, figs. 3 and 4. Also, Simpson's Rep. Great Basin, Utah, p. 367, pl. v, figs. 2 and 3.

described a species under the name of *L. minuscula*,* which evidently belongs to the subgenus *Leptolimnæa* Swainson. It is represented on Plate 29.

The species that have just been mentioned are all that are known to have existed in North America up to the close of the Eocene epoch, which pertain to the comprehensive genus *Limnæa*. The fresh-water strata, which are known as the White River Group, and are referred to the Miocene Tertiary, are the only strata of that epoch which are at present known to contain any remains of *Limnæa*. In that group two species of *Limnæa* have been discovered, namely, *L. meekii* Evans & Shumard, and *L. shumardi* Meek.† Both of these species belong, apparently, to the typical section of the genus, and both are represented by copies of Mr. Meek's original figures on Plate 32.

If the non-marine molluscan fauna, of the epoch of which the White River Group is a partial representative, were better known, it may be regarded as certain that we should find in it many representatives of living types; but so far as that fauna is at present known, it is a very meager one, and confined to the pulmonate gasteropods. The apparent entire absence of gill-bearing mollusks in those portions of that formation which have been examined, may, perhaps, have been due to a solution in the waters in which they were deposited, of certain salts or other substances which made them uncongenial for molluscan life. If this were really the case, the presence there of the remains of pulmonate gasteropods might be accounted for on the supposition that they were drifted into those waters by tributary streams in or upon the banks of which they lived.

The only other species of *Limnæa* to be mentioned in this article is the one which was described by Mr. Meek under the name of *L. kingii*, and for which he proposed the subgeneric name of *Polyrhitis*.‡ It was obtained from certain strata in Cache Valley, Utah, which are not of earlier date than the Miocene, and which are probably of Pliocene age. Copies of Meek's original figures of this form are given on Plate 32. It is an interesting form because of the fact that it is the only known representative of the only extinct subordinate type of *Limnæa* that is yet known, and because it comes down to a later date than most of the other extinct types of mollusca, of which mention is made in this article.

Of the other genera of the family Limnæidæ, *Planorbis* and *Carinifex*, remain to be considered. The earliest species of *Planorbis* yet discovered in North American strata is *P. veturnus* Meek & Hayden, § which those

* Proc. U. S. Nat. Museum, vol. iii, p. 160.

† For descriptions and figures of these two species see U. S. Geol. Sur. Terr., vol. iv, pp. 598 and 599, pl. 45, figs. 5 and 6.

‡ For description and figures of this species see U. S. Geol. Sur. Terr., 40th parallel, vol. iv, p. 192; and for Meek's diagnosis of the subgenus see U. S. Geol. Sur. Terr., vol. ix, p. 532.

§ Paleontology of the Upper Missouri, p. 107, pl. iv, fig. 1.

authors reported as coming from Jurassic strata in the vicinity of the Black Hills, where they found it associated with *Unio nucalis* and other species, which have already been referred to. It is represented on Plate 3.

It cannot be doubted that various species of *Planorbis* existed during the whole of the Cretaceous period, but no evidence of the fact has yet been obtained. In the Bear River Laramie beds, however, a small, undescribed species is known, as already mentioned, which belongs to the subgenus *Gyraulus*.

In the Laramie period the genus *Planorbis* is believed to have flourished; not because many examples have been found in those strata, but because the examples which have been discovered indicate that the different species which they represent reached a wide range of differentiation. Meek & Hayden described *Planorbis convolutus** from Laramie strata, in the Upper Missouri River region, which they regarded as of the age of the Judith River beds. This species seems to be referable to, or not widely different from, the typical section of the genus as it is known among living forms. It is represented on Plate 27.

The subgenus *Bathyomphalus* Agassiz, although not known to be now living in North America, is represented by three species in the Laramie Group; but it has not been recognized in any strata that are referred to a later date. One of these species was obtained from the Judith River beds, and was described by Meek & Hayden under the name of *Planorbis* (*Bathyomphalus*) *amplexus;*† and the other, by the same authors, from the Fort Union beds, under the name of *P.* (*B*) *planoconvexus.*‡

Still another species, obtained from the Laramie strata of Southern Utah by Professor Powell, was described by myself under the name of *Planorbis* (*Bathyomphalus*) *kanabensis.*§ All three of these forms are represented on Plate 27.

Besides the species of *Gyraulus* that has already been mentioned as existing in the Bear River Laramie beds, another was obtained by one of the parties under the direction of Lieutenant Wheeler, from strata that belong to either the upper part of the Laramie Group, or the lower portion of the Eocene. This species I have described under the name of *Planorbis* (*Gyraulus*) *militaris.*|| It is illustrated on Plate 28.

A fine large species of *Planorbis* was described by Mr. Meek from the Bridger Group of Southern Wyoming, under the name of *P. utahensis*, and also a variety of the same under the name of *P. spectabilis.*¶ Both these forms are illustrated on Plate 29.

* U. S. Geol. Sur. Terr., vol. ix, p. 536, pl. 43, fig. 11.

† U. S. Geol. Sur. Terr., vol. ix, p. 539, pl. 42, fig. 16.

‡ U. S. Geol. Sur. Terr., vol. ix, p. 538, pl. 44, fig. 9.

§ Powell's Rep, Geology of the Unita Mountains, p. 119.

|| Proceedings U. S. National Museum, vol. iii, p. 159.

¶ For Meek's descriptions and figures of these two forms see U. S. Geol. Sur., 40th Parallel, pp. 189, 190, pl. xvii, figs. 13 and 14; Simpson's Rep. Great Basin, Utah, pp. 266, 267, pl. v, figs. 6 and 7. Also see Expl. and Sur. West of 100th Merid., vol. iv, p. 209, pl. xxi, fig. 8, for description and figures by White.

This species is similar in outward form to those which have been grouped under the subgeneric name of *Gyraulus;* but in size it is very much greater than any of the species which have been referred to that subgenus.

A species somewhat similar to the last, but smaller, more nearly discoid in form, and having much more slender volutions, was obtained by myself from the Green River Group of Southern Wyoming, and described under the name of *Planorbis cirratus.** It is illustrated on Plate 29. From the same region and from the same formation I also obtained *Planorbis æqualis* White,† which is illustrated on Plate 29. It seems to possess all the characteristics of the typical section of the genus.

From the fresh-water strata that are referred to the Miocene epoch, only four species of *Planorbis* have yet been published, which, being the only known fossil species of that genus of later date than the Eocene, are the remaining species to be noticed in this article. Three of these are described by Meek & Hayden from the White River Group in Dakota, under the names respectively of *Planorbis vetustus*, *P. leidyi*, and *P. nebrascensis.*‡ They are illustrated on Plate 32. The remaining species§ was described by T. A. Conrad, under the name of *P. lunatus*, from "Bridge Creek, Oregon," where it was found associated with *Zonites marginicola*, mentioned on a following page. Copies of Conrad's figure are given on Plate 32.

Reference has already been made, in connection with a notice of *Sphærium rugosum and S.? idahoense*, to two deposits similar to each other in their faunal contents, the one being found in the neighborhood of the Kawsoh Mountains, in Northern Nevada, and the other in Southern Idaho, which are regarded as of Miocene age. These strata have furnished a limited but interesting molluscan fauna, among the species of which are two that were described by Meek under the names respectively of *Carinifex* (*Vorticifex*) *tryoni* and *C.* (*V.*) *binneyi.*‖ Both these forms are illustrated on Plate 32.

Although, as has already been shown, the family Limnæidæ (to which *Carinifex* is here referred) flourished ever since Mesozoic time, no other fossil species of *Carinifex* have yet been found in strata of any age, and no representatives of that genus are now known to be living in North America except a few upon the Pacific slope. If the Miocene lake, the deposits of which contain the two species of *Carinifex* which have just been noticed, had drained into what is now the hydrographic basin of the Mississippi, representatives of that type as well as those of its associate mollusca would no doubt now be found living there. But as the

* An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 44, pl. 19, fig. 5.

† Proceedings U. S. Nat. Museum, vol. iii, p. 159.

‡ For descriptions and figures of these three species by their authors, see U. S. Geol. Sur. Terr., vol. ix, pp. 600, 601, pl. 45, figs. 1, 2, and 3.

§ Am. Jour. Conch, vol. vi, p. 315, pl. 13, fig. 8.

‖ U. S. Geol. Sur. 40th Parallel, vol. iv, pp. 187, 188, pl. xvii, figs. 11 and 12.

type referred to is found among the living mollusca in Pacific drainage waters, it may be fairly inferred that that Miocene lake was drained into western and not eastern oceanic waters. It should be remarked, however, that no representatives of some of the types which were associated with those ancient forms of *Carinifex* are now known to be living.

PHYSIDÆ.

The Physidæ have been found to be comparatively well represented in nearly all the strata which have furnished any fossil pulmonate mollusca. Both *Physa* and *Bulinus* are represented by several species (all of which are regarded as extinct), ranging from the Cretaceous to the Miocene, inclusive. Notwithstanding their great antiquity, there seems to be among them all very little deviation from the types which are expressed by the numerous living species of those genera.

The earliest known species referable to the Physidæ is *Physa carletoni* Meek,* which was obtained by him from the Cretaceous estuary deposit at Coalville, Utah, which has before been referred to in connection with *Anomia propatoris*, *Cyrena carletoni*, and *Melampus? antiquus*. *P. carletoni* is represented by a figure on Plate 5.

In many cases the earliest known species of a genus which is capable of subdivision into subordinate types or sections is not referable to that section which has been selected by naturalists as the typical one; but in the present case *Physa carletoni* seems to be a typical *Physa*, while some of the later species seem to depart more from the typical form. These facts are, however, of no great significance, because the section of a genus which is designated as typical is usually only conventionally selected; and, also, because we cannot know with certainty whether the earliest known species was in reality the earliest. Although only the one species just mentioned has yet been discovered in any strata of greater age than those of the Laramie Group (if we except a fragment which has been found in the marine Cretaceous strata at Coalville, Utah, and which was probably drifted to that position from the then adjacent shore†), we cannot doubt that the Physidæ were comparatively abundant in the Cretaceous period, because that species is so unmistakable in its generic characteristics, and also because it belongs to a type that has reached the present time unchanged.

An unnamed form, which is probably a true *Physa*, has been found in the Bear River Laramie beds of Southwestern Wyoming, a figure of which is given on Plate 6.‡

Plate 25 contains figures of a fine large species which Professor Cope obtained from the Judith River Laramie beds in the Upper Mis-

*An. Rep. U. S. Geol. Sur. Terr. for 1877, p. 306, pl. 7, fig. 12.

† U. S. Geol. Sur. Terr. for 1877, p. 307, pl. 7, fig. 13. The figure is also given on Plate LXV, accompanying this article.

‡ An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 85, pl. 30, fig. 11.

souri River region, and which I described under the name of *Physa copei.**

Some fragments of a *Physa* have been found in the Laramie strata of Crow Creek Valley in Colorado, east of the Rocky Mountains, that indicate a somewhat remarkable and interesting form. It was described by me under the name of *Physa felix.*† The best example yet discovered is figured on Plate 25.

A species which occurs in the Wahsatch Group of Eocene strata in Southern Wyoming and adjacent parts of Colorado and Utah, and which reaches a greater size than any other known fossil *Physa*, perhaps excepting *P. copei*, has been described by myself under the name of *P. pleromatis.*‡ The type specimen of the species is figured on Plate 30. Some imperfect specimens have been found in Colorado, apparently belonging to this species, that indicate a very much greater size. A partially restored figure of one of these is given on Plate 30.

Another fine species has been described by Meek from the Bridger Eocene group of Southern Wyoming, under the name of *Physa bridgerensis.*§ It is illustrated on Plate 30.

Physa pleromatis is apparently a typical *Physa*, but *P. bridgerensis* perhaps ought to be referred to *Bulinus.* For present convenience, however, it is referred to *Physa.*

From the Miocene White River Group of Dakota, Evans & Shumard described *Physa secalina*,‖ which is represented on Plate 32. It has a very modern aspect, although it is regarded as an extinct species. No fossil *Physa* of later age than this has yet been published from any North American strata, but one or more species is known to exist in certain strata of Southern Wyoming and Northwestern Colorado, which Professor Powell has named the Brown's Park Group, and are probably of Pliocene age.

The genus *Bulinus* is well represented in the Laramie Group, but no other species of that genus has yet been published from any other North American strata, unless *Physa bridgerensis* should prove to be a *Bulinus*, as already suggested. Associated with *Physa copei* in the Judith River Laramie beds, Professor Cope found a fine large species of *Bulinus* which I described under the name of *B. atavus.*¶ It is figured on Plate 25.

From the Laramie strata, at the mouth of Judith River, Meek & Hayden obtained the type specimens of *Bulinus subelongatus;*** which is represented on Plate 25.

From the Fort Union Laramie beds two other specimens of *Bulinus*

*An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 84, pl. 22, fig. 1.

†An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 84, pl. 22, fig. 1.

‡Expl. and Sur. West of the 100th Merid., vol. iv, p. 211; pl. xxi, fig. 1.

§ An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 45, pl. 19, fig. 10.

‖ U. S. Geol. Sur. Terr. vol. ix, p. 604, pl. 45, fig. 4.

¶ An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 86, pl. 24, fig. 5.

** U. S. Geol. Sur. Terr., vol. ix, p. 540, pl. 42, fig. 13.

were described by Meek & Hayden, under the names respectively of *B. longiusculus* and *B. rhomboideus*,* both of which are represented on Plate 25. These two forms are so closely like *Physa* that they may apparently be with equal propriety referred to that genus. Indeed if these two species are properly referred to *Bulinus*, then *Physa bridgerensis* and one or two other species herein referred to *Physa* ought to be referred to *Bulinus* also.

In the Laramie strata, east of the Rocky Mountains, in Colorado, *Bulinus disjunctus* White,† occurs. It is represented on Plate 25.

Another Laramie species was discovered in Southern Utah by Professor Powell, which I described under the name of *Physa kanabensis*, ‡ but which ought to be referred to *Bulinus*. This species is yet known only by specimens that are too imperfect for satisfactory illustration.

ANCYLIDÆ.

The Ancylidæ, when present, always form an inconspicuous feature in any fresh-water fauna, and the family is represented by only two published species, so far as is now known, in all the North American strata. One of these species, *Acroloxus minutus*, Meek & Hayden, was obtained by them from the Laramie strata near Fort Union, in the Upper Missouri River region.§ It is illustrated on Plate 24.

The other fossil representative of the family is *Ancylus undulatus*, Meek,‖ from the Miocene deposit of the Kawsoh Mountains of Northern Nevada, where it was found associated with the two species of *Carinifex* that have already been mentioned, and also with certain other freshwater forms. It is represented on Plate 32.

In the Southern Idaho equivalent of the Eocene beds just mentioned, associated with *Melania taylori*, *Lithasia antiqua*, *Sphærium rugosum*, &c., an interesting shell has been found which seems to agree with the genus *Latia* Gray, although that genus has hitherto been known only in certain portions of Oceanica, and only in the living state.

This form may be briefly characterized as follows:

Latia dallii (sp. nov.), plate 32, figures 37, 38, 39, and 40. Shell subovate in marginal outline; irregularly convex above; the posterior portion narrowing rapidly to a small prominent umbo, which ends in a very small, closely-incurved beak; the beak turned a little to the right side, and making about one full volution; semilunar shelf or septum comparatively large. Surface marked by many strong, irregular, concentric undulations; but otherwise it is comparatively smooth, being marked only by fine lines of growth.

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* U. S. Geol. Sur. Terr., vol. ix, pp. 541, 542, pl. 43, figs. 16 and 17.
† An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 86, pl. 24, fig. 6.
‡ Powell's Rep. Geology of the Uinta Mountains, p. 119.
§ U. S. Geol. Sur. Terr., vol. ix, p. 543, pl. 44, fig. 10.
‖ U. S. Geol. Sur. 40th Parallel, vol. iv, p. 186, pl. xvii, fig. 12.

Length, 16 millimeters; breadth, 10 millimeters; height, 7 millimeters.

The specific name is given in honor of Mr. W. H. Dall, whose important works upon the mollusca are well known.

VITRINIDÆ.

It is a suggestive fact that so large a proportion of the fossil non-marine mollusca, which have been found in North American strata, are air-breathing land snails. This result of field-investigation is unexpected, both because individuals of none of the living land-snails are found in as great numbers as many of the gill-bearing water snails are, and because all the specimens that have been preserved in the fossil state must have been transported from the land into the waters in the sediments of which they were preserved after the death of the mollusks which formed them. We must therefore conclude that in former geological epochs the land-snails were proportionally quite as abundant as they are now, and it seems probable, also, that the shores of, and the region round about, the Laraime sea, and those of the great fresh-water lakes which succeeded that sea, formed a peculiarly favorable habitat for land mollusca.

Judging from the character of a portion of the fossil shells that have been discovered, and from the wide diversity in the families of land mollusca, which is indicated by the collections that have been made from various formations, we cannot doubt that the family Vitrinidæ was represented, at least during the Laramie and Tertiary periods. It is not to be denied, however, that with a knowledge of the shells only, and they usually more or less imperfect, it is not always possible to say with certainty that those which we refer to that family really belong to it; or that they may not belong to the Helicidæ.

The three following-named species were described by Meek & Hayden, and referred by them, not without some doubt, to the Vitrinidæ. They obtained them from the Judith River Laramie beds of the Upper Missouri River region, and named them respectively, *Vitrina? obliqua*, *Hyalina? occidentalis*, and *H.? evansi.** All three of these forms are represented by figures on Plate 27.

From the Wind River Group of Eocene strata, in Wyoming, Meek & Hayden also obtained a fine large species, which they described under the name of *Macrocyclis spatiosa*,† which is represented on Plate 30.

ARIONIDÆ.

Among the most interesting remains of land mollusca that have been discovered are those which Dr. J. W. Dawson has published at different times from the Coal-Measures of Nova Scotia. He was the first to demon-

*U. S. Geol. Sur. Terr. vol. ix, pp. 545–548, pl. 42, figs. 6 and 7.

†U. S. Geol. Sur. Terr., vol. ix, p. 594, pl. 42, fig. 9.

strate that a widely differentiated land molluscan fauna existed during the Coal Measure period, if not much earlier.

If the species which Dr. Dawson described under the name of *Zonites priscus*,* from the Coal Measure strata of South Joggins, Nova Scotia, is really a *Zonites*, or a closely related form, we have proof of the remarkable fact that the family Arionidæ was well established in the Carboniferous age. The correctness of the reference of this species to the Arionidæ being accepted, we naturally conclude that other members of the family have existed somewhere during all the time that has elapsed since the Carboniferous age; but yet remains of no other representatives of the Arionidæ are now known to exist in any North American strata, if we except the one mentioned below. Copies of Dr. Dawson's original figures of *Zonites priscus* are given on Plate 2. His specimens were found associated with *Pupa vetusta* and *P. bigsbyi* Dawson, both of which species are mentioned in their order on following pages.

Mr. T. A. Conrad published a form under the name of *Helix* (*Zonites*) *marginicola*,† from Bridge Creek, Oregon, which probably comes from a fresh-water Eocene deposit. His specimens seem to have been very imperfect and unsatisfactory. A copy of his figure is given on Plate 32.

HELICIDÆ.

Among other molluscan remains that have been discovered in the Coalmeasure strata of Indiana and referred to the Pulmonata is a form to which Professor Bradley gave the generic name of *Dawsonella*, describing the species under the name of *D. meekii*.‡ Dr. Dawson, in commenting upon this form, expresses the opinion that it belongs to the Helicidæ "near *Helix* (*Triodopsis*) *palliata* and *H.* (*Stenotrema*) *monodon*;"§ but Professor Whitfield expresses the opinion that it was an operculate shell resembling *Helicina*.‖

For present convenience, and without reference to the merits of the question raised, this species is here left where Dr. Dawson first placed it. It is in either case very probable that true members of the Helicidæ really did exist during the Coalmeasure epoch, contemporaneously with the Pupidæ which are known to have existed then, and which are presently to be mentioned. *Dawsonella meekii* is represented on Plate 2 by copies of Professor Whitfield's figures.

If *Dawsonella* should prove not to belong to the Helicidæ, the earliest examples of that family which are yet known to occur in North American strata are found in the Laramie Group. From the Judith River Laramie beds of the Upper Missouri region Meek & Hayden obtained two species which are referred to this family. The first they described

*Am. Jour. Sci., vol. xx (3), p. 411, figs. 10 and 11.

†Am. Jour. Conch., vol. vi, p. 315, pl. 13, fig. 9.

‡Am. Jour. Sci., vol. iv (3), p. 88.

§Am. Jour. Sci., vol. xx (3), p. 413.

‖Am. Jour. Sci., vol. xxi (3), p. 127.

as *Helix vetusta*, and the other under the name of *Thaumastus limnæformis*;* the first being represented on Plate 27 and the latter on Plate 25. The former is perhaps not a typical *Helix*, but the latter is probably a true representative of *Thaumastus*, as that genus is known among living mollusca. If so, it is the only fossil representative of the section of the Helicidæ to which it belongs that is at present known in North America strata (if we except the *Bulinus floridanus* of Conrad from the Eocene of Florida and perhaps also the species mentioned on page 445 under the name of *Limnæa* (*Limnophysa?*) *compactilis*, although living species of *Thaumastus* are not uncommon in the southern part of North America.

From the Fort Union Laramie beds of the Upper Missouri River region Meek & Hayden also described two species of Helicidæ under the names respectively of *Columna teres* and *C. vermicula*.† These also are the only representatives of their genus that are yet known in North American strata, and, like the next preceding species, no living congeners are found in North America so far northward as the localities from which the fossil species were obtained. Both these forms are represented on Plate 25.

From the Laramie strata of Southern Utah Professor Powell obtained a species of *Helix* that seems to possess the characteristics of the subgenus *Strobila* Morse, and which I have described under the name of *Helix kanabensis*.‡ It is figured on Plate 25. It was found associated with *Physa kanabensis* and *Planorbis* (*Bathyomphalus*) *kanabensis*, both of which have already been noticed.

A series of coal-bearing strata near Evanston, Southwestern Wyoming, which apparently belong to the upper part of the Laramie Group, have furnished a number of species of pulmonate mollusca, among which are two species of *Helix*, namely *H. Sepulta* and *H. evanstonensis* White.§ The former seems to possess the subgeneric characteristics of *Patula* Haldeman, and although its characteristics have been quite clearly ascertained, the specimens are all too imperfect for figuring. *H. evanstonensis* is apparently referable to the subgenus *Triodopsis* Rafinesque. It is figured on Plate 27.

From the Wind River Group, a series of fresh-water Eocene strata in Western Wyoming, a fine species was obtained by Meek & Hayden and described by them under the name of *Helix? veterna*.‖ It is represented by copies of Mr. Meek's figures on Plate 30. Certain characteristics presented by this shell cause some doubts to arise as to its real

* For figures and descriptions of both these species see U. S. Geol. Sur. Terr., vol. ix., pp. 552, 553, pl. 42, fig. 7; and pl. 44, fig. 8.

† U. S. Geol. Sur. Terr., vol. ix, pp. 555, 556, pl. 44, figs. 11 and 12.

‡ Powell's Rep. Geology of Uinta Mountains, p. 120.

§ The first of these species was originally described in Proc. U. S. Nat. Museum, vol. iii, p. 160; and the other in Bull U. S. Geol. Sur. Terr., vol. iv, p. 714.

‖ U. S. Geol. Sur. Terr., vol. ix, p. 596, pl. 42, fig. 8.

affinities; but it is at present left with the Helicidæ, where those authors placed it.

Professor Powell obtained from the Bitter Creek Group, in Central Utah, the earliest of the fresh-water Eocene series, a species which I described under the name *Helix peripheria*,* and which appears to possess the subgeneric characteristics of *Aglaia* Albers. From the Eocene Green River Group of Southern Wyoming he also obtained *H. riparia*† White, which is apparently referable to the subgenus *Arianta* Leach. Both the last-mentioned species are figured on Plate 29.

Whether *Helix kanabensis*, *H. sepulta*, *H. evanstonensis*, *H. peripheria*, and *H. riparia* are correctly referred to the respective subgenera in connection with which they have just been mentioned, or not, their diversity of form gives sufficient indication that the Helicidæ had become widely differentiated during those early epochs in which they lived, probably quite as widely as their living representatives are, and under closely similar forms.

At present, the only known Miocene species of *Helix* is *H. leidyi* Hall & Meek; which is also the only known fossil species of that genus of later date than the Eocene.‡ It is represented on Plate 32.

PUPIDÆ.

If it were not that the existence of a diversified land molluscan fauna during the Coal-Measure period is a well-established fact, we should be slow to accept the conclusion of Dr. Dawson that the shell which he has described from the Erian (Devonian) plant-beds of St. Johns, New Brunswick, under the name of *Strophites grandæva*§ is really a land snail. In view of the fact just stated, and of the reasons which he gives for his conclusions, we seem to have no reason to doubt that the shell in question is, as he suggests, closely related to *Pupa*. A copy of his figure of it is given on Plate 1.

Although an unexpectedly large number of species of non-marine mollusca has been obtained from strata so ancient as those of the Coal-Measures, the fact that the Gasteropoda are all land snails shows clearly that the complete non-marine mollusca of that period is very far from being fully known. It cannot be supposed that coördinate families, similar to those with which representatives of the species referred to are raneously with those ancient species which have been discovered. The known to have been afterwards associated, did not exist contempo- continental area, however, having been at that time smaller than it afterward became, the rivers were necessarily comparatively few and small. Therefore, the fresh-water mollusca, as compared with those of the land, were perhaps proportionally fewer then.

* Powell's Rep. Geology Uinta Mountains, p. 130.

† *Ibid.*

‡ See mention of some California species of Helicidæ found in a fossilized condition, under the head of spurious and doubtful species, on a following page.

§ Am. Jour. Sci., vol. xx (3), p. 413.

Among the non-marine mollusca which have been discovered in the Coal-Measure strata of Canada and the United States are four species which belong to the Pupidæ. Dr. Dawson was the first to recognize the pulmonate character of these mollusks, and he described the first-discovered species under the name of *Pupa vetusta*, the type specimens of which he obtained from the Coal Measure strata at South Joggins, Nova Scotia.* Copies of his figures of this species are given on Plate 2.

Professor Bradley described *P. vermillionensis*† from the Coal-Measures of Indiana, and subsequently Dr. Dawson described a second species under the name of *P. bigsbyi*‡ from the same strata and same locality in Nova Scotia that had furnished examples of *P. vetusta*. Both these species are represented by copies of Dr. Dawson's figures on Plate 2.

Within the present year (1881) Professor Whitfield has described a fourth Pupa-like form from the Coal-Measure strata near Marietta, Ohio, for which he proposed the new generic name of *Anthracopupa*, describing the species under the name of *A. ohioënsis*.§ Copies of Professor Whitfield's figures are given on Plate 2.

Whether the species described as *Pupa* by Dawson and Bradley strictly belong to the typical forms of that genius, as it is represented by living species, or not, there seems to be no room for reasonable doubt that all four of the Carboniferous forms that have just been noticed belong to the family Pupidæ. This being the case, it cannot be doubted that the family was well represented during all subsequent epochs; and yet no other fossil species besides these have been discovered in North American strata, except those which have been found in the fresh-water Eocene deposits of Southern Wyoming.

One of these Eocene species was described by Mr. Meek, from the Bridger Group, in Southern Wyoming, under the name *Pupa? leidyi*.‖ The type specimen of this species seems to have been lost, and therefore no figure of it can be given. It evidently differed considerably from the typical forms of *Pupa*, and Mr. Meek was in doubt whether it might not with propriety be referred to *Holospira* Albers.

The remaining three species of the Pupidæ to be noticed in this article were all obtained from the Green River Eocene Group at one locality, in Southern Wyoming. They have been published under the following names, respectively: *Pupa incolata*, *P. arenula*, and *P. atavuncula* White.¶

The first-named species seems to belong to the subgenus *Leucocheila*

*Acadian Geology, 1855, p. 160; Am. Jour. Sci., vol. xx (3), p. 405.

† Am. Jour. Sci., vol. iv (3), p. 87.

‡ Am. Jour. Sci., vol. xx (3), p. 410.

§ For generic diagnosis and specific description see Am. Jour. Sci. vol. xx (3), p. 126.

‖ An. Rep. U. S. Geol. Sur. Terr., for 1872, p. 517.

¶ For descriptions and figures of these three species, see An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, pp. 46, 47, pl. 19, figs. 7, 8, and 9.

Alb. & Mart.; and the other two are referred provisionally to *Pupilla* Leach. All three of these forms are represented on Plate 29. Owing to the imperfection of the type specimens of these three species, their reference to the subgenera which have just been mentioned is not made with entire confidence; but whether this reference is correct or not, it is a well-established fact that the family Pupidæ had acquired, as early, at least, as the earliest Eocene, nearly or quite all the characteristics which distinguish it at the present day.

SUCCINIDÆ.

Although so large a number and great variety of other land-snails have been discovered in the strata of various geological periods, only a single species referable to the Succinidæ has yet been found in North American strata. This is *succinea papillispira*, White,* which was obtained from the upper portion of the Green River Eocene group in Southern Wyoming, and which plainly belongs to the subgenus *Brachyspira* Pfeiffer.

NERITIDÆ.

Since the greater part of the known species of this family, both living and fossil, are of marine origin, only those of its fossil representatives which are found associated with such forms as indicate that they lived in a brackish or nearly fresh water habitat will be considered in this article. The species thus falling under consideration embrace two subordinate types of *Neritina* and these only. One of the types is apparently identical with that of the common fluvatile living species of *Neritina*, which may be regarded as the typical section of the genus,† but the other type is extinct. Instead of having been confined to either brackish or fresh water, both these types have representatives in strata of both brackish water and marine origin. That is, for example, a species of each type is found in the Laramie group, associated with *Corbicula*, *Corbula*, *Unio*, *and Melania.* Other species of both types are found in Cretaceous strata, associated with such unmistakably marine forms as the Aviculidæ, Arcidæ, Turritellidæ, &c.

The earliest species referable to this family which is at present known, and which comes within the scope of this article, is *Neritina nebrascensis*, Meek & Hayden,‡ which was found in the vicinity of the Black Hills, in strata believed by those authors to be of Jurassic age. It is plainly a true *Neritina*, but those authors found it associated with species that are regarded as indicating a purely fresh-water habitat, namely, *Unio*, *Viviparus*, *Lioplacodes*, *&c.* It is represented on Plate 3.

*An. Rep. U. S. Geol. Sur. Terr., for 1878, Part I, p. 45, pl. 19, fig. 4.

† The Laramie species, *N. volvilineata*, shows a faint crenulation of the border of the inner lip; and some small examples, apparently the young of this species, lately discovered, show a distinct denticulation of that border. Perhaps this species ought to be referred to *Nerita*, but for the present I leave it with *Neritina*.

‡ Paleontology of the Upper Missouri, p. 109.

The next species that are to be mentioned in the order of geological time are two that were discovered by Mr. Meek in the estuary deposit at Coalville, Utah, which has already been several times mentioned. One of these species was described by him under the name of *Neritina bannisteri*,* and is represented on Plate 5. It is closely allied with the foregoing Jurassic species, and specimens of both have been found which still show the original color-markings of the surface. *Neritina bannisteri* has also a near ally in *N. incompta* White, from the marine Cretaceous strata of the same epoch, and which is found in the same region. Indeed, it is not improbable that these two forms are only varieties of one and the same species. If so, the fact implies that the species ranged from marine into brackish waters, with no more than a varietal change as a consequence.

Associated with this typical *Neritina* in the Cretaceous estuary deposit at Coalville is a species which Mr. Meek described under the name of *N. bellatula;* and with it, also, another form, which he named *N. carditoides*.† The type specimen of the latter is very imperfect; but, judging from the characters which it shows, it is thought to be identical with *N. bellatula*. Both the forms are represented on Plate 5.

These two last-named forms of *Neritina* belong to a subordinate type to which Mr. Meek gave the subgeneric name of *Velatella*. The type is an extinct one, as has already been intimated, and is at present known only in Cretaceous and Laramie strata.‡

In the Bear River Laramie beds a very small species occurs, which I have described under the name of *Neritina naticiformis*.§ It apparently belongs to the typical section of the genus. It is represented on Plate 7.

The Laramie species belonging to the subgenus *Velatella*, which has been referred to, was first discovered at Black Buttes Station, in Southern Wyoming, and described by me under the name of *N.* (*V.*) *baptista*.‖ Numerous specimens of it have since been discovered in the Laramie strata east of the Rocky Mountains in Colorado, all of which, including the type specimens, have preserved upon their surface the original color markings with which they were ornamented while living, and which are represented by Figs. 16–20 on Plate 23.

Associated with *N.* (*V.*) *baptista*, at the Wyoming locality, is the form which I have described under the name of *Neritina volvilineata*,¶ and which is illustrated on Plate 23. The type specimens were found in Southern Wyoming and Northwestern Colorado, none of which showed

*An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 25, pl. 12, fig. 10.

†For descriptions and figures of these two forms, see An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 27, 28, pl. 12, figs. 7 and 8.

‡For a diagnosis of this subgenus, see An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 27.

§An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 89, pl. 30, fig. 3.

‖An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 89, pl. 29, fig. 6.

¶An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 88, pl. 21, fig. 6.

the color markings such as are seen to characterize several species already noticed, and also the form referred to in the following paragraph.

Associated with *N.* (*V.*) *Baptista* in Northern Colorado, east of the Rocky Mountains, is a form of *Neritina* which is closely related to *N. volvilineata*, which being undescribed I propose for it the name *N. bruneri* in honor of Mr. Lawrence Bruner, who first discovered the species. It differs from *N. volvilineata* in being somewhat more globose, having a less elevated spire, and the inner lips broader and less retreating. It is marked by revolving lines, somewhat like that species, but they are sometimes obsolete. It is also ornamented by zigzag color-markings. The type specimen is represented by Figs. 14 and 15 on Plate 23.

Associated with the foregoing is still another form, much smaller, which seems to be the young of *N. volvilineata.* It is without color markings, and the inner border of the inner lip is dentate.

Although belonging to so early an epoch, these Laramie species of *Neritina* are the latest members of that family of non-marine origin that are now known to occur in North American strata. Consequently, no others besides those mentioned come within the scope of this article.

The typical form of Neritina has doubtless come down to the present day by securing a congenial habitat along the changing coasts of the growing continent; but although the subgeneric type *Velatella* existed before the inclosure of the Laramie sea, that sea seems to have embraced all the forms of that type which survived during the Laramie period. When, therefore, the waters of that sea became wholly fresh, that type, together with others, seems to have been extinguished as a consequence.

CERITHIIDÆ.

Only a single species, referable to this family, which may be regarded as a non-marine form, has been found in any North American strata. It was obtained from the Judith River Laramie beds, in the Upper Missouri River region by Meek and Hayden, and by them described under the name of *Cerithidea nebrascensis.** Those authors referred it to the subgenus *Pirenella* Gray, but they expressed some doubt as to the true generic character possessed by the shell. Although *Cerithidea* is a well known living genus of the Old World, this species at present stands alone, or without near known allies, either living or fossil, among North American mollusca, if its generic relations are correctly understood, as stated above. It is represented on Plate 26.

MELANIIDÆ.

Most naturalists agree in the opinion that no living North American species of mollusca are properly referable to the genus *Melania;* although formerly many species were referred to that genus which are now placed in the family Ceriphasiidæ, and mostly referred to the

* U. S. Geol. Sur. Terr., vol. ix, p. 559, pl. 43, fig. 9.

genus *Goniobasis*. It has also been considered doubtful by many naturalists whether any one of the fossil species that have been found in the rocks of North America, ought to be referred to the family Melaniidæ. The five or six following species, however, are in this article provsionally referred to that family; two because they are at present believed to strictly belong there; and the others partly because of their apparent affinities in that direction, and partly because they seem to be not properly referable to the Ceriphasiidæ. They are all interesting shells, embracing three distinct types, two of which, at least, are not known to have living representatives; but two of the species, while they appear to have no generic representative living in North America, seem to be referable to true *Melania* of Old World type.

One of the species last referred to is *Melania wyomingensis* Meek, (=*M. larunda* White,*) which has been found on both sides of the Rocky Mountains in Southern Wyoming and Northern Colorado. Figures of this fine species are given on Plate 26.

The other species, which appears to be a true *Melania*, is *M. claibornensis* Heilprin, from the marine Eocene deposits of Alabama.† It is represented on Plate 28.

In Southern Wyoming Mr. Meek also obtained from the Laramie strata a form which he described under the name of *Melania insculpta*.‡ It seems to be nearly related to *M. wyomingensis*, but differs from it in wanting its prominent subspinous ornamentation. This species has also been found in the Laramie strata east of the Rocky Mountains in Colorado, the specimens figured on Plate 26 having been collected in the valley of South Platte River.

There occurs somewhat abundantly in the Bear River Laramie beds of Southwestern Wyoming and the adjacent parts of Utah a shell which Mr. Meek first referred to *Melania*, but to which he afterward gave the new generic name of *Pyrgulifera*, describing it under the name of *Pyrgulifera humrosa*.§ It is illustrated on Plate 6. Mr. Meek placed this shell among the Ceriphasiidæ or American Melanians, but as it seems to differ quite as widely from the typical forms of that family as it does from the true Melanians, I here place it provisionally

* An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 95, pl. 28, fig. 6.

† Although the associates of this shell are all marine, it is given a place in this article because *Melania* is generally regarded as a fresh-water genus. In this connection, however, it is proper to remark that among certain fossil faunæ shells undistinguishable from *Melania* are found associated with marine forms. (See Professor Heilprin's description and remarks, Proc. Acad. Nat. Sci., Phila., 1879, p. 214.) *M. wyomingensis* and *M. insculpta* have also been found in such association with *Ostrea* and *Anomia*, as to indicate that they all lived and flourished together in the same waters, which were certainly in some degree saline, or the *Ostrea* and *Anomia* could not have existed there.

‡ See An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 94, pl. 20, fig. 4.

§ For diagnosis of this genus, and description and figures of the species, see U. S. Geol. Sur. 40th Parallel, vol. iv, p. 146, pl. 17, fig. 19.

with the latter family. It is the only known species of the genus which has been proposed to receive it, either fossil or living.*

From the fresh-water Miocene deposits, which have already been mentioned as occurring in Southern Idaho and in the vicinity of the Kawsoh Mountains, Mr. Meek described two forms and Mr. Gabb another, which they referred to *Melania*, Mr. Meek doing so with an expression of doubt but Mr. Gabb with none. Copies of their original figures of these forms are given on Plate 32.

Mr. Meek gave the names *M.? sculptilis* and *M.? subsculptilis*† to his two species, and Mr. Gabb, that of *M. taylori*‡ to the one he described. Conrad's *M. decursa* is probably a synonym of the latter.

All three of these forms belong to one and the same type, and perhaps represent only one species. This type differs considerably from the other types that have herein been referred to the Melaniadæ. The species belong to a fauna from which, as before stated, no genetic lines seem to have reached the present Mississippi drainage system, and, like a portion of their associates, are quite unlike any other North American species, either living or fossil. All the known species of that fauna are herein referred to and figured, but, for the purpose of separate view, their names are given, as follows: *Melania? sculptilis, M.? subsculptilis, M.? taylori, Lithasia antiqua, Carinifex, (Vorticifex) tryoni, C. (V.) binneyi, Ancylus undulatus, Sphærium rugosum*, and *S.? idahoense.*

The genus *Melanopsis* Lamarck is not known among the living mollusca of North America, and until very lately it was believed to be also absent from all North American strata. A small shell from the Laramie strata east of the Rocky Mountains in Colorado, associated with *Corbicula, Corbula, Melania, Neritina, Anomia* and *Ostrea*, is here described for the first time, and referred provisionally to *Melanopsis*. It is evidently congeneric with the living *Melanopsis costellata* Ferussac, and also with the Eocene *M. buccinoidea* Ferussac; both from Western Europe.

Melanopsis ? americana (sp. nov.), Plate 23, Figs. 21, 22, and 23.

Shell very small, sides straight, and meeting at the apex at an acute angle; volutions six or seven, those of the spire not convex, but so flattened as to show only a linear suture between them, which is somewhat irregular; proximal portion of the last volution gently convex, its length being more than half the entire length of the shell; outer lip thin, not expanded, its margin not distinctly sinuous; inner lip having a very strong callous nearly filling the distal end of the aperture, leaving a narrow groove between it and the margin of the outer lip, and gradually diminishing in thickness towards the proximal end of the aperture; aperture, as bounded by the outer lip and callous inner lip, rudely sub-

* See foot-note on page 464.

† U. S. Geol. Sur. 40th Parallel, pp. 195, 196, pl. 17, figs. 8 and 9.

‡ Paleonotology of California, vol. ii, p. 13, pl. 2, fig. 21.

elliptical, angular at its distal end, rounded at its proximal end, and terminating at the end of the columella in a distinct, narrow canal, which is slightly bent to the left. Surface marked only by faint lines of growth.

Length, 7 millimeters; diameter of last volution, 3½ millimeters.

CERIPHASIIDÆ.

The Ceriphasiidæ, or American Melanians, constitute an important feature of the non-marine fossil molluscan faunæ of North America, especially in the Laramie and Eocene fresh-water strata of the west. We have yet no evidence of the existence of this family before the Laramie period; but in view of its known abundance during that period, and also during that of the Eocene, it may be safely assumed that the origin of the family was at an earlier period. It is nevertheless true that the forms of *Goniobasis*, which occur in the purely fresh-water Eocene strata, somewhat more nearly resemble those which are regarded as typical forms among living species than most of those of the Laramie period do. This, however, may have little significance as regards physical changes since the Laramie, because the Uniones of that period are more characteristically like living Uniones than those of the Eocene strata are.

All except two or three of the fossil species that have been described as belonging to the Ceriphasiidæ have been referred to the genus *Goniobasis* Lea; but a part of them have been so referred with some doubt. Among those concerning which no doubt of this kind has been expressed by the respective authors who have described them, there may be recognized at least three somewhat distinct subordinate types perhaps worthy to be called subgenera.

Of these three types, *Goniobasis cleburni* White, *G. tenera* Hall, and *G. nebrascensis* Meek & Hayden, may be regarded as representatives respectively; but I regard it as probable that the latter type is more nearly related to *Lioplax* than to *Goniobasis*.

The Bear River Laramie strata not only furnish what are probably the earliest known species of the Ceriphasiidæ, but they furnish most of the known species, four in number, which may be referred to that proposed section of *Goniobasis* of which *G. cleburni* is the type.* The other three species are, respectively, *G. chrysallis* Meek, *G. chrysalloidea* White, and *G. macilenta* White.† All four of them are figured on Plate 6. They are found associated together in the Bear River Laramie beds of Southwestern Wyoming and the adjacent parts of Utah, and none of them

*The species of this type bears some resemblance to *Melanopsis*, but none of them are canaliculate at base in any degree. No examples of *Melanopsis*, except the one described on page 461 of this article, are known in North America, either fossil or recent; if we except the species Conrad described as *Bulliopsis*.

† See description and figures of these four species, together with other references, An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, pp. 91–93, pl. 30, figs. 4, 5, 6, 7, and 10.

have been found in any other strata of the Laramie Group except those which are strictly equivalent with those beds.

One other species, which I have described under the name of *Goniobasis endlichi,** is found *associated* with the four species that have just been mentioned. It is represented on Plate 6. This form belongs to another type, which includes *G. nebrascensis*, presently to be mentioned, and which, as before suggested, probably belongs near *Lioplax* Troschel.

Five species were described by Meek & Hayden from the Judith River Laramie beds of the Upper Missouri River region, under the generic name of *Goniobasis*, namely, *G. convexa*, *G. invenusta*, *G. sublævis*, *G. omitta*, and *G.? subtortuosa*,† all of which are represented on Plates, 26 and 27. It seems probable that *G. sublævis* and *G. invenusta* are only varieties of *G. convexa*. *G. omitta* is much like *G. gracilenta* from the Fort Union beds, presently to be mentioned; but *G.? subtortuosa* is quite different from any other form that has been referred to *Goniobasis*. It probably belongs to some other genus, perhaps to *Cassiopella* White, which will be further mentioned on a following page, but that question cannot yet be determined because the characters of the base and aperture of the former are not yet known.

From the Fort Union Laramie beds of the Upper Missouri River region three species have been described by Meek & Hayden, namely, *Goniobasis gracilenta*, *G. nebrascensis*, and *G. tenuicarinata*.‡ The two latter species have already been referred to as representing a separate section of the genus *Goniobasis*, if, indeed, they belong to that genus. They are represented on Plate 26. Both species have also been recognized in the coal-bearing strata at the town of Wales, Utah, and *G. tenuicarinata* has been found in the Laramie strata of Crow Creek Valley in Northern Colorado, east of the Rocky Mountains. At the last-mentioned locality, as well as at Black Buttes Station in Southern Wyoming, *Goniobasis gracilenta* has been recognized. The species is represented on Plate 26.

It will thus be seen that thirteen species in all have been described and referred to *Goniobasis* from the Laramie Group alone. Even in case several of the specific names that have been applied to these forms should, as already suggested, prove to be merely synonyms, still it is clear that in the great Laramie Group there is a goodly number of well-defined species of *Goniobasis*, as that genus is now understood.

From the Laramie strata at Black Buttes Station, which have been so often mentioned, several specimens of a shell have been obtained, to

* An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 92, pl. 30, fig. 7.

† For descriptions and figures of these five species, see U. S. Geol. Sur. Terr., vol. ix, pp. 562–570, pl. 42.

‡ For descriptions and figures of these three species, see U. S. Geol. Sur. Terr., vol. ix, pp. 565–568, plates 42 and 43.

which I have given the generic name of *Cassiopella*,* describing the species under the name of *C. turricula*. It is figured on Plate 23. Like *Pyrgulifera*, it is the sole representative of an extinct generic type.† It is umbilicate, and in this respect differs from any other shell that has been referred to the Ceriphasiidæ. It is referred to that family only provisionally, and because there appears to be equal or greater objections to referring it to any other established family. It is so referred mainly because of its agreement in form, and the character of its outer and inner lips.

Passing now to the three groups of fresh-water Eocene strata, the Wahsatch, Green River, and Bridger groups, as they are developed in Wyoming, Colorado, and Utah, we find that the genus *Goniobasis* constitutes even a more conspicuous feature of the faunæ of those groups, as regards proportionate numbers of individuals, than it did in the Laramie period, although the number of species was so much greater then. Notwithstanding this great generic prominence, and also the fact that four species have been described by different authors from those fresh-water Eocene groups under the name of *Goniobasis*,‡ I am not at present prepared to admit that more than one well-defined species has yet been found in any of the strata of those three groups. Taking this view, we must of course regard those forms which have been described as separate species, as only varieties of the first one described; although it cannot be denied that the variation is, in some cases, very considerable; and if intermediate forms had not been discovered, their specific separation would never have been called in question. In this view of the case I have selected *tenera* Hall as the specific name by which to designate this variable and abundant Eocene species of *Goniobasis*, because it was the first specific name that was applied to it by any author. It will be convenient and proper, however, to retain the other names as those of varieties, or even in some sense as species. For the same purpose I propose the name *Goniobasis columinis* for the extravagantly ornamented forms represented by Figs. 29 and 30 on Plate 31. A considerable series of these forms from different localities in those fresh-water Tertiary groups is given on Plate 31, which shows the wide range of variation and the transition of the forms and the character of their ornamentation.

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* For diagnosis of this genus and description and figures of the species, see An. Rep. U. S. Geol. Sur. Terr. for 1878, part I, pp. 66, 67, pl. 27, fig. 3.

† Since these paragraphs were written, Mr. Edgar A. Smith has published, in the Proceedings of the Zoological Society of London, two species under the new generic name of *Paramelania*, found living in Lake Tanganyika, in Africa, which seem to be congeneric with *Pyrgulifera*.

‡ These proposed species are respectively as follows: *Goniobasis tenera* (= *Cerithium tenerum* Hall), Frémont's Rep. Oregon & N. California, p. 308, pl. III, fig. 6; *G. simpsoni* Meek, Simpson's Rep. Great Basin Utah, p. 365, pl. v, fig. 1; *G. nodulifera* Meek (= *Cerithium nodulosum* Hall, Fremont, op. cit.), and *G. carteri* Conrad, Am. Jour. Conch., vol. iv, p. 280, pl. 18, figs. 6 and 7.

Although the genus *Goniobasis* has not been recognized in any of the strata of North America of later age than the Eocene, it cannot be doubted that it existed somewhere during the later epochs; probably in some of the streams which have since become upper branches of the Mississippi River system, where it is now abundant.

In the Miocene fresh-water deposit, which has been several times referred to as occurring in Southern Idaho and Northern Nevada, called the Truckee Group by King, no species of the genus *Goniobasis* have been recognized; but Mr. Gabb obtained a shell which he referred to *Lithasia* (a genus which is regarded as a member of the Ceriphasiidæ), and described it under the name of *L. antiqua*.* It is illustrated on Plate 32.

RISSOIDÆ.

The Rissoidæ, in consequence of their small size and comparative rarity, form an inconspicuous feature of the non-marine fossil faunæ which are discussed in this articie; and yet they are interesting because they show that as early at least as the close of Mesozoic time several genera of that family inhabited the then existing fresh and brackish waters; and that the most of those which have been discovered are either congeneric with existing forms, or so closely like them, that we cannot properly do otherwise than refer them to existing genera, although we may entertain some doubt as to their real affinities. Up to the present time eight fossil species have been published and referred to this family, most of which were obtained from the Laramie Group.

Among these the two living genera *Hydrobia* and *Bythinella* are recognized, and also one new genus, *Micropyrgus*, which was proposed by Mr. Meek.†

Four species, *Hydrobia subconica*, *H. anthonyi*, *H. eulimoides*, and *H. warrenana*, were described from the Laramie strata of the Upper Missouri River region by Meek & Hayden.‡ The first one comes from the Judith River beds, and the other three from the Fort Union beds. They are all illustrated on Plate 27. Except in the case of *H. anthonyi*, those authors express some doubt as to the true generic relations of these shells with *Hydrobia*, and reason for similar doubt seems to exist in relation to that species also. For present convenience, however, all four of these forms are left under *Hydrobia*, where those authors placed them.

The Fort Union Laramie beds also furnished Meek & Hayden with the types of their *Micropyrgus minutulus*,§ which they referred to the Rissoidæ. It is represented by copies of Mr. Meek's figures on Plate 26.

* Paleontology of California, vol. ii, p. 13, fig. 22.

† U. S. Geol. Sur. Terr., vol. ix, p. 574.

‡ For figures and descriptions of these four species, see U. S. Geol. Sur. Terr., vol. ix, pp. 571–573, pl. 43.

§ U. S. Geol. Sur. Terr., vol. ix, p. 575, pl. 43, fig. 18.

Among the species which occur in the coal-bearing beds near Evanston, Wyo., several of which species have already been herein noticed, there occurs a slender form which I have described as *Hydrobia recta.** It is represented on Plate 27.

Another species was obtained by Professor Powell from certain strata in Utah, which he then referred to the Bitter Creek Group, but which may probably prove to be of Laramie age. This form was described by me under the name of *Hydrobia utahensis.*† It is represented on Plate 27.

The only remaining species to be noticed under the Rissoidæ is *Bythinella gregaria*‡ Meek; which was obtained from the fresh-water Eocene strata at Pacific Springs, Southern Wyoming, by Dr. Hayden. This species is also represented on Plate 27.

VIVIPARIDÆ.

Among the non-marine gasteropods of North America, no family is more conspicuous than the Viviparidæ, and, although this family ranks high in its class, it seems to have been fully established, essentially as it exists to-day, in the Jurassic period, and its origin was doubtless much earlier. It seems to have existed in greatest abundance in the Laramie and Eocene periods, but that is perhaps largely due to the fact that the conditions of their existence and preservation were greater then. After the Eocene, the preservation of the family doubtless took place in rivers, the great lacustrine waters of the continent having then passed away, or what remained seemed to have been uncongenial to Viviparine life.

The small collection of fresh-water shells which was obtained by Meek & Hayden from near the Black Hills, and by them referred, with some doubt, to the Jurassic period, has already been mentioned in connection with *Unio nucalis* and *Planorbis veternus.* Two other species were included in that collection, namely, *Viviparus gillianus* and *Lioplacodes veternus*§ Meek & Hayden, both of which forms are illustrated on Plate 3.

Besides the original specimens of *Lioplacodes* no other representatives of the genus, either fossil or recent, have ever been discovered, and it therefore falls into the category of extinct types, a subject which will be briefly discussed on subsequent pages. These two species, being of Jurassic age, are the oldest members of the Viviparidæ that are yet known in North American strata.

No member of this family of Cretaceous age is yet known; and the next to be mentioned is a very large species from the Bear River

* Powell's Rep. Geology of the Uinta Mountains, p. 132.

† Powell's Geology of the Uinta Mountains, p. 132.

‡ An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 48, pl. 19, fig. 6.

§ For diagnosis of *Lioplacodes*, and description and figures of *L. veternus* and *Viviparus gillianus*, see Paleontology of the Upper Missouri, pp. 115, 116, pl. v.

Laramie beds of Southwestern Wyoming and the adjacent parts of Utah, which I described under the name of *Viviparus couesii.** It is represented on Plate 8.

The only species of *Viviparus* that is yet known to occur in the Judith River beds of the Upper Missouri River region is *V. conradi* Meek & Hayden,† which is illustrated on Plate 24; but the genus is abundantly represented in the Fort Union beds. Six species and one variety have been described by Meek & Hayden from the latter beds, under the following names (figures of which are given on Plates 24, 25, and 27): *Viviparus peculiaris*, *V. trochiformis*, *V. leidyi*, *V. leidyi* var. *formosa*, *V. reynoldsianus*, *V. leai* and *V. retusus.*‡ A glance at these illustrations will show that the species they represent are evidently allied to each other, the relationship being so close in some cases as to suggest that future discoveries of specimens will probably reveal intermediate forms that must reduce the number of recognizable species by one-half at least.

A form similar to but shorter and more compact than *Viviparus leai* has been obtained from the Laramie strata of Crow Creek Valley east of the Rocky Mountains in Colorado, which is figured on Plate 25, and which I have described under the name of *Viviparus prudentius.*§

From certain strata in Central Utah, probably belonging to the Laramie Group, Professor Powell obtained some forms of *Viviparus* which closely resemble *V. trochiformis* and *V. leidyi*, respectively, and with which they are probably identical.

At Black Buttes Station, in Southern Wyoming, *Viviparus plicapressus*‖ White, together with numerous other fresh and brackish water forms, have been found in the Laramie strata there, most of which have been mentioned on previous pages. This species is represented on Plate 24.

Another form, somewhat similar to *V. trochiformis*, to which I gave the name of *V. panguitchensis*,¶ was obtained by Professor Powell from strata in Southern Utah, which, doubtless, belong to the Laramie Group. It is figured on Plate 25.

One of the most interesting species that has as yet been obtained from the Laramie Group is *Tulotoma thompsoni*** White, which has been found in Southern Wyoming, west of the Rocky Mountains, and also east of the same in Colorado. It is illustrated on Plate 24. It is referred to the genus *Tulotoma* Haldeman, rather than to *Viviparus*, because of its nodular ornamentation; but since the operculum has

*An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 99, pl. 30, fig. 1.

†U. S. Geol. Sur. Ter., vol. ix, p. 579, pl. 42, fig. 15.

‡For descriptions and figures of all these forms, see U. S. Geol. Sur. Terr, vol. ix, pp. 577-584, pl. 44.

§An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 98, pl. 28, fig. 5.

‖An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 98, pl. 28, fig. 6.

¶ Powell's Rep. Geology Uinta Mountains, p. 123.

**An. Rep. U. S. Geol. Sur. Terr for 1878, Part I, p. 100, pl. 28, fig. 2.

never been discovered, all its known characteristics, except the one mentioned, agree with Viviparus, from which genus some naturalists do not separate *Tulotoma.* There appears to be good reason, however, for separating the two groups as distinct genera among living North American mollusca; but it is nevertheless reasonable to suppose that they had a common origin in a single generic form in some one of the geological epochs. Such a community of origin, and probable original generic identity of these fossil Viviparine forms, is strongly suggested by comparing some of the specimens of *T. thompsoni*, upon which the nodules are only faintly developed, with typical specimens of *V. trochiformis*, which have a closely similar form and similar revolving ridges, but no nodules. Indeed, some of the characteristics are so strikingly alike in both these species that one can hardly resist the suggestion that they themselves present the examples of such a community of origin as has been supposed. If this really was the case, and we accept *Tulotoma* as a genus separate from *Viviparus*, we have an example of the evolution of a new generic form without a break in a recognizable line of descent. In other words, it is a case in which the generic and specific divergences in the line of descent were coincident, the former being the more distinct of the two, at least in the features presented by the shell.

From certain strata in Utah, which were referred to the Tertiary, but which probably belong to the Laramie Group, I described a species of *Viviparus*, under the name of *V. ionicus*;* but all the known examples of it are very imperfect.

In the Eocene fresh-water strata of the West, perhaps the most abundant species next to *Goniobasis tenera* Hall, with which it is constantly associated, is *Viviparus paludinæformis* Hall.† This species has been found especially plentiful in those strata of Colorado, Wyoming, and Utah. It presents some degree of variation in different districts, and in different layers at one and the same locality; but it is not nearly so variable a shell as is its associate *Goniobasis tenera.* Illustrations of *V. paludinæformis* are given on Plate 30.

The only remaining species of *Vivaparus* to be regularly noticed in this article is *V. wyomingensis* Meek;‡ which is figured on Plate 30. It has been found only in the Bridger Group, where it is comparatively rare.§

The differences which are recognizable between the shells of living species of *Viviparus* and *Campeloma*, respectively, are quite as distinctly discernible among the fossil forms which are noticed in this article. Recognizing the two genera as separate and distinct, we find, as one of the earliest known North American species of *Campeloma*, a form that

*U. S. Expl. and Sur. West of the 100th Merid., vol. iv, p. 215, pl. xxi, fig. 6.

†Fremont's Rep. Oregon and N. California, p. 309, pl. iii, fig. 13.

‡Proc. Acad. Nat. Sci. Phila., vol. i, (3), 1871, p. 182.

§See references to *V. lyelli* Conrad, *V. glabra* H. C. Lea, and *Paludina subglobosa* Emmons, on a subsequent page, under the head of spurious and doubtful species.

was described by Meek from the Bear River Laramie beds of Southwestern Wyoming, under the name of *C. macrospira.** It is illustrated on Plate 8.

Meek & Hayden obtained from the Judith River Laramie beds of the Upper Missouri River region a species to which they gave the name of *Campeloma vetula;*† and examples of the same species have also been recognized in the Laramie strata at Black Buttes Station, in Southern Wyoming. It is illustrated on Plate 27.

Two other species of *Campeloma*, namely, *C. multistriata* and *C. multilineata* Meek & Hayden, were originally described from the Laramie strata near Fort Clarke, in the valley of the Upper Missouri.‡ Both forms are represented on Plate 27. The former has also been somewhat doubtfully recognized at Black Buttes Station, in Southern Wyoming, and the latter in the valley of Crow Creek, east of the Rocky Mountains, in Colorado.

Among a collection of Laramie fossils made several years ago in the valley of the Yellowstone River by Mr. J. A. Allen are some examples of *Campeloma multistriata* that show the species to be much more variable than was indicated by the description and figures given by Meek & Hayden. Some of these have the typical form and characteristics as described by them, but others are strongly shouldered at the distal side of the two last volutions. Examples of these are given on Plate 27.

Associated with the foregoing are numerous examples of a very variable species, some of which examples have the characteristics of *Campeloma*, except that they are more than usually elongate, and some of them appear to have the characteristics of *Lioplax*, Troschel. The species represented by these specimens appears to have never been described, and I therefore apply to it the name of *Campeloma* (*Lioplax ?*) *producta*, indicating the form represented by figures 21 and 22 on Plate 26, as the type. Figures of the associated forms, and which perhaps belong to the same species, are also given on the same plate.

Shell, elongate-ovate; test, moderately thick; spire, more than usually produced for a species of this genus; volutions, six or seven, usually slightly flattened, or having a faint revolving depression upon the distal side near the suture, which is more apparent upon the larger than the smaller volutions; suture, deep and abrupt upon the proximal side; aperture and lips having the usual characteristics of *Campeloma* or *Lioplax;* surface, marked by the usual lines of growth, and by somewhat numerous revolving striæ which are often obscure, but upon the smaller volutions of some of the examples a few of the striæ are so strong as to produce a faint angularity. Among these examples are others which possess the general characteristics of those which are regarded as the

*See An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 102, pl. 30, fig. 2.

† U. S. Geol. Sur. Terr. vol. ix, p. 587, pl. 42, fig. 14.

‡ U. S. Geol. Sur. Terr., vol. ix, pp. 586 and 588, pls. 43, fig. 15, and 44, fig. 1

types; but two or three of the revolving striæ upon the smaller volutions of these examples are much more prominent than in the case of typical examples. I at present, however, regard these as only varieties of a very variable species. Examples of this variety are illustrated with the others on Plate 26.

The collection made by Mr. Allen also contains *Viviparus trochiformis* and *V. retusus* and *V. leai* Meek & Hayden, and *Unio senectus* White.

VALVATIDÆ.

The Valvatidæ like the Rissoidæ are inconspicuous among the fossil non-marine faunæ of North America, but the family which is essentially a fresh-water one, seems to have become established at least as early as Mesozoic time. Indeed, although the *Valvalidæ* are among the more highly organized of the fresh-water mollusca, they seem to have co-existed with the earliest fresh-water gill-bearing mollusks that are yet known to us.

Among the fresh-water Jurassic fossils that were obtained by Meek & Hayden from the vicinity of the Black Hills, and which have been already several times mentioned on previous pages, is a form to which those authors gave the name of *Valvata scabrida*,* and which is the earliest known species of that genus in North American strata. It is illustrated on Plate 3, by a copy of Meek's figure.

The next known species in the order of time is *V. nana* Meek,† which was obtained by him from the Cretaceous estuary deposit at Coalville, Utah, which has before been mentioned. It is illustrated on Plate 5.

From the Judith River Laramie beds of the Upper Missouri River region, Meek & Hayden described a form under the name of *Valvata ? montanaensis;* and from the Fort Union beds of that region, two others, under the names, respectively, of *V. subumbilicata* and *V. parvula*.‡ The latter is probably only a variety of the former. All three of the last named forms are illustrated on Plate 27 by copies of Meek's figures.

For the purpose of presenting the subject of the foregoing pages synoptically, the following table has been prepared. It is intended as a list of all the known species of the fossil non-marine mollusca of North America; and is also intended to show the geological position of each species, and consequently the present known range in geological time, of the families and genera to which they belong. The names of the divisions of geological time used in this table will be found explained on page 414 *et seq.*

In making up the following list, preoccupied names, and generic names which have been wrongly used, are omitted, but such as are regarded as

*Paleontology of the Upper Missouri, p. 113, pl. iv, fig 2.

† See An. Rep. U. S. Geol. Sur. Terr. for 1878, Part I, p. 33, pl. 12, fig. 17.

‡ For descriptions and figures of these three forms see U. S. Geol. Sur. Terr., vol. ix, pp. 590–592, pl. 42, and woodcuts.

synonyms that have been made such by mistaken identification of species are given in italics. It is probable that several other like synonyms still remain among those that are not italicised, but it is not thought best to thus characterize them without further investigation, because, as has been already remarked, this article is not a revision of these faunæ, but merely a review. Those which are enumerated under the head of spurious and doubtful species on subsequent pages are purposely omitted from this list. Materials for large additions to this list will, without doubt, be obtained through future operations of the Survey, and from other sources.

TABULAR VIEW OF THE NON-MARINE FOSSIL MOLLUSCA OF NORTH AMERICA.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary.			Post-tertiary.	
							Eocene.	Miocene.	Pliocene.	Quaternary.	Recent.
CONCHIFERA.											
OSTREIDÆ.											
Ostrea subtrigonalis Evans & Shumard						×					
O. glabra Meek & Hayden						×					
O. wyomingensis Meek						×					
O. arcuatilis M.						×					
O. insecura White						×					
ANOMIIDÆ.											
Anomia propatoris W					×						
A. micronema M						×					
A. gryphorhynchus M						×					
MYTILIDÆ.											
Volsella (Brachydontes) regularis W						×					
V. (B.) laticostata W						×					
UNIONIDÆ.											
Anodonta? catskillensis (Vanuxem) Hall	×										
A.? angustata (Vanuxem) Hall	×										
A. propatoris W						×					
A. parallela W						×					
Naiadites carbonaria Dawson		×									
N. elongata D		×									
N. lævis D		×									
Margaritana nebrascensis M. & H.					×						
Unio cristonensis M.			×?								
Unio gallinensis M.			×?								
U. terræ-rubræ M			×?								
U. nucalis M. & H.				×							
U. stewardi W				×							
U. (Margaritana?) hubbardi Gabb					×						
U. penultimus G					×						
U. belliplicatus M.						×					
U. vetustus M						×					
U. subspatulatus M. & H.						×					
U. danæ M. & H.						×					
U. deweyanus M. & H.						×					
U. cryptorhynchus W						×					
U. senectus W						×					
U. primævus W						×					
U. priscus M. & H.						×					
U. couesii W.						×					
U. endlichi W						×					

Tabular view of the non-marine fossil mollusca of North America—Continued.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary. Eocene.	Tertiary. Miocene.	Tertiary. Pliocene.	Post-tertiary. Quaternary.	Post-tertiary. Recent.
CONCHIFERA—Continued.											
UNIONIDÆ—Continued.											
Unio propheticus White						×					
U. brachyopisthus W						×					
U. proavitus W						×					
U. aldrichi W						×					
U. goniambonatus W						×					
U. holmesianus W						×					
U. gonionotus W						×					
U. mendax W						×					
U. clinopisthus W							×				
U. meekii W							×				
U. shoshonensis W							×				
U. washakiensis Meek							×				
U. haydeni M							×				
U. tellinoides Hall							×				
CYRENIDÆ.											
Cyrena dakotensis Meek & Hayden					×						
C. carletoni M					×						
Corbicula (Veloritina) durkeei M						×					
C. occidentalis M. & H						×					
C. bannisteri M						×					
C. cytheriformis M. & H						×					
C. nebrascensis M. & H						×					
C. (Leptesthes) fracta M. & H						×					
C. (L.) subelliptica M. & H						×					
C. (L.) macropistha W						×					
C. (L.) planumbona M						×					
C. umbonella M						×					
C. augheyi W						×					
C. berthoudi W						×					
C. cleburni W						×					
C. obesa W						×					
C. cardiniæformis W						×					
Sphærium planum M. & H						×					
S. recticardinale M. & H						×					
S. formosum M. & H						×					
S. subellipticum M. & H						×					
S. rugosum M								×			
S. ? idahoënse M								×			
PISIDIIDÆ.											
Pisidium saginatum W						×					
CORBULIDÆ.											
Corbula pyriformis M						×					
C. englemanni M						×					
C. undifera M						×					
C. undifera, var. subundifera W						×					

Tabular view of the non-marine fossil mollusca of North America—Continued.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary. Eocene.	Tertiary. Miocene.	Tertiary. Pliocene.	Post-tertiary. Quaternary.	Post-tertiary. Recent.
CONCHIFERA—Continued.											
CORBULIDÆ—Continued.											
Corbula subtrigonalis Meek & Hayden						×					
C. perundata M. & H.						×					
C. crassatelliformis Meek						×					
C. tropidophora M.						×					
C. mactriformis M. & H						×					
GASTEROPODA.											
AURICULIDÆ.											
Melampus? antiquus M					×						
Rhytophorus priscus M						×					
R. meekii White						×					
LIMNÆIDÆ.											
Limnæa (Limnophysa) nitidula M						×					
L. (Acella) haldemani W						×					
L. (Pleurolimnæa) tenuicostata M						×					
L. vetusta M							×				
L. similis M							×				
L. (Leptolimnea) minuscula W							×				
L. meekii Evans & Shumard								×			
L. shumardi M								×			
L. (Polyrhytis) kingii M									×?		
Planorbis veternus M. & H				×							
P. convolutus M. & H						×					
P. (Bathyomphalus) amplexus M. & H						×					
P. (B.) planoconvexus M. & H						×					
P. (B.) kanabensis W						×					
P. (Gyraulus) militaris W						×					
P. utahensis M							×				
P. spectabilis M							×				
P. cirratus W							×				
P. æqualis W							×				
P. vetustus M. & H								×			
P. nebrascensis E. & S								×			
P. leidyi M. & H								×			
P. lunatus Conrad								×?			
Carinifex (Vorticifex) tryoni M								×			
C. (V.) binneyi M								×			
PHYSIDÆ.											
Physa carletoni M					×						
P. copei W						×					
P. felix W						×					
P. pleromatis W							×				
P. bridgerensis M							×				
P. secalina E. & S								×			
Bulinus atavus W						×					
B. subelongatus M. & H						×					

Tabular view of the non-marine fossil mollusca of North America—Continued.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary. Eocene.	Tertiary. Miocene.	Tertiary. Pliocene.	Post-tertiary. Quaternary.	Post-tertiary. Recent.
GASTEROPODA—Continued.											
PHYSIDÆ—Continued.											
Bulinus longinsculus Meek & Hayden						×					
B. rhomboideus M. & H						×					
B. disjunctus White						×					
B. kanabensis W						×					
ANCYLIDÆ.											
Acroloxus minutus M. & H						×					
Ancylus undulatus Meek								×			
Latia dallii W								×			
ARIONIDÆ.											
Zonites priscus Dawson		×									
Z. marginicola Conrad								×?			
VITRINIDÆ.											
Vitrina? obliqua M. & H.						×					
Hyalina? occidentalis M. & H.						×					
H.? evansi M. & H.						×					
Macrocyclis spatiosa M. & H.							×				
HELICIDÆ.											
Dawsonella meekii Bradley		×									
Helix vetusta M. & H.						×					
H. (Strobila?) kanabensis W						×					
H. (Patula?) sepulta W						×					
H. (Triodopsis?) evanstonensis W						×					
H. (Aglaia?) peripheria W							×				
H. (Arianta?) riparia W							×				
H. (A.?) leidyi Hall & Meek								×			
H.? veterna M. & H.							×				
Thaumastus limnæformis M. & H.						×					
Bulimus floridanus Conrad							×				
Columna teres M. & H						×					
C. vermicula M. & H						×					
PUPIDÆ.											
Strophites grandæva Dawson	×										
Pupa vetusta D		×									
P. bigsbyi D		×									
P. vermillionensis Bradley		×									
Anthracopupa ohioensis Whitfield		×									
Pupa (Leucocheila?) incolata W							×				
P. (Pupilla?) arenula W							×				
P. (P.?) atavuncula W							×				
SUCCINIDÆ.											
Succinea (Brachyspira) papillispira W							×				
NERITIDÆ.											
Neritina nebrascensis M. & H.				×							
N. naticiformis W						×					

Tabular view of the non-marine fossil mollusca of North America—Continued.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary.			Post-tertiary.	
							Eocene.	Miocene.	Pliocene.	Quaternary.	Recent.
GASTEROPODA—Continued.											
NERITIDÆ—Continued.											
Neritina volvilineata White						×					
N. bruneri W						×					
N. bannisteri Meek					×						
N. (Velatella) bellatula M					×						
N. (*V.*) carditoides M					×						
N. (V.) baptista W						×					
CERITHIIDÆ.											
Cerithidea nebrascensis Meek & Hayden						×					
MELANIIDÆ.											
Melania wyomingensis M						×					
M. claibornensis Heilprin							×				
M. larunda W						×					
M. ? insculpta M						×					
M. ? sculptilis M								×			
M. ? subsculptilis M								×			
M. ? taylori Gabb								×			
Pyrgulifera humerosa M						×					
Melanopsis ? americana W						×					
CERIPHASIIDÆ.											
Goniobasis cleburni W						×					
G. chrysallis M						×					
G. chrysalloidea W						×					
G. macilenta W						×					
G. (Lioplax ?) endlichi W						×					
G. convexa M. & H						×					
G. invenusta M. & H						×					
G. sublævis M. & H						×					
G. omitta M. & H						×					
G. ? subtortuosa M. & H						×					
G. gracilenta M						×					
G. (Lioplax ?) nebrascensis M. & H						×					
G. (Lioplax ?) tenuicarinata M. & H						×					
G. tenera Hall							×				
G. nodulifera M							×				
G. simpsoni M							×				
G. carteri Conrad							×				
Lithasia antiqua Gabb								×			
Cassiopella turricula W						×					
RISSOIDÆ.											
Hydrobia subconica M						×					
H. anthonyi M. & H						×					
H. eulimoides M						×					
H. warrenana M. & H						×					
H. recta W						×					
H. utahensis W						×					

Tabular view of the non-marine fossil mollusca of North America—Continued.

	Devonian.	Carboniferous.	Triassic.	Jurassic.	Cretaceous.	Laramie.	Tertiary. Eocene.	Tertiary. Miocene.	Tertiary. Pliocene.	Post-tertiary. Quaternary.	Post-tertiary. Recent.
GASTEROPODA—Continued.											
RISSOIDÆ—Continued.											
Micropyrgus minutulus Meek & Hayden						×					
Bythinella gregaria Meek							×				
VIVIPARIDÆ.											
Viviparus gillianus M. & H				×							
Lioplacodes veternus M. & H				×							
Viviparus couesii White						×					
V. conradi M. & H						×					
V. peculiaris M. & H						×					
V. trochiformis M. & H						×					
V. leidyi M. & H						×					
V. leidyi var. formosus M. & H						×					
V. leai M. & H						×					
V. reynoldsianus M. & H						×					
V. retusus M. & H						×					
V. prudentius W						×					
V. plicapressus W						×					
V. panguitchensis W						×					
V. ionicus W						×?					
V. paludinæformis Hall							×				
V. wyomingensis M							×				
Tulotoma thompsoni W						×					
Campeloma macrospira M						×					
C. vetula M. & H						×					
C. multistriata M. & H						×					
C. multilineata M. & H						×					
C. (Lioplax?) producta W						×					
VALVATIDÆ.											
Valvata scabrida M. & H				×							
V. nana M					×						
V. montanaensis M						×					
V. suburnbilicata M. & H						×					
V. parvula M. & H						×					

SPURIOUS AND DOUBTFUL SPECIES.

The species mentioned in the following notes were not included in the foregoing list because a part of them do not belong to the non-marine mollusca as they were supposed to do by the authors who first described them; concerning the true character of others there is some room for doubt, and the published information concerning the remainder is either unsatisfactory or erroneous.

In the Annual Report of the Geological Survey of New York for 1839, pp. 65, 66, Mr. T. A. Conrad published descriptions of four species of mollusks from the Medina Sandstone (Upper Silurian) under the names respectively, of *Planorbis trilobatus*, *Cyclostoma pervetusta*, *Unio primigenius*, and *U. orthonotus*. All these are now known to be marine species, and to belong, respectively, to the genera *Bucania*, *Pleurotomaria*, *Cypricardites*, ? and *Modiolopsis*.

In the American Journal of Science and Arts (1.), Vol. XXIX, p. 149 *et seq*, Plate 1, Figs. 17–22, Dr. S. G. Morton briefly described and rudely figured five forms which he named, respectively, *Unio petrosus*, *U. tumulatus*, *U. terrenus*, *U. saxulum*, and *Anodonta hildrethi;* and which he reported as having been obtained from Coal-measure strata in southern Ohio. If these fossils were really obtained from Coal-measure strata, our present knowledge of the fauna of that period, at least as it was developed in the region indicated, makes it improbable that they were correctly referred to the genera *Unio* and *Anodonta*. It is more probable that they were obtained from a post Tertiary deposit, and that they really belong to living species.

In the proceedings of the Academy of Natural Sciences of Philadelphia, 1868, pp. 162–164, Dr. Isaac Lea described ten species under the following names, respectively: *Unio nasutoides*, *U. radiatoides*, *U. subrotundoides*, *U. cariosoides*, *U. humerosoides*, *U. roanokoides*, *U. ligamentoides*, *U. alatoides*, *Anodonta grandioides*, and *A. corpulentoides*. They were obtained from a deposit in New Jersey which Dr. Lea regarded as "Lower Cretaceous," but which is almost certainly of post Tertiary date. Moreover, they probably belong to the living species, the resemblance to which is so plainly indicated by the respective names which Dr. Lea applied to them.

In Paleontology of California, Vol. II, p. 88, Mr. Gabb speaks of having found the following species of *Helix* in a fossil condition, in different parts of that State, part of them being referred to strata of Pliocene age, although the species are all now living in that region: *Helix fracta* Newcomb, *H. hildebrandi* Newcomb, *H. mormonum* Pfr., *H. tryoni* Newcomb, and *H. tudiculata* Binney.

Mr. H. C. Lea described a shell under the name of *Turbo glaber* in the

Transactions of the American Philosophical Society, Vol. IX, p. 267, Plate 37, Fig. 87, which Mr. Conrad stated in Proc. Acad. Nat. Sci. Philad. 1862, p. 567, to be identical with the *Paludina subglobosa* of Emmons (Geology of North Carolina, p. 273, Fig. 186). This assumed identity is doubtful. The latter is probably either a *Viviparus* or a *Campeloma*. The former is probably neither.

From the Eocene strata of Wilmington, North Carolina, Sir Charles Lyell obtained the natural cast of a shell which he referred to *Paludina* and published (Jour. Geol. Soc. Lond., Vol. I, p. 431) a figure of it, but without a specific name. Conrad subsequently (Am. Jour. Conch., Vol. I, p. 32) gave the name *Viviparus lyelli* to this form. It is probably a true *Viviparus*, but its characters are not sufficiently known to settle the question definitely.

In Fremont's Report on Oregon and Northern California, pp. 308, 309, Plate III, Professor Hall has figured and described several forms which have not been mentioned in the body of this article. They probably belong to a fresh-water fauna, although it was supposed that they were of marine origin when they were described. The specimens he had were evidently imperfect, but I have never seen them, and I have been unable by aid of Professor Hall's descriptions and figures to identify the species which they represent among any collections made in the West. The following are the names given them by Professor Hall in the work cited: *Nucula impressa* (?), *Cytherea parvula*, *Plemotomaria uniangulata*, *Cerithium fremonti*, *Natica* (?) *occidentalis*, and *Turritella bilineata*.

In Vol. III, p. 10, American Journal of Conchology, Mr. T. A. Conrad published a description and figure of a shell from the Carboniferous strata of Kansas, under the new generic name of *Prisconaia*, referring it to the Unionidæ. It is probably a species of *Schizodus*, and therefore belongs to the Trigoniidæ.

In Vol. VI, of the same Journal, Conrad described *Melania decursa* and *Anodonta decurtata* "from Colorado." Because he did not state any locality or formation from which they were obtained, these species are not include in the text of this article. The former is probably from Oregon and identical with *M. taylori* Gabb.

GENERAL DISCUSSION.

Upon the preceding pages I have presented a synopsis of all the known fossil non-marine mollusca of North America, in the course of which it has been shown that many of the types now recognizable among the living non-marine mollusks have great antiquity; but that certain of the types which have been recognized only among the fossil species, and are therefore regarded as certainly extinct, were contemporaneous with many of those which survived. Before closing this article it will be proper to present some general discussion of the nature of the relations which these fossil forms bear to each other and to those now living, and to make some suggestions as to the probable lines of descent of the latter, and the causes of the destruction of those which have failed to survive.

In the present state of general knowledge of the subject, it seems hardly necessary to state in detail that these relations are regarded by naturalists as genetic in their character, and that the various forms which we discover, both living and fossil, have been evolved from pre-existing primary forms. If the theory of the evolution of organic things is to be accepted in any sense, it seems necessary to conclude that molluscan life began in the sea, and that all fresh-water and land mollusca have been primarily derived from those of marine origin.*

While it is not my purpose to discuss this theory as such, it will be necessary, in the course of the remarks which are to follow, not only to refer to some of the phases which the subject presents when viewed in relation to the probable origin and distribution of the non-marine fossil mollusca, but it will also be necessary to adopt that theory at least as a working and explanatory hypothesis. Indeed, without an hypothesis of this kind, the structural relations which we find to exist between those fossil forms among themselves and between the fossil and living forms are meaningless and unimportant. With the acceptance of such a theory investigations like these become part of the elucidation of a grand history which has fortunately been self-registering and subject to errors only of interpretation arising mainly from imperfection of evidence.

If, as has been premised, the first molluscan life began in the sea, and the first non-marine mollusca were evolved from those which originated in marine waters, we may well inquire whether at least a part of those non-marine forms which subsequently existed had not also a similar origin, and whether we may not consequently regard the great tide of

* It is well known that in the case of some families of living mollusca, while certain species will thrive in brackish waters, none of them will live in perfectly fresh waters. Living examples of this fact are common, and some have been observed among the Laramie fauna. But too many facts are known concerning the ability of other mollusks to pass from saline to fresh waters, to leave room for reasonable doubt that the fresh-water mollusca were primarily derived from the marine. Moreover, the evidence seems conclusive that many species whose living congeners are found exclusively in fresh waters were in former geological epochs able to live in waters that were more or less saline. It is the opinion of the writer also that in all or nearly all cases where marine types of mollusks, fishes, &c., have been found in brackish and fresh waters, or their remains in deposits of such origin, they have become habituated to such waters by having been landlocked by the rising sea-bottom around them. That is, they were probably forced to conform to a change of habitat that they would not have voluntarily chosen. It is probable also that, as a rule, the fresh water mollusca have been developed as such by compulsion of this character and not by voluntarily forsaking marine for fresh waters. Once developed as purely fresh water mollusca, certain forms at least became incapable of a return to marine waters; but certain other forms seemed capable of surviving a partial but not complete freshening of the waters.

non-marine molluscan life that has come down to us from the past as having been made up of many contributing streams which had the sea as their source, rather than regard it, figuratively speaking, as a stream having an ancient and perhaps single source, augmenting in volume and throwing off from itself numerous branches which became collateral lines of descent. It is reasonable to suppose that both these conditions of evolution have prevailed, namely, that while some of the genetic lines of the non-marine mollusca may, and doubtless do, run back to paleozoic time, the families of non-marine mollusks have had many accessions from the sea from time to time during the successive geological ages, and that each of these accessions was, at least potentially, the source of subsequent collateral lines of descent. But the question of the primary origin of these lines of descent is not an essential one in these discussions, because I propose now only to consider the evidence that they have existed, and make some inquiry into the character and relations of certain of those lines which may be regarded as directly lineal. In these inquiries I shall treat coincidences of structure among the fossil and recent shells which come under consideration not only as indications but as proof of genetic relationship; and this relationship as fundamentally pertaining to the geological and zoological history of the molluscan life which they represent.

It is true that the incompleteness of the material which is or that we may ever hope to have available for study is so great as to leave many gaps, at least in the details, of the life-histories of all the types which have been recognized among the fossil mollusca.

When, therefore, we come to trace the probable lines of succession of the various types of non-marine mollusks, we are met with certain difficulties, both apparent and real; and in endeavoring to account for the manner in which those lines may have been preserved unbroken through successive geological periods, the difficulty seems especially great, when casually considered, in the case of the fresh-water gill-bearing mollusca.

The prevalence of the sea has always been practically universal; and the various movements which the earth's crust has undergone since life began in the sea, while they have repeatedly disturbed or destroyed the habitats of its molluscan denizens in certain localities, and have broken many of the lines of genetic succession of types that had from time to time become established, there has evidently never been anything like such a general destruction of life in the sea as would either break or materially interfere with the greater part of the principal lines of such succession. In short, the marine field for the development and perpetuity of molluscan life has been ample and unbroken from the beginning to the present time, and we are at no loss to understand how continuous lines of genetic succession of its denizens may have extended down through all the geological ages, modified, it is true, by immediately environing and cosmical causes, but still unbroken. We may at least conclude that if every molluscan species that now exists in the sea has not been lineally derived from the earliest molluscan forms that have existed in it, there have been no such changes of its physical conditions as would preclude such a possibility.

When we come to the study of the fossil pulmonate mollusca, especially the land-shells, we have also little or no difficulty in understanding how it has been possible for continuous lines of existence of these mollusks to be preserved through successive geological periods upon any continental area, such for example as North America, notwithstanding the numerous and great physical changes that have taken place within its area during those periods. Being air-breathers, nothing has apparently occurred to prevent their safe migration to other ground whenever that which they may have at any time occupied became uncongenial by reason of physical changes, because, as a rule, those changes were effected so slowly that a continuity of congenial habitat for such mollusks was not necessarily broken. They were thus apparently as capable of preserving a continuous existence through successive geological periods as the marine mollusca were.

But, as before intimated, when we come to the study of the fossil shells of the fresh-water gill-bearing mollusca, which in their living state must necessarily have been confined to fluvatile and lacustrine waters, it is not easy to understand, without a special explanation, how continuous genetic lines could have been preserved (as we find they were preserved even down to the present time) through a succession of geological periods, during which the great lakes, as we know, and all the rivers, as is generally but erroneously believed, in which those mollusks lived, have been successively obliterated.* Rivers are separated from each other by intervening land, and, running to the sea, their mouths are separated by marine waters, neither of which barriers are fresh-water gill-bearing molluska capable of passing. But if it can be shown that throughout those geological periods and down to the present time there has been direct continuity of fresh water by means of lakes or rivers, or both, the case is plain enough. Indeed, as precarious as the existence of continuous life of that kind may seem to have been, under the circumstances of such vast physical changes as are known to have occurred, we are forced to conclude that it is in this direction that we must seek for an explanation of the manner in which were preserved

*It may be suggested that the distribution of these forms from one river or river system to another, may have taken place by the transportation of the mollusks or their eggs by aquatic birds. While such transportation is admitted to have been possible in some cases, it cannot be admitted as a probable cause of any considerable part of the distribution that must have occurred during the several geological epochs in which the molluscan types referred to are known to have existed. Notwithstanding the annual migration of myriads of aquatic birds between the northern and southern portions of North America at the present time, and doubtless also ever since it has been a continent, the fresh-water molluscan faunæ of those regions, respectively, are still distinct.

the fresh-water molluscan types that have been found in the various groups of North American Mesozoic and Cenozoic strata, and that we also find among living mollusca. That is, they have been preserved through a continuity of habitat in the congenial fresh waters of lakes and rivers, flourishing in the lakes, when they existed, as well as in the rivers, and escaping by the streams which were the former outlets and inlets of the lakes, but which continued to flow after the obliteration of the latter, as rivers or tributaries of river systems.

Lakes are only parts of unfinished river systems which disappear by being drained when the system is finished by the gradual wearing down of its channel. A lake consequently contains essentially the same aqueous fauna that the fluvatile portion of the system does in case the water of the lake is wholly fresh; or a modification of that fauna if the waters of the lake are more or less saline. The great lakes which existed in Western North America in the Tertiary and Laramie periods successively became obliterated, but we may reasonably conclude that at least a part of the river channels of to-day have existed as such from earlier geological times; that the greater part of them were established in epochs anterior to our own, and that those of some of the tributaries of the present Mississippi River system are identical, at least in part, with former outlets or inlets, or both, of the great ancient lakes which have just been referred to. Consequently we may reasonably conclude also that the molluscan fauna of the Mississippi River system is lineally descended from the faunæ of those ancient lakes, and the river systems of which they constituted lacustrine portions.* This view is confirmed

* I here include the Laramie Sea in the use of the term "lacustrine," the term "sea" being used simply to indicate that its waters were saline and not fresh; just as the Black and Caspian are called seas instead of lakes, and for the same reason. It may seem to be the use of a misnomer to speak of the Laramie Sea as a part of a river system, because it was so immensely large, and the continental area which was drained into it was proportionally so small, but if these views concerning the conditions which then existed are correct, that sea, with its tributaries and outlet, differed only in degree and not in kind, from any river system which has a lake of any size in its principal course. The waters of that sea having been saline, the Laramie hydrographic system more nearly resembled that of the Black Sea than any other now existing that is equally well known; and, although the ancient sea has long since disappeared from the face of the earth, its "Hellespont" still flows as a part of the Missouri River, or of some one of its tributaries.

The commingling of brackish-water and fresh-water fossil forms in an estuary deposit is readily explained by the supposition that the river which debouched into the estuary brought down the latter and mingled them with the former. But the commingling of brackish-water and fresh-water forms occurs in some portions of the Laramie deposits under such conditions as to compel the belief that some of them at least lived and thrived together. There is evidence also that the fresh-water fauna proper of the Laramie system not only inhabited the streams which emptied into its sea, but that in great and shifting areas of the sea itself the waters were sufficiently fresh to allow the existence in them of such mollusks as *Unio*, *Goniobasis*, *Viviparus*, *Campeloma*, &c., and saline enough in other parts for the existence of *Ostrea*, *Anomia*, *Corbula*, &c. This view of the conditions of the Laramie Sea being accepted it is plainly seen to have been, what Ritter has aptly termed, an unfinished river system, though an extreme example.

by the identity of the living with the fossil molluscan types, which has already been referred to.

Rivers have of course existed ever since a sufficient extent of continental surface was raised above the sea to accumulate the waters that fell from the clouds; and in view of the mighty changes that have taken place during the progressive growth of the North American continent, especially the elevation of its great mountain systems and plateaus, it would be natural to suppose that the earliest rivers at least have been obliterated. Some have no doubt been obliterated, but contrary to what has been the general belief, the recent labors of Powell, Dutton, and others have shown that the rivers of North America have been among the most persistent of its physical features; that many of them are older than the mountain ranges of the regions which the rivers traverse, and that they have not yielded their "right of way" when the mountain ranges and plateaus were raised, but continued during and after that elevation to run in essentially the same lines which they had chosen when the region they traversed was a plain instead of a mountainous one. That ancient river systems have been in some, and perhaps many instances, to a greater or less extent divided, as a consequence of unequal continental elevation, or from other causes, is quite certain; and it was doubtless in part by this means that the dispersion of fresh-water mollusca into different river systems has been effected. That some formerly existing rivers with their lacustrine portions have been obliterated and their molluscan faunæ destroyed is doubtless also true, but these facts do not necessarily affect the correctness of the view concerning the general persistent integrity of rivers and river systems which has been referred to.*

The coalescence of separate minor drainage systems by the confluence of their lower portions into a common channel during the progressive elevation of the continent has also been an important means of the dispersion of fluvatile mollusca. By such coalescence, what were once seperate rivers or minor drainage systems became parts of larger ones; as, for example, the union of the separate peripheral members of the great Mississippi River system, which now forms a common drainage for the principal part of the continent. The Ohio and Upper Mississippi, the two most ancient portions of the present great system, were once separate rivers, emptying into a northern extension of the Great Gulf; and it is practically certain that neither of them received that portion of the mol-

* The discovery of so few traces of fluvatile deposits as have been made among the strata of the earth is probably due to the persistent adherence of rivers to their ancient channels. When land upon which rivers have formerly run has subsided beneath the level of the sea, the fluvatile deposits were doubtless destroyed by the encroaching marine waters. If the land continued to rise, as has been so generally the case in the gradual production of the North American continent, the earlier river deposits were swept away in later times by their own waters, as their valleys were broadened and deepened. It is therefore, as a rule, only in the deposits of lacustrine portions of ancient river systems that their faunæ have been preserved.

luscan fauna, which now so strongly characterizes them, until after the confluence with them of the western portions of the present great river system which brought that fauna from its ancient home in the western part of the continent.*

Rivers having been thus persistent, and the manner in which confluence of the waters of many of them has been effected being understood, it is no more remarkable that the types of fresh-water gill-bearing mollusca have come down to us from former geological periods practically unchanged, than it is that marine and land mollusca have reached us bearing the imprint of their really ancient, but what we have been accustomed to call, modern types.

The manner in which the various types of molluscan life have probably come down to the present time from former geological periods having been pointed out, we come next to inquire to what extent the views thus expressed are confirmed by a comparison of the living with the fossil non-marine mollusca. As regards the fresh-water and land mollusca, it may be stated without hesitation that those views are fully confirmed by such a comparison. That is, we find between the fossil and living faunæ such an extensive agreement of types as to compel the conclusion that the former represent the latter ancestrally. It is true our investigations have shown that some of the types of fresh-water gill-bearing mollusca which existed in Mesozoic and Cenozoic time are not represented among living forms, having become extinct; but every family, almost every if not every genus, and many of the subordinate divisions of those genera that are known among living North American fresh-water mollusca, have been recognized among the species that constitute the different faunæ, the fossil remains of which have been collected from the Mesozoic and Cenozoic strata of Western North America.† These investigations also show the interesting fact that while considerable numbers of types among the mollusca referred to have been from time to time extinguished, the extinguishment having in some instances taken place as late as the Pliocene epoch, few or no new ones appear to have been introduced to replace any of them

* These remarks are made with especial reference to the Unionidæ; but they are also applicable to other gill-bearing mollusca, and they will no doubt apply with equal force to at least a part of the ichthyc fauna of that great river system. The progenitors of the ganoids now living in that river system were doubtless originally land-locked in the Laramie sea, continued through the fresh water Eocene lakes, and finally escaped to the present river system in the manner already suggested.

† The extinctions referred to seem to have been caused by a failure of the waters in which the lost types lived, to secure a continuous flow into any existing river system, This is of course equivalent to supposing an exception to the rule already announced. that rivers have been persistent; but such exceptions being well authenticated would only add strength to the argument in favor of the rule. The portion of the Laramie Group known as the Bear River beds, and the Miocene Truckee Group of Nevada, Idaho, and Oregon; both containing extinct types, may be taken as indicating a failure of the waters in which they were respectively deposited to secure persistent continuity during subsequent time.

since the closing epochs of Mesozoic time. Fresh-water mollusca ap pear to have been less subject than marine mollusca to those cosmical influences which, from age to age and from epoch to epoch of geological time, progressively impressed the marine mollusca with their wonderful diversity of form and structure.

While so large a proportion of the types among the fossil fresh-water and land mollusca are clearly recognized among those now living, a large proportion, if not the greater part of the fossil brackish-water types which are presented in this article are different from those of the corresponding fauna now living. This is doubtless due to the fact that the lines of succession of most of the brackish-water mollusca, the remains of which we have had opportunity for study, were denizens of the brackish-water Laramie Sea, and were cut off by the final freshening of its waters, from which there was no escape to the coasts of the open sea, where they might have had a congenial habitat, while their contemporaries of the land and fluvatile waters survived. This fact has been mentioned on previous pages in connection with the presentation of the several types referred to. It is, however, a remarkable fact that at least five of the types that are recognized among the fauna of the Laramie Group, namely, *Bathyomphalus*, *Cerithidea*, *Pyrgulifera*, *Melanopsis*, and true *Melania*, have never been found among the living fauna of North America, but are represented by living species in the old world. But this and other questions pertaining to the Laramie invertebrate fauna will be discussed in a monograph of that fauna now in preparation.

PLATE 1. DEVONIAN.

STROPHITES GRANDÆVA Dawson. (Page 455.)

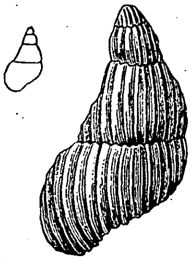
FIG. 1. Fragment, enlarged. The small outline to the left shows the natural size. After Dawson.

ANODONTA? ANGUSTATA (Vanuxem) Hall. (Page 424.)

FIG. 2. Right side view, natural size.
FIG. 3. Dorsal view of same. After Vanuxem.

ANODONTA? CATTSKILLENSIS (Vanuxem) Hall. (Page 424.)

FIG. 4. Right side view, natural size. After Vanuxem.



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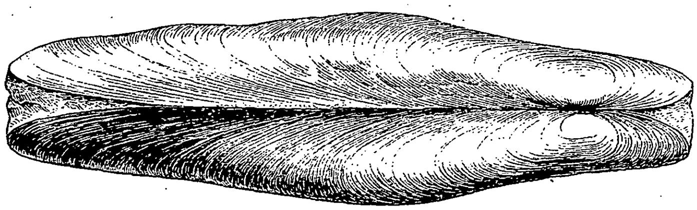

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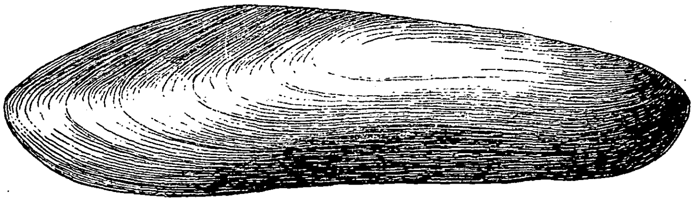

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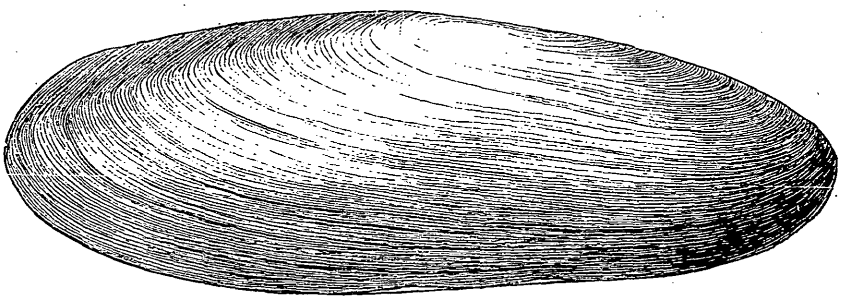

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DEVONIAN.

PLATE 2. CARBONIFEROUS.

PUPA VETUSTA Dawson. (Page 456.)

FIG. 1. Lateral view, enlarged.
FIG. 2. Apertural view, enlarged. After Dawson.

DAWSONELLA MEEKI Bradley. (Page 453.)

FIG. 3. Apertural view, enlarged.
FIG. 4. Outline of under view, enlarged. After Whitfield.

ANTHRACOPUPA OHIOENSIS Whitfield. (Page 456.)

FIG. 5. Lateral view, enlarged.
FIG. 6. Lateral view, outline showing edge of outer lip.
FIG. 7. Lateral view, outline showing aperture.
FIG. 8. Outline view of aperture, more enlarged. After Whitfield.

PUPA BIGSBYI D. (Page 456.)

FIG. 9. Lateral view, enlarged.
FIG. 10. Lateral view of a smaller example, enlarged. After Dawson.

ZONITES PRISCUS D. (Page 453.)

FIG. 11. Lateral view, enlarged.
FIG. 12. View showing the aperture, enlarged. After Dawson.

PUPA VERMILLIONENSIS B. (Page 456.)

FIG. 13. Lateral view, enlarged.
FIG. 14. Lateral view, showing the aperture, enlarged. After Dawson.

NAIADITES CARBONARIA D. (Page 425.)

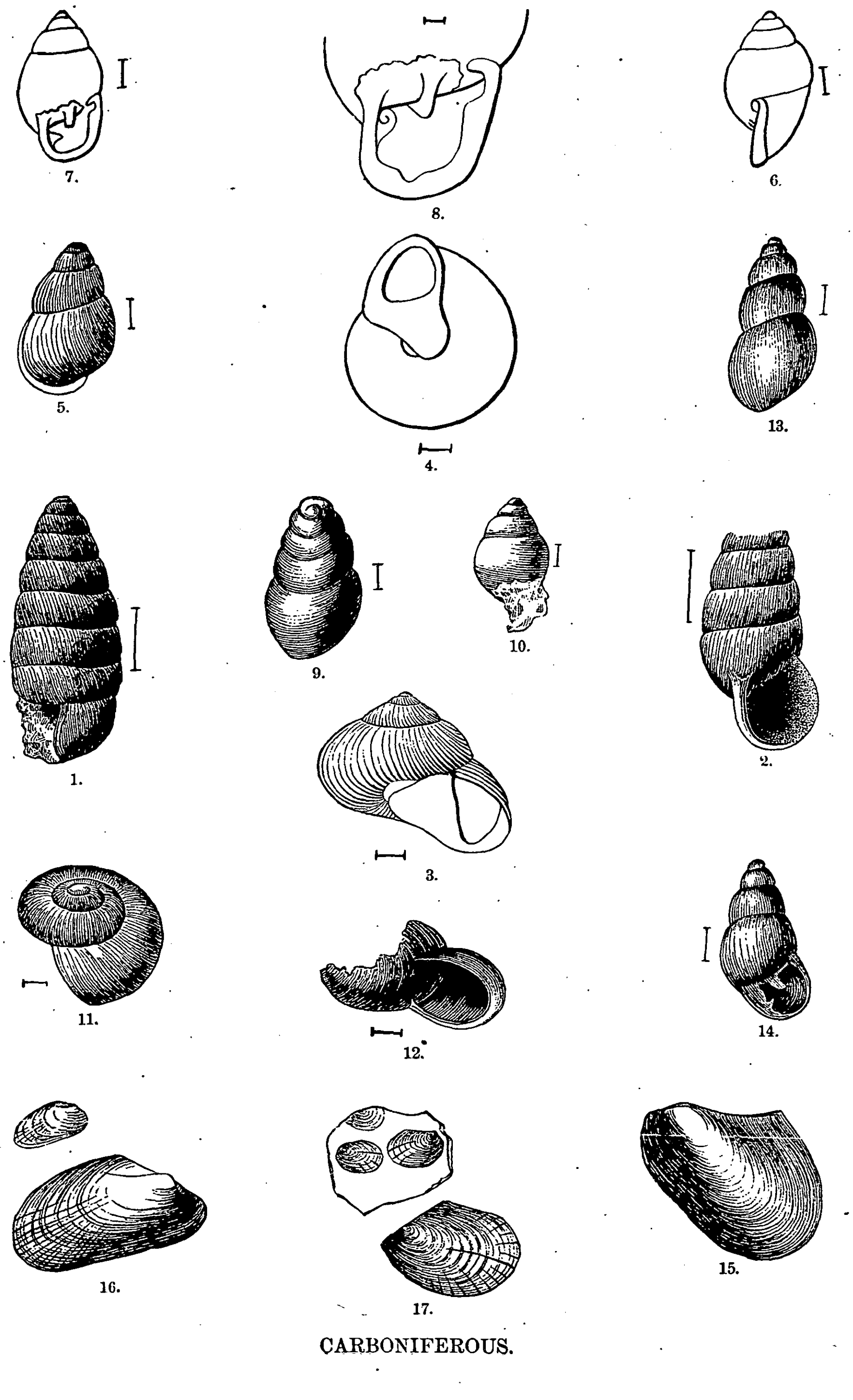
FIG. 15. Left side view, natural size. After Dawson.

NAIADITES ELONGATA D. (Page 425.)

FIG. 16. Right side view, natural size, and enlarged. After Dawson.

NAIADITES LÆVIS D. (Page 425.)

FIG. 17. Left valve enlarged, and smaller examples of natural size. After Dawson.



CARBONIFEROUS.

PLATE 3. JURASSIC AND TRIASSIC?

UNIO STEWARDI White. (Page 426.)

FIG. 1. Outline of a left valve restored from fragments, natural size.

UNIO NUCALIS Meek & Hayden. (Page 426.)

FIG. 2. Lateral view of a left valve slightly restored from a specimen a little crushed.
FIG. 3. Dorsal view of the same; the right valve restored in symmetry with the left.
FIG. 4. Dorsal view of one of the originally figured types, slightly restored, the specimen being a little crushed; all natural size.

UNIO CRISTONENSIS Meek. (Page 425.)

FIG. 5. Right side view of Mr. Meek's most perfect type, natural size.

PLANORBIS VETERNUS M. & H. (Page 446.)

FIG. 6. Lateral view, natural size, and the same enlarged; also, a transverse section showing the number and shape of volutions. After Meek.

VALVATA SCABRIDA M. & H. (Page 470.)

FIG. 7. Copy of original figure of Meek & Hayden.

VIVIPARUS GILLIANUS M. & H. (Page 470.)

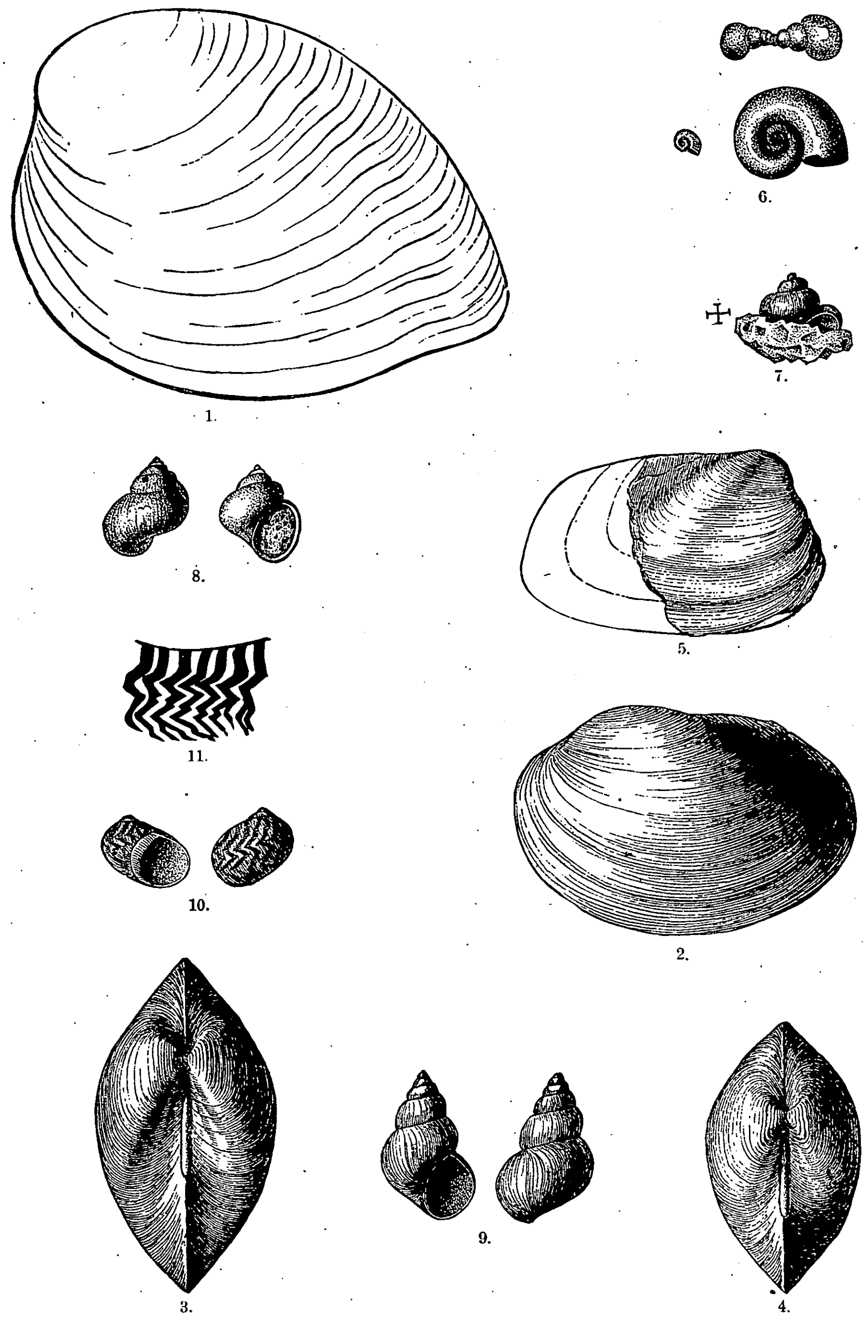
FIG. 8. Two views of the type specimen, natural size. After Meek & Hayden.

LIOPLACODES VETERNUS M. & H. (Page 470.)

FIG. 9. Two views of the type specimen, natural size. After Meek & Hayden.

NERITINA NEBRASCENSIS M. & H. (Page 457.)

FIG. 10. Two views of the type specimen, natural size. After Meek & Hayden.
FIG. 11. Enlarged view of a portion of the surface showing the pattern of the color markings.



JURASSIC AND TRIASSIC?

PLATE 4. CRETACEOUS.

MARGARITANA NEBRASCENSIS Meek & Hayden. (Page 427.)

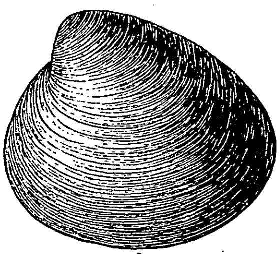
FIG. 1. Left side view, natural size.
FIG. 2. Dorsal view of the same.

CYRENA DAKOTENSIS M. & H. (Page 436.)

FIG. 3. Left side view, natural size.
FIG. 4. Dorsal view of the same. After Meek.

PHYSA ——? (Page 444.)

FIG. 5. Lateral view of an imperfect natural cast, natural size.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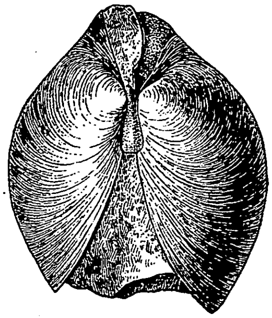
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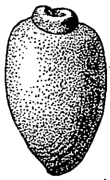
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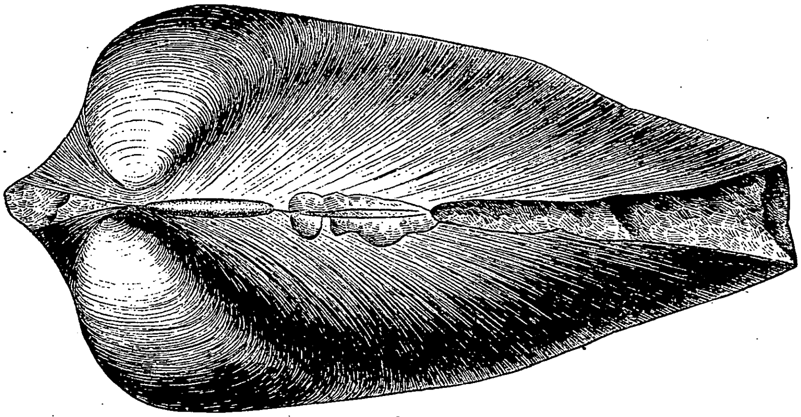
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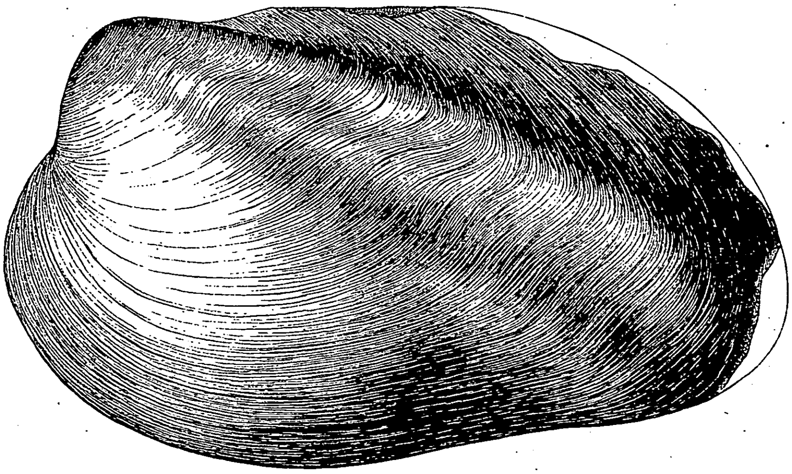
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CRETACEOUS.

PLATE 5. CRETACEOUS.

UNIO PENULTIMUS Gabb. (Page 427.)

FIG. 1. Copy of Mr. Gabb's original figure, natural size.

UNIO HUBBARDI G. (Page 427.)

FIG. 2. Left side view, natural size.
FIG. 3. Outline of front view. After Gabb.

CYRENA CARLETONI Meek. (Page 436.)

FIG. 4. Left view, natural size.
FIG. 5. Dorsal view of the same.

ANOMIA PROPATORIS White. (Page 422.)

FIG. 6. Exterior view of an upper valve, natural size.
FIG. 7. Lateral view of the same.

NERITINA (VELATELLA) BELLATULA M. (Page 458.)

FIG. 8. Dorsal view of a small example, enlarged.
FIG. 9. Lateral view of another example, enlarged.

NERITINA (VELATELLA) CARDITOIDES M. (Page 458.)

FIG. 10. Dorsal view of the type specimen, natural size.

NERITINA BANNISTERI M. (Page 458.)

FIG. 11. Lateral view, enlarged, showing the color markings. The specimen has been a little compressed.
FIG. 12. Two views of a small example, enlarged. The color markings are not preserved in this example.

MELAMPUS? ANTIQUUS M. (Page 444.)

FIG. 13. Lateral view of a small example, enlarged.
FIG. 14. Opposite view of the same.
FIG. 15. Fragment of a very large example, natural size.
FIG. 16. Apex very much enlarged, showing the reversed initial whorl.

MELAMPUS? ——? (Page 444.)

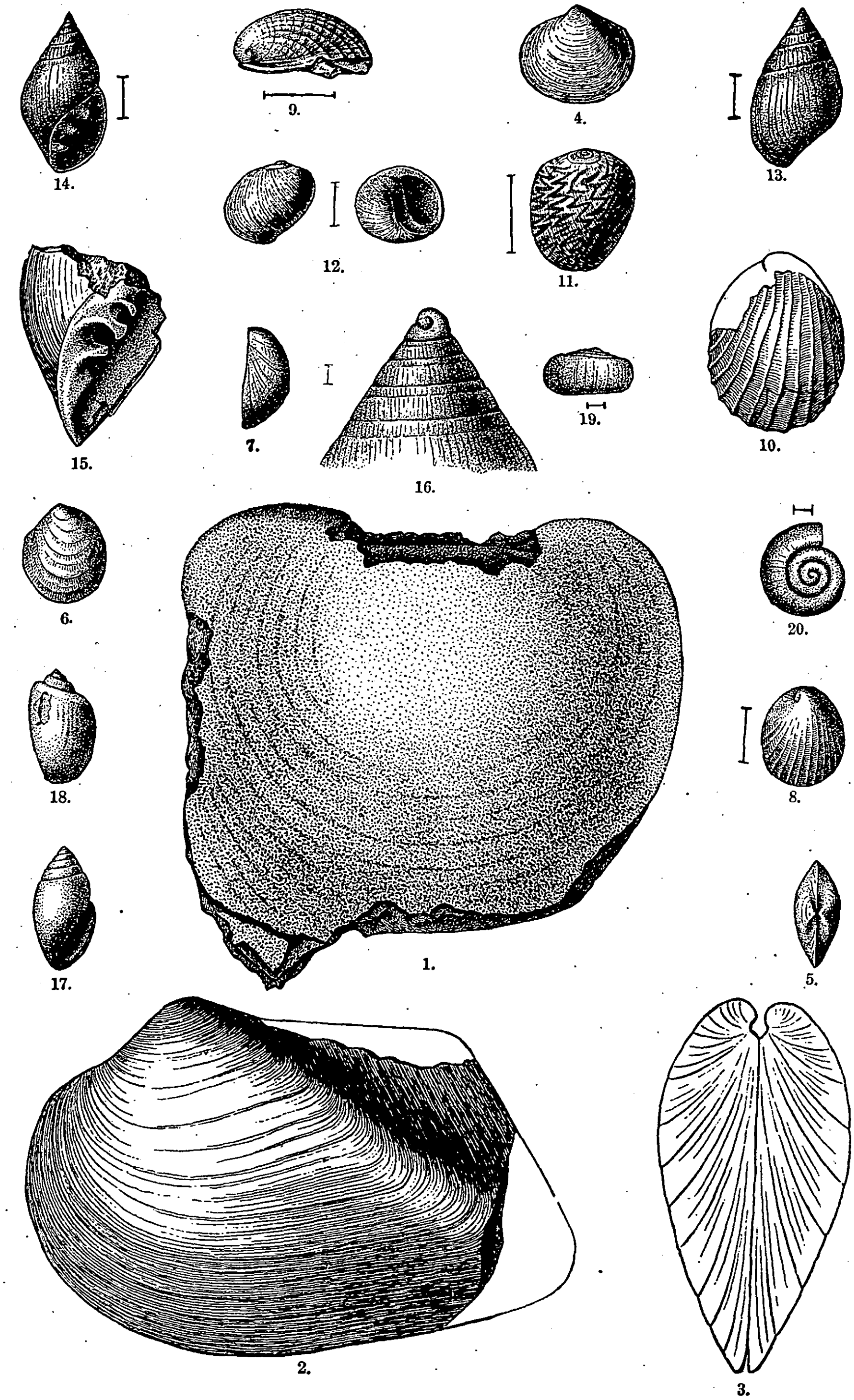
FIG. 17. Lateral view, natural size.

PHYSA CARLETONI M. (Page 449.)

FIG. 18. Lateral view, natural size.

VALVATA NANA M. (Page 470.)

FIG. 19. Lateral view, enlarged.
FIG. 20. Summit view of the same.



CRETACEOUS.

PLATE 6. BEAR RIVER LARAMIE.

UNIO BELLIPLICATUS Meek. (Page 430.)

FIG. 1. Left side view, natural size.
FIG. 2. Similar view of another example.
FIG. 3. Dorsal view of a left valve, a little distorted, showing the plications of the umbo.

PYRGULIFERA HUMEROSA M. (Page 460.)

FIG. 4. Lateral view of a large example, natural size.
FIG. 5. Opposite view of the same. This is the same example that is figured by Meek on p. 177 U. S. Geol. Sur. 40th Parallel, vol. iv, but it has since been cleaned of extraneous matter.
FIG. 6. Lateral view of a smaller example.

GONIOBASIS CLEBURNI White. (Page 462.)

FIG. 7. Lateral view, natural size.
FIG. 8. Similar view of another example.
FIG. 9. Fragment of a large example.

GONIOBASIS CHRYSALLOIDEA W. (Page 462.)

FIG. 10. Lateral view, natural size.
FIG. 11. Similar view of another example.

GONIOBASIS MACILENTA W. (Page 462.)

FIG. 12. Lateral view, enlarged.

GONIOBASIS CHRYSALIS M. (Page 462.)

FIG. 13. Lateral view, enlarged.
FIG. 14. Similar view of another example.

LIMNÆA (LIMNOPHYSA) NITIDULA M. (Page 445.)

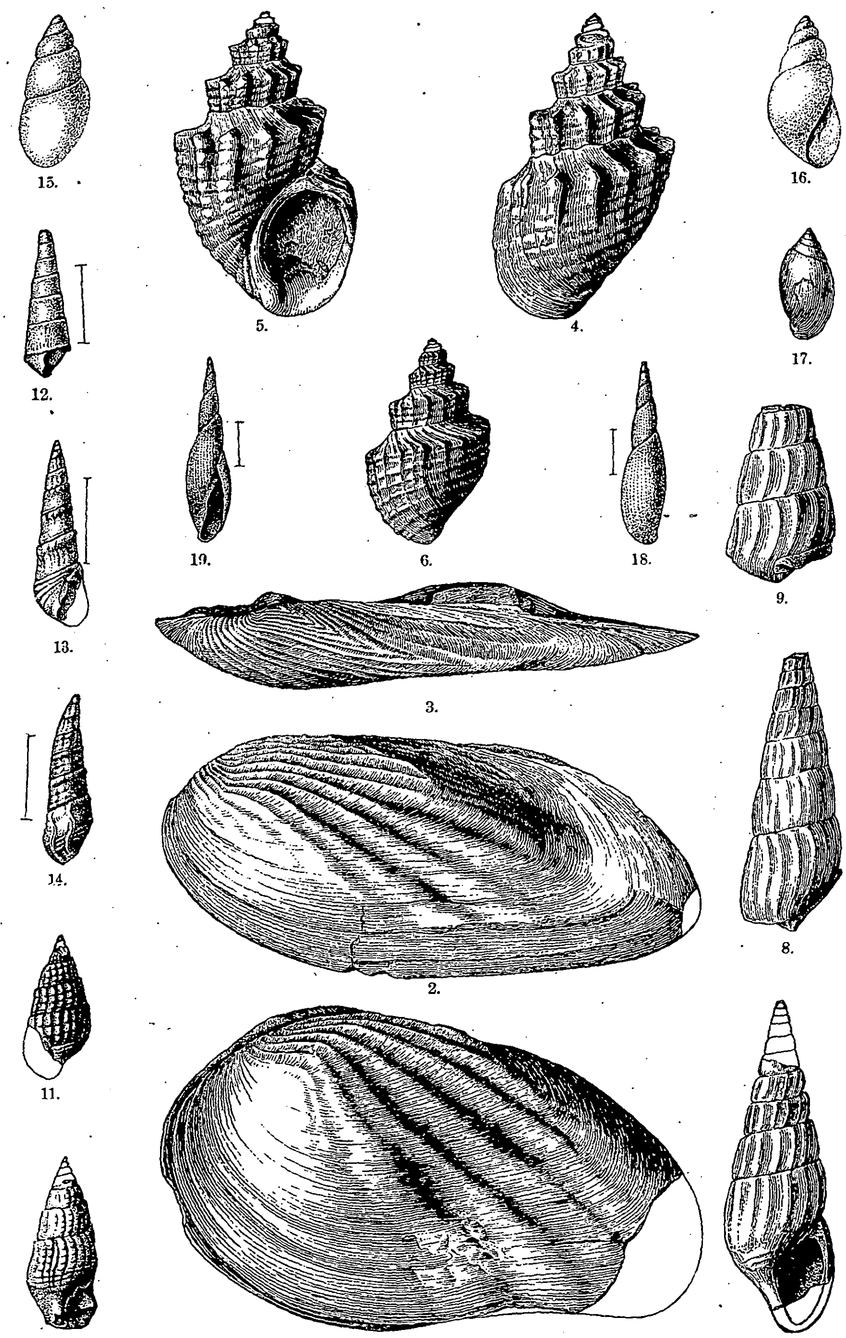
FIG. 15. Lateral view, enlarged two diameters.
FIG. 16. Opposite view of the same.

PHYSA ——— ? (Page 449.)

FIG. 17. Lateral view, natural size.

LIMNÆA (ACELLA) HALDEMANI W. (Page 445.)

FIG. 18. Lateral view, enlarged.
FIG. 19. Opposite view of the same.



BEAR RIVER LARAMIE.

PLATE 7. BEAR RIVER LARAMIE.

UNIO VETUSTUS Meek. (Page 430.)

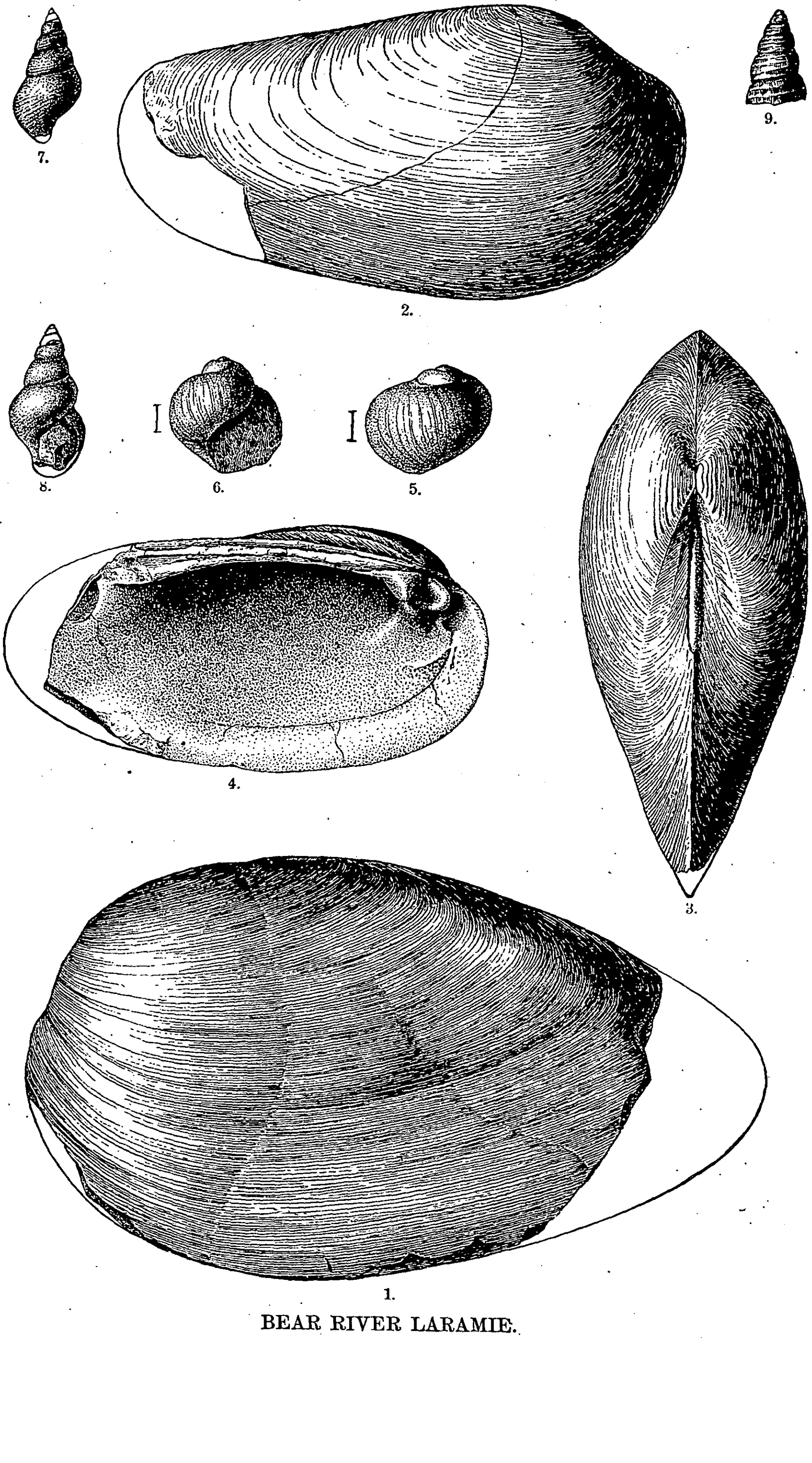
FIG. 1. Left side view of a large example; a little compressed laterally.
FIG. 2. Right side view; the posterior portion a little compressed vertically.
FIG. 3. Dorsal view of Fig. 2; the left valve restored in symmetry with the right.
FIG. 4. Interior view of a left valve.
(All natural size.)

NERITINA NATICIFORMIS White. (Page 458.)

FIG. 5. Lateral view; enlarged.
FIG. 6. Opposite view of the same.

GONIOBASIS ENDLICHI W. (Page 463.)

FIG. 7. Lateral view; revolving lines faint.
FIG. 8. Another example; revolving lines obsolete.
FIG. 9. Apical portion of another example; revolving lines unusually distinct.
(All natural size.)



BEAR RIVER LARAMIE.

PLATE 8. BEAR RIVER LARAMIE.

VIVIPARUS COUESII White. (Page 467.)

FIG. 1. Lateral view of a very large example, natural size.

RHYTOPHORUS PRISCUS Meek. (Page 444.)

FIG. 2. Lateral view, natural size.
FIG. 3. Opposite view of the same. After Meek.

RHYTOPHORUS MEEKII W. (Page 444.)

FIG. 4. Lateral view, natural size.
FIG. 5. Opposite view of a larger example.

CAMPELOMA MACROSPIRA M. (Page 469.)

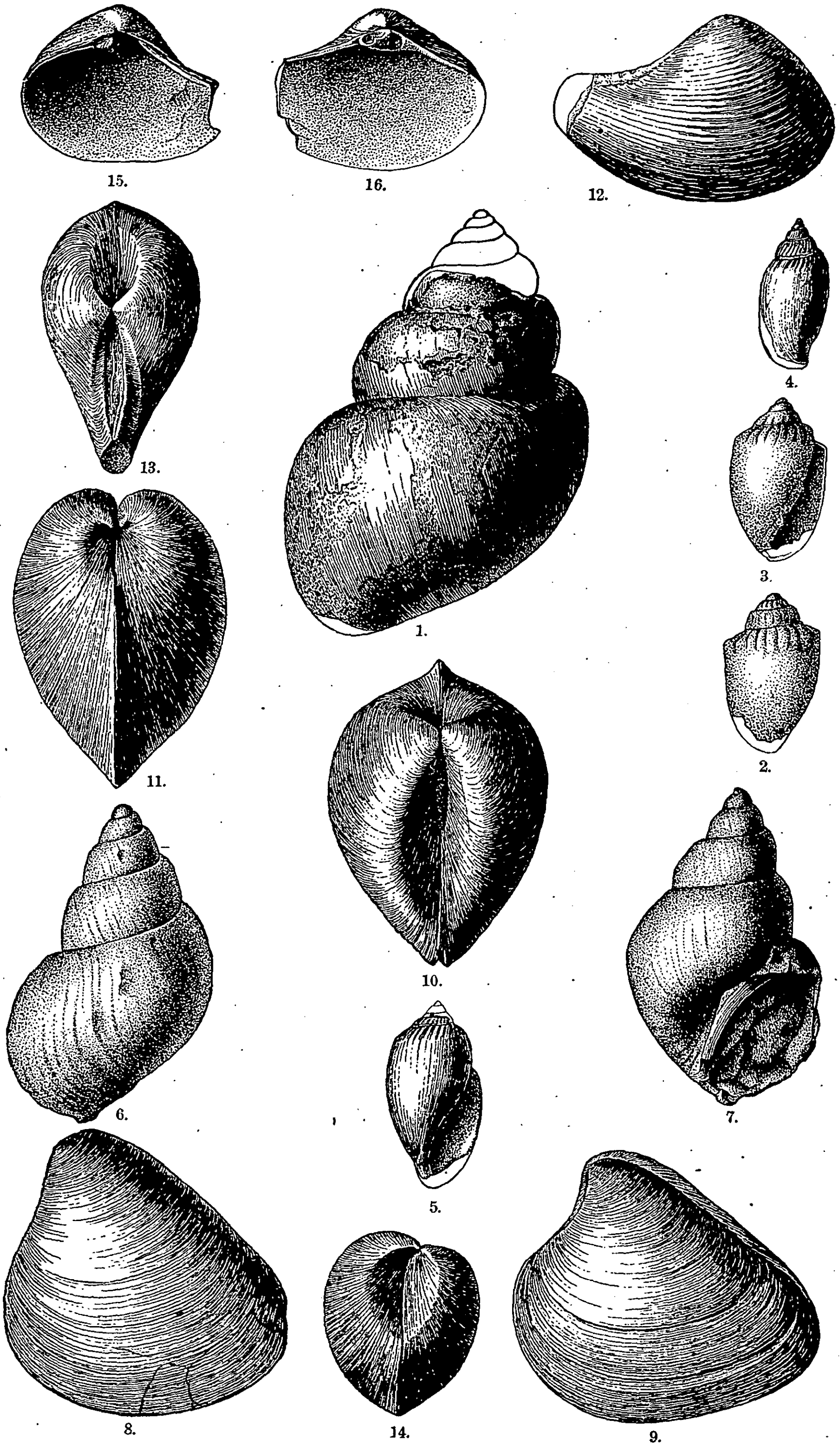
FIG. 6. Lateral view, natural size.
FIG. 7. Opposite view of the same.

CORBICULA (VELORITINA) DURKEEI M. (Page 437.)

FIG. 8. Left valve.
FIG. 9. Similar view of another example.
FIG. 10. Dorsal view of another example.
FIG. 11. Front view.
(All natural size.)

CORBULA PYRIFORMIS M. (Page 441.)

FIG. 12. Right side view.
FIG. 13. Dorsal view of the same.
FIG. 14. Front view of the same.
FIG. 15. Interior view of a right valve.
FIG. 16. Interior view of a left valve.
(All natural size.)

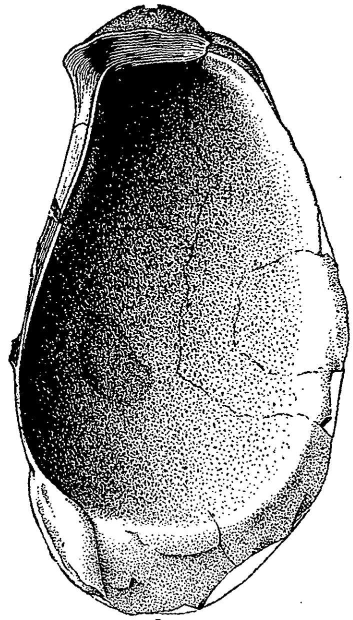


BEAR RIVER LARAMIE.

PLATE 9. LARAMIE.

OSTREA GLABRA Meek & Hayden. (Page 421.)

FIG. 1. Exterior view of type; lower valve. After Meek.
FIG. 2. Interior view of the same.
FIG. 3. Exterior view of a lower valve, from the valley of the South Platte, Colorado.
FIG. 4. Interior view of the same.
(All natural size.)



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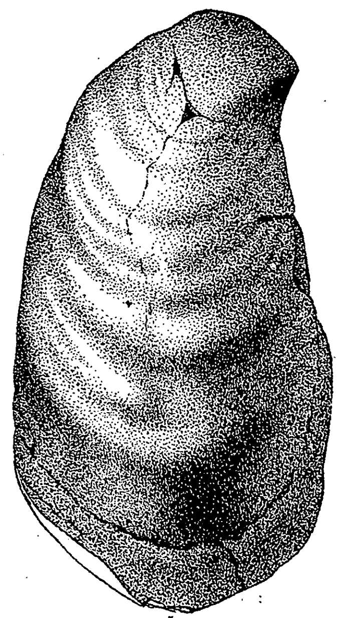

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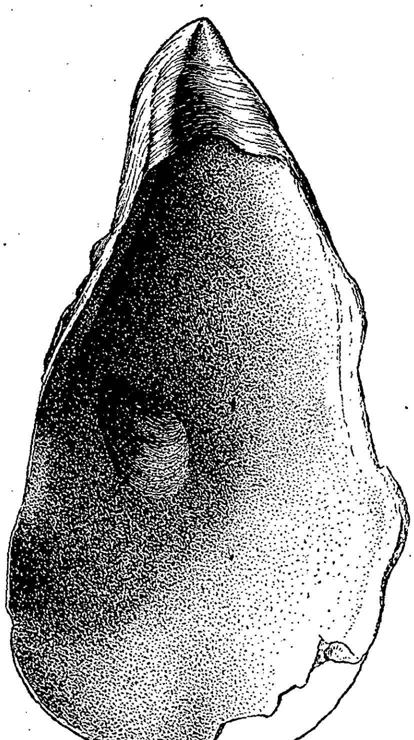


4.

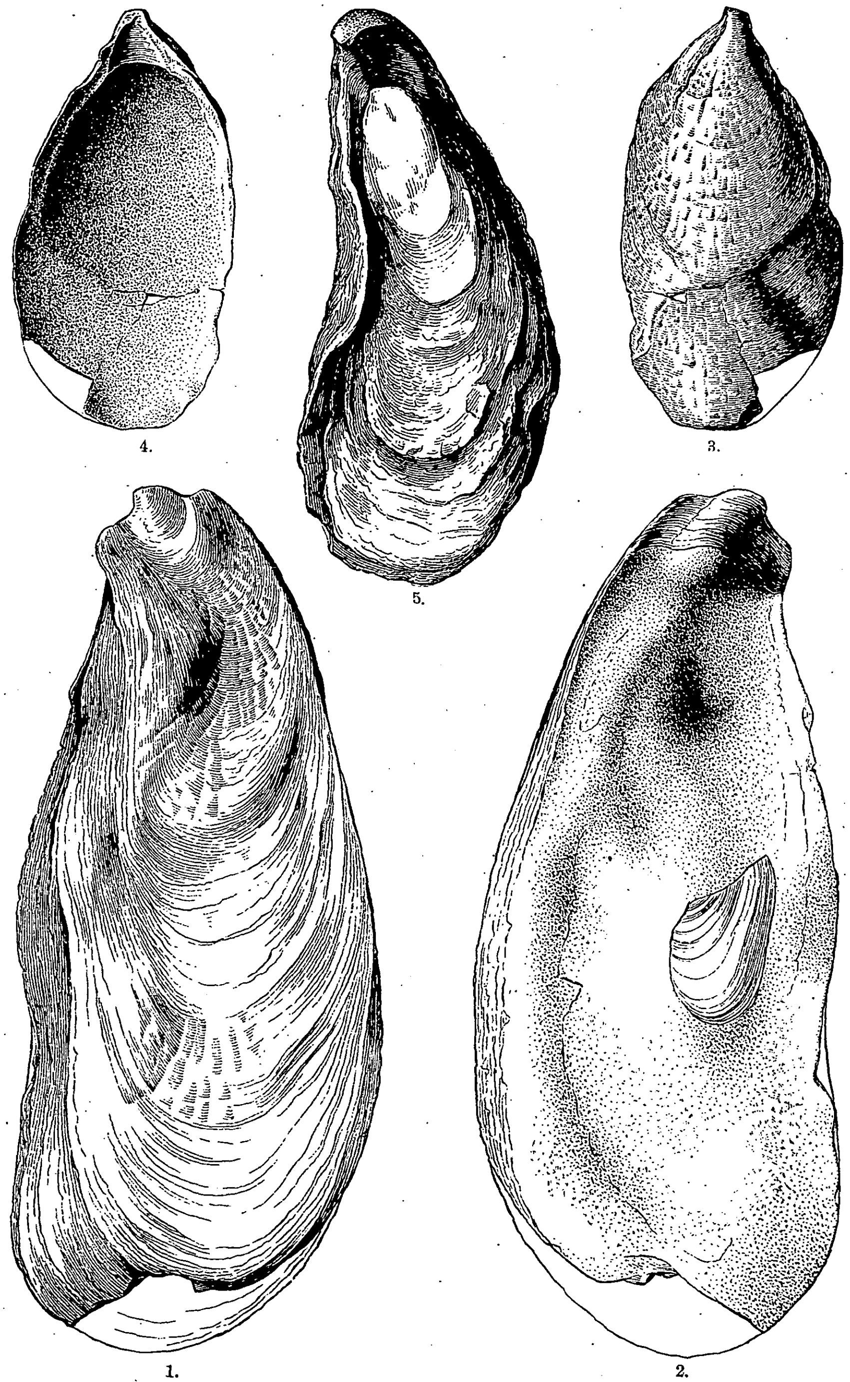
3.

LARAMIE.

PLATE 10. LARAMIE.

OSTREA GLABRA Meek & Hayden. (Page 421.)

FIG. 1. Exterior view of an upper valve, from the valley of the South Platte, Colorado.
FIG. 2. Interior view of the same.
FIG. 3. Lower valve of the type of the variety *O. insecuris* White; exterior view.
FIG. 4. Interior view of the same.
FIG. 5. Type specimen of variety *O. arcuatilis* Meek.
(All natural size.)

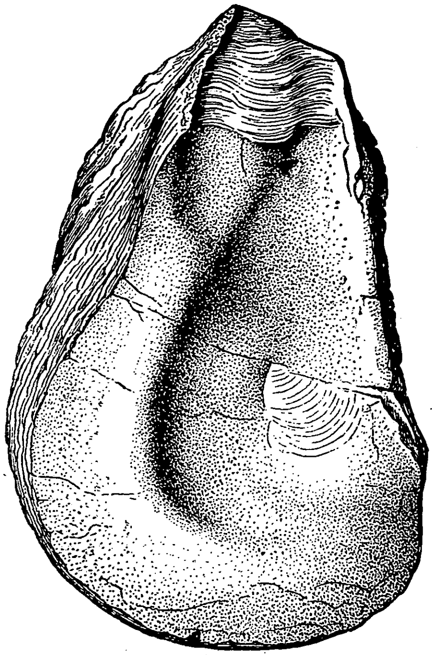


LARAMIE.

PLATE 11. LARAMIE.

OSTREA GLABRA Meek & Hayden. (Page 421.)

FIG. 1. Exterior view of an upper valve of the variety *O. wyomingensis* Meek, from the valley of the South Platte, Colorado.
FIG. 2. Interior view of the same.
FIG. 3. Exterior view of an example of the upper valve of the same variety, from Point of Rocks, Southern Wyoming.
FIG. 4. Interior view of the same.
(All natural size.)



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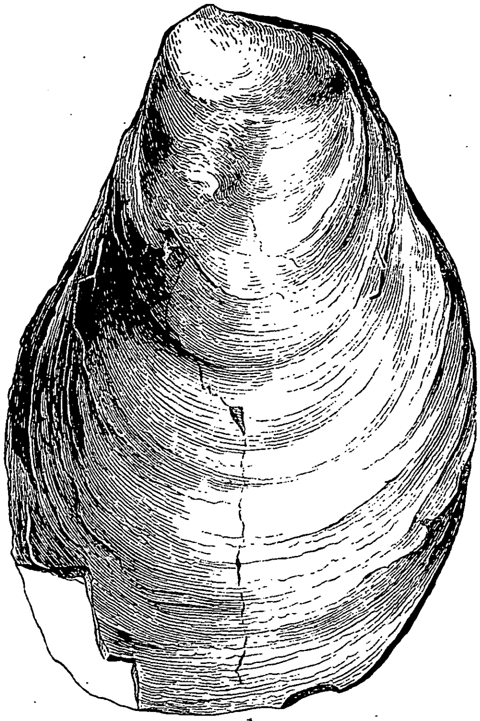

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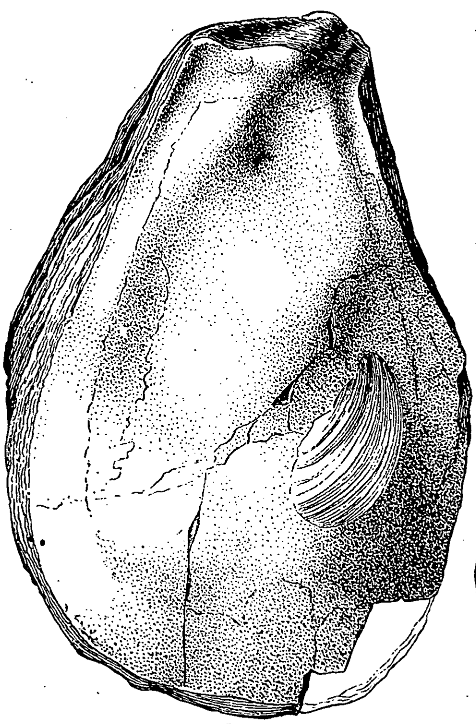

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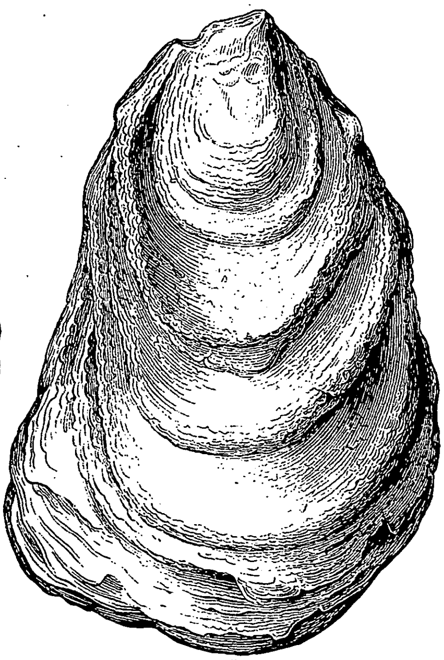


3.

LARAMIE.

PLATE 12. LARAMIE.

OSTREA GLABRA Meek & Hayden. (Page 421.)

FIG. 1. Interior view of an under valve of the variety *O. wyomingensis* Meek; from Point of Rocks, Southern Wyoming. Natural size.

OSTREA SUBTRIGONALIS Evans & Shumard. (Page 421.)

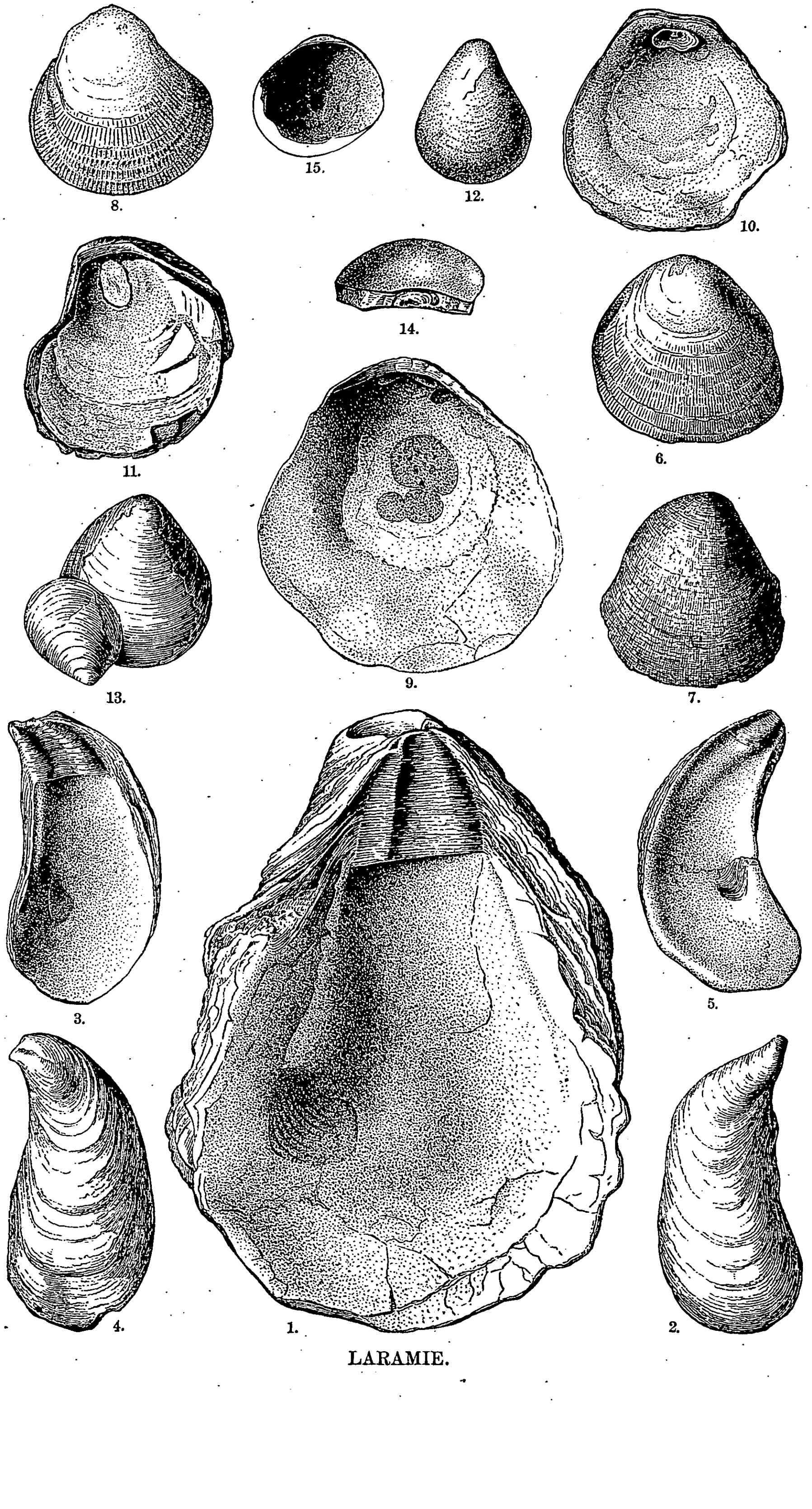
FIG. 2. Exterior view of a lower valve.
FIG. 3. Interior view of another example of the lower valve.
FIG. 4. Exterior view of an upper valve.
FIG. 5. Interior view of the same.
(All natural size.)

ANOMIA MICRONEMA Meek. (Page 422.)

FIG. 6. Exterior view of an upper valve, showing radiating lines of ordinary character.
FIG. 7. Similar view of another example, the lines upon which are very fine, and less conspicuous than they appear upon the figure.
FIG. 8. Similar view of another example, having radiating lines much coarser than usual.
FIG. 9. Interior view of a large, nearly flat, upper valve, showing the four muscular scars, and the process beneath the beak.
FIG. 10. Similar view of another example, showing the process more plainly; but the scars are obliterated.
FIG. 11. Interior view, showing the under valve, with its byssal plug.
(All natural size.)

ANOMIA GRYPHORHYNCHUS M. (Page 422.)

FIG. 12. Exterior view of a lower valve.
FIG. 13. Similar view of two other valves.
FIG. 14. Lateral view of Fig. 12.
FIG. 15. Interior view of an upper valve, showing the muscular markings and the small process beneath the beak.
(All natural size.)



LARAMIE.

PLATE 13. LARAMIE.

VOLSELLA (BRACHYDONTES) REGULARIS White. (Page 423.)

FIG. 1. Right valve, natural size.

VOLSELLA (BRACHYDONTES) LATICOSTATA W. (Page 423.)

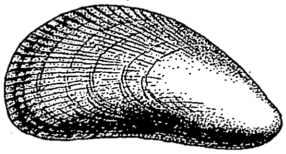
FIG. 2. Right valve, natural size.

UNIO PROAVITUS W. (Page 433.)

FIG. 3. Left valve, exterior view.
FIG. 4. Similar view of right valve.
FIG. 5. Front view of another example.
FIG. 6. Interior view of a left valve.
(All natural size.)

UNIO GOINONOTUS W. (Page 433.)

FIG. 7. Right side view.
FIG. 8. Front view of another example.
FIG. 9. Left side view of young example.
FIG. 10. Dorsal view of the same.
(All natural size.)



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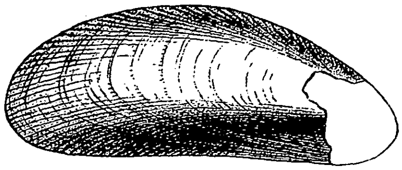

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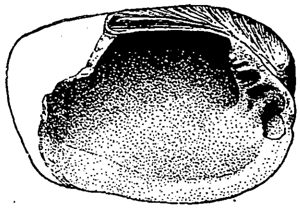

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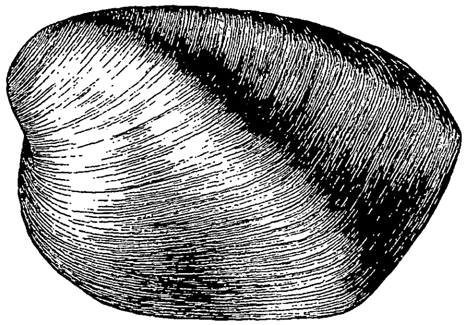

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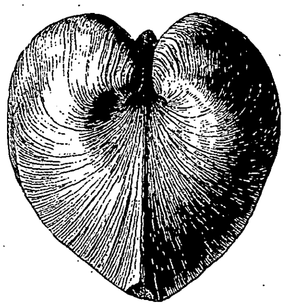

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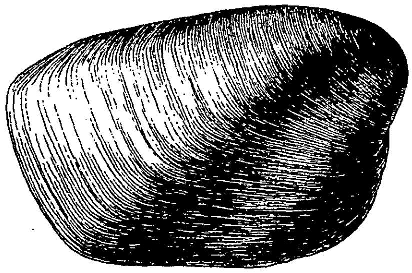

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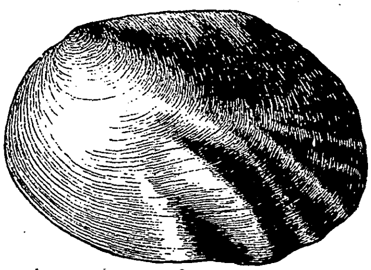

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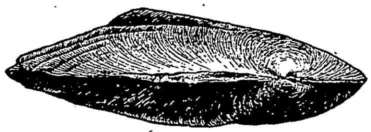

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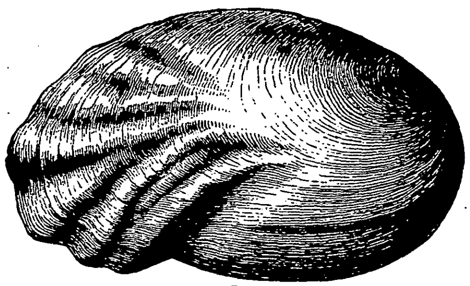

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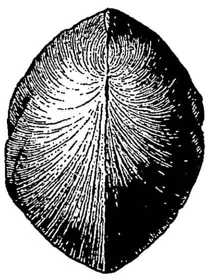


8.

LARAMIE.

PLATE 14. LARAMIE.

UNIO PRISCUS Meek & Hayden. (Page 432.)

FIG. 1. Copy of the original figure of Meek & Hayden.

UNIO SUBSPATULATUS Meek. (Page 431.)

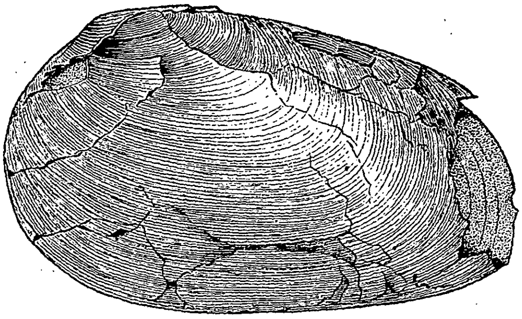
FIG. 2. Left side view.
FIG. 3. Dorsal view of the same. After Meek.

UNIO PRIMÆVUS White. (Page 432.)

FIG. 4. Exterior view of a small left valve.
FIG. 5. Interior view of a large right valve.
(Both natural size.)

UNIO CRYPTORHYNCHUS W. (Page 431.)

FIG. 6. Exterior view of an imperfect right valve.
FIG. 7. Interior view of a fragment of a left valve, showing the cavity behind the cardinal plate.



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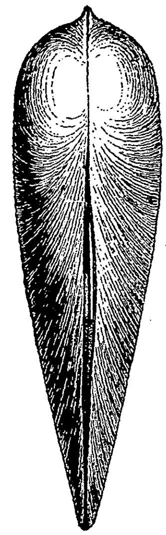

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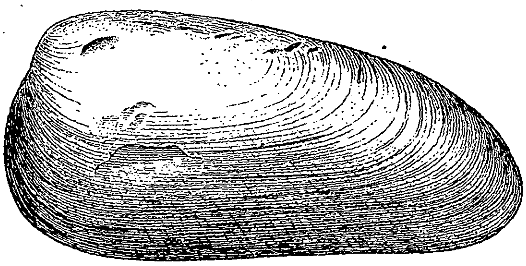

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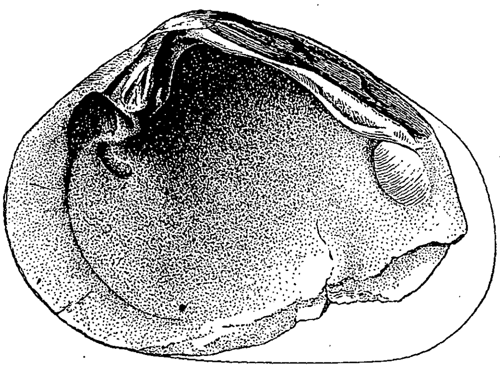

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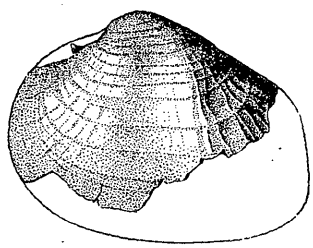

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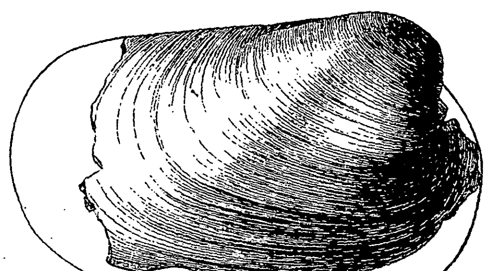
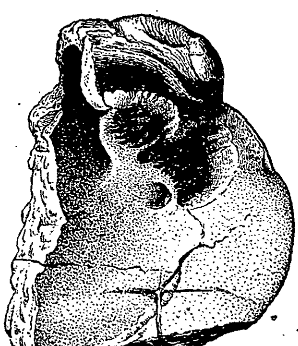


6.



7.

LARAMIE.

PLATE 15. LARAMIE.

UNIO ENDLICHII White. (Page 432.)

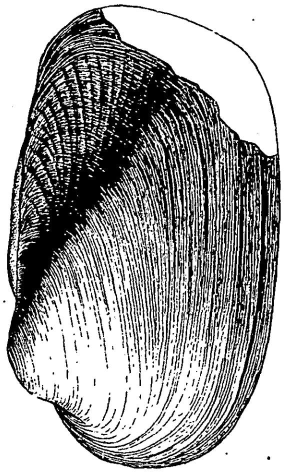
FIG. 1. Right valve of a large example, exterior view.
FIG. 2. Interior view of a smaller left valve.
(Both natural size.)

UNIO PROPHETICUS W. (Page 433.)

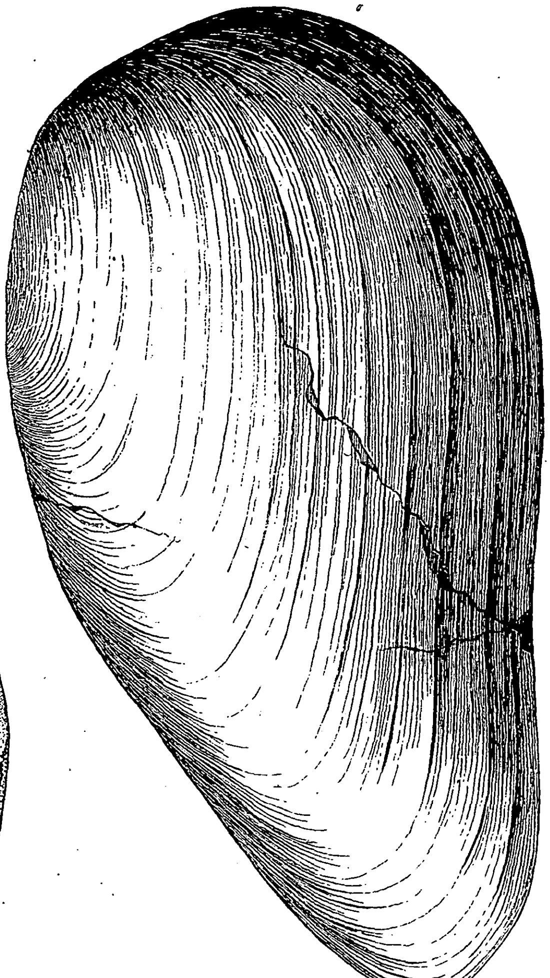
FIG. 3. Exterior view of a left valve. Natural size.

UNIO ALDRICHII W. (Page 433.)

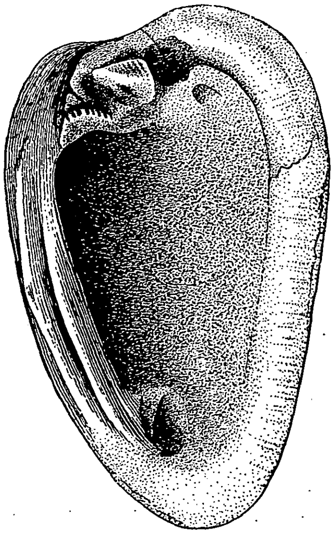
FIG. 4. Left side view.
FIG. 5. Dorsal view of the same. Natural size.



4.



1.



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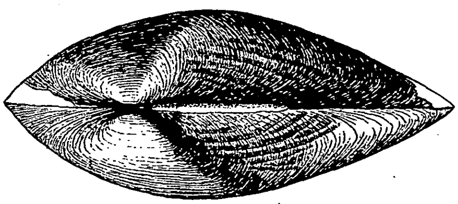
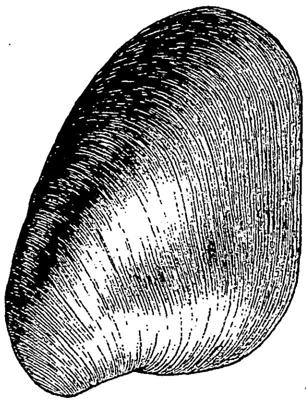


5.



3.

LARAMIE.

PLATE 16. LARAMIE.

UNIO COUESII White. (Page 432.)

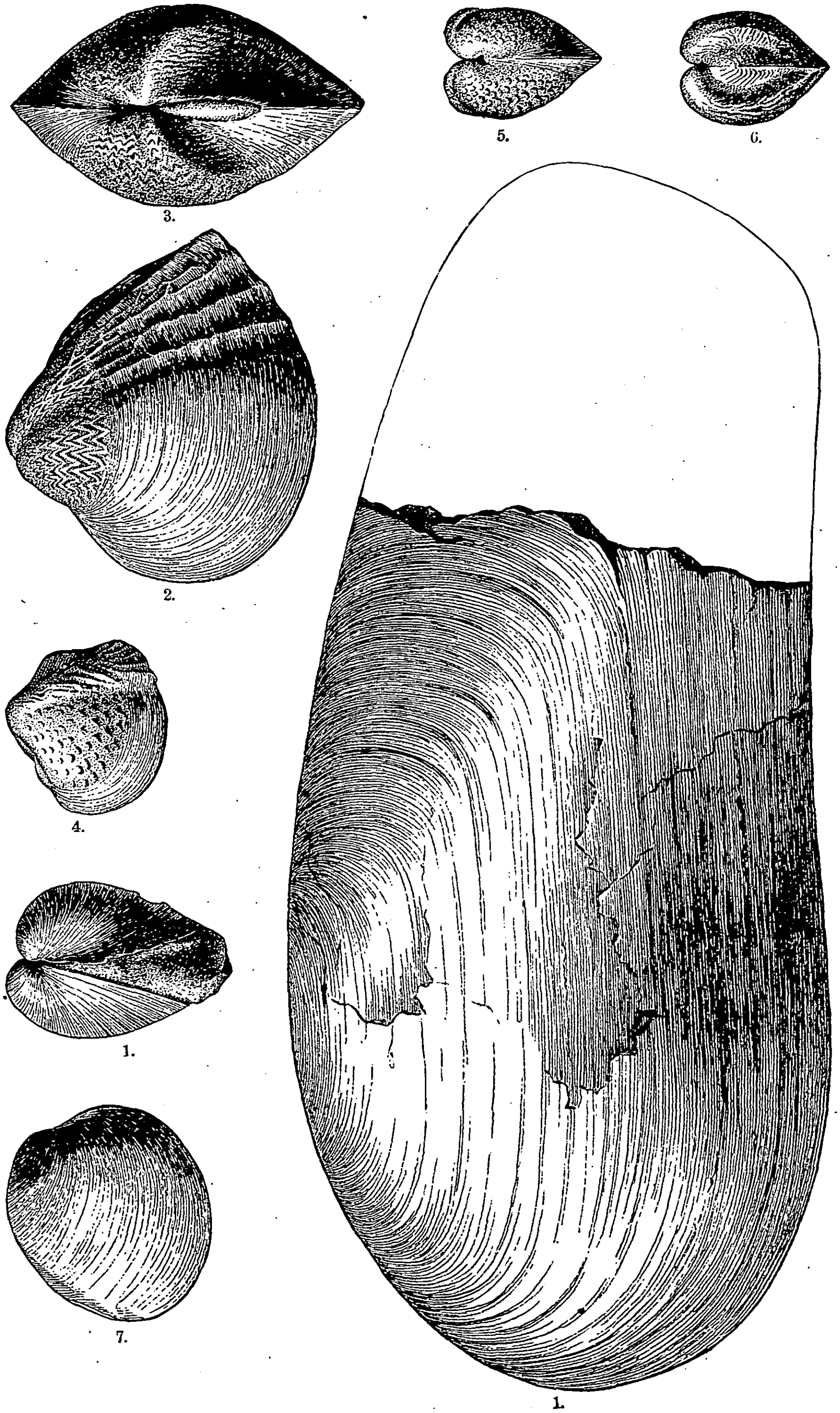
FIG. 1. Exterior view of a left valve. Natural size.

UNIO HOLMESIANUS W. (Page 433.)

FIG. 2. Left side view of an adult example.
FIG. 3. Dorsal view of the same.
FIG. 4. Left side view of a young example.
FIG. 5. Front view of the same.
FIG. 6. Posterior view of the same.
(All natural size.)

UNIO BRACHYOPISTHUS W. (Page 433.)

FIG. 7. Right side view of an example not fully adult.
FIG. 8. Front view of the same. Natural size.



LARAMIE.

PLATE 17. LARAMIE.

UNIO DANÆ Meek & Hayden. (Page 431.)

FIG. 1. Left side view.
FIG. 2. Dorsal view of the same example.
FIG. 3. Right side view of another example. After Meek.

UNIO DEWEYANUS M. & H. (Page 431.)

FIG. 4. Left side view.
FIG. 5. Interior view of the same. After Meek.

CORBICULA OCCIDENTALIS M. & H. (Page 437.)

FIG. 6. Left side view of the type of *C. bannisteri* Meek.
FIG. 7. Dorsal view of the same; natural size.
(For other figures of *C. occidentalis*, see Plate XXIII.)

SPHÆRIUM PLANUM M. & H. (Page 439.)

FIG. 8. Exterior view of a left valve and outline of a dorsal view of the same; natural size. After Meek.

SPHÆRIUM RECTICARDINALE M. & H. (Page 439.)

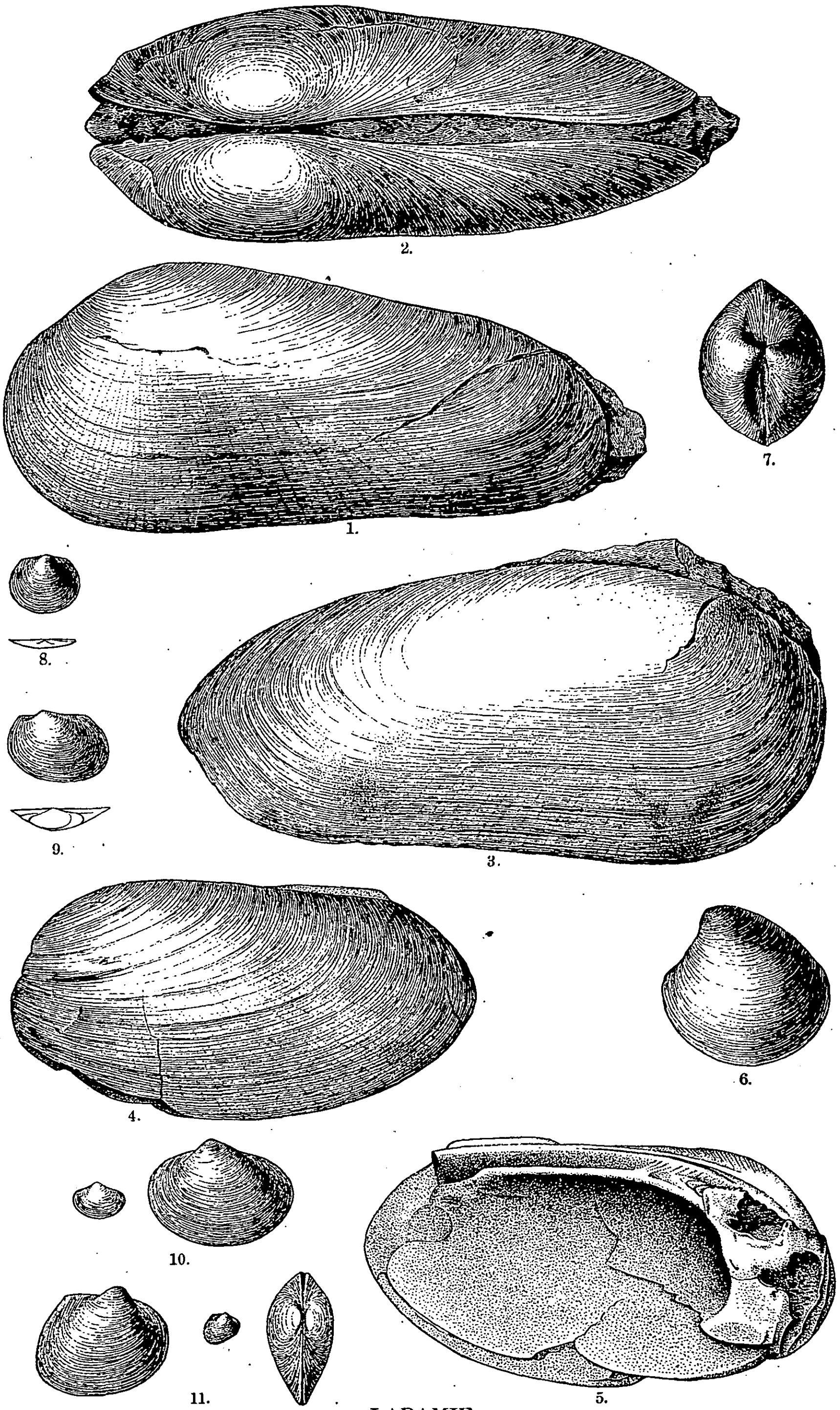
FIG. 9. Exterior view of a left valve and outline of a dorsal view of the same; natural size. After Meek.

SPHÆRIUM SUBELLIPTICUM M. & H. (Page 439.)

FIG. 10. Exterior view of the left valve, natural size, together with the same much enlarged. After Meek.

SPHÆRIUM FORMOSUM M. & H. (Page 439.)

FIG. 11. Exterior view of the right side, natural size, together with side and dorsal views of the same much enlarged. After Meek.



LARAMIE.

PLATE 18. LARAMIE.

UNIO DANÆ Meek & Hayden? (Page 433.)

FIG. 1. Exterior view of the right valve of an example from Black Buttes Station, Southern Wyoming.
FIG. 2. Interior view of a left valve from the same locality.
(Both natural size.)

UNIO MENDAX White. (Page 433.)

FIG. 3. Exterior view of a left valve; adult.
FIG. 4. Similar view of a smaller right valve.
FIG. 5. Interior view of part of a right valve.
(All from the Cañon of Desolation, Utah; and all natural size.)

CORBULA UNDIFERA Meek. (Page 440.)

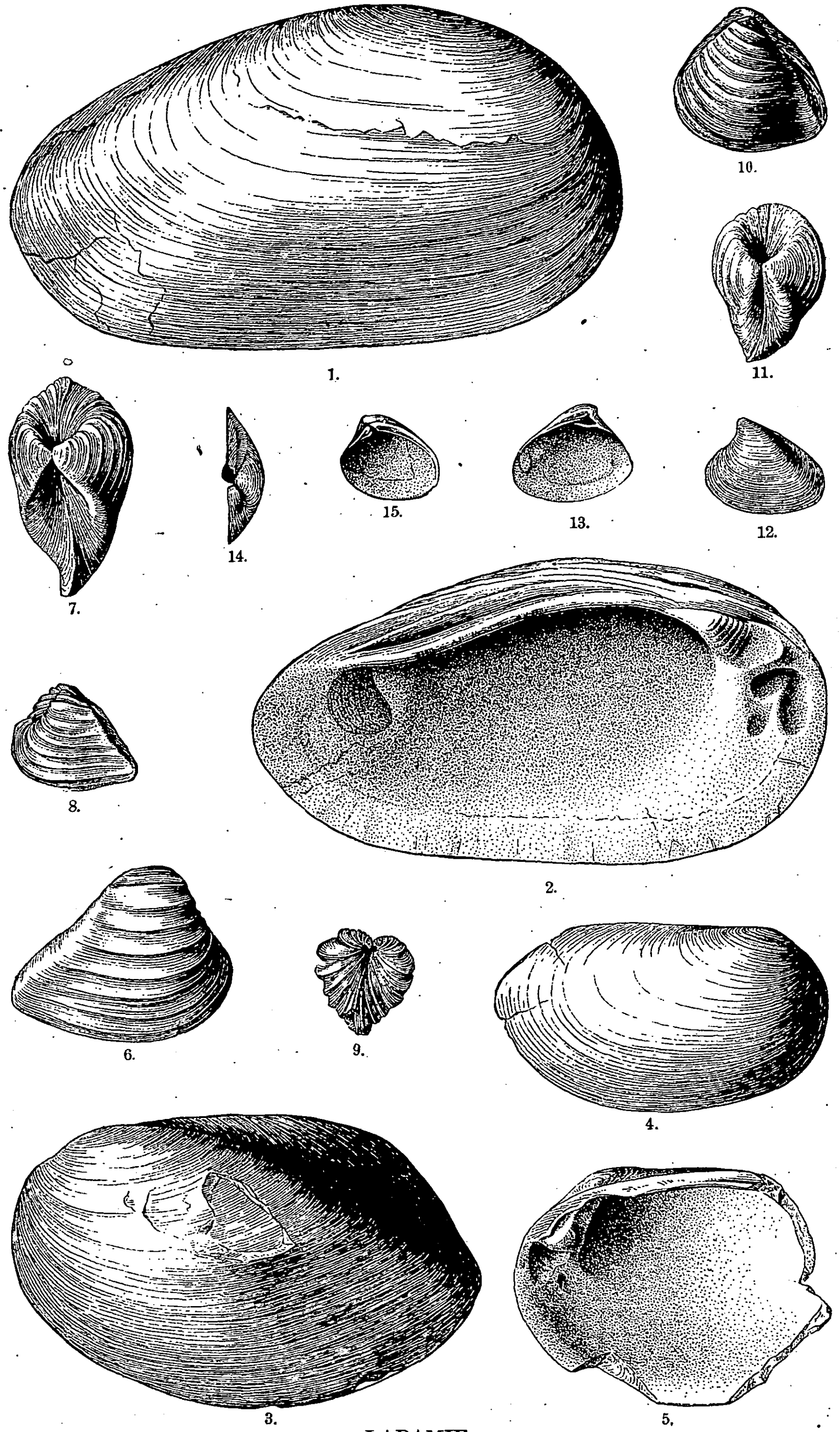
FIG. 6. Right side view of an adult example.
FIG. 7. Dorsal view of the same.
FIG. 8. Left side view of a smaller example.
FIG. 9. Front view of the same.

CORBULA UNDIFERA var. SUBUNDIFERA W. (Page 440.)

FIG. 10. Left side view of the type specimen.
FIG. 11. Dorsal view of the same, natural size.

CORBULA MACTRIFORMIS M. & H. (Page 440.)

FIG. 12. Exterior view, left valve.
FIG. 13. Interior view of the same.
FIG. 14. Dorsal view of the same.
FIG. 15. Interior view of the right valve of another example.
(All natural size, and all after Meek.)



LARAMIE.

PLATE 19. LARAMIE.

UNIO SENECTUS White (Page 432.)

FIG. 1. Exterior view of a portion of a right valve.
FIG. 2. Interior view of a portion of a left valve.
(Both natural size.)

UNIO GONIAMBONATUS W. (Page 433.)

FIG. 3. Left side view, natural size.
FIG. 4. Dorsal view of the same.
(Both figures are partial restorations, the type specimen having been distorted by compression.)

ANODONTA PARALLELA W. (Page 429.)

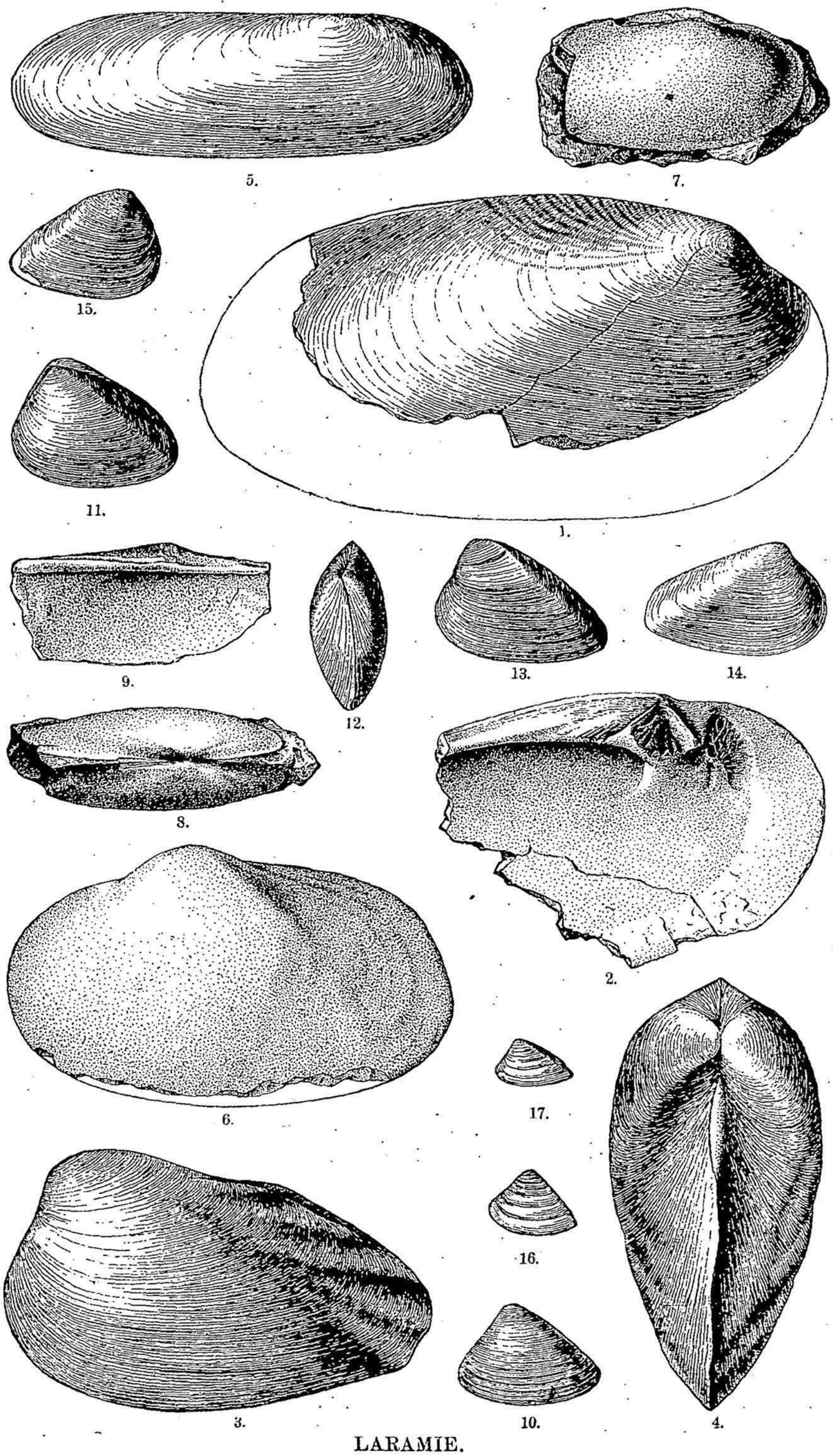
FIG. 5. Left side view, restored from fragments; natural size.

ANODONTA PROPATORIS W. (Page 429.)

FIG. 6. Left side view of an internal cast of large example.
FIG. 7. Right side view of a similar cast of a larger example.
FIG. 8. Dorsal view of the same.
FIG. 9. Fragment showing the edentulous hinge.
(All natural size.)

CORBULA SUBTRIGONALIS Meek & Hayden. (Page 442.)

FIG. 10. Exterior view of a left valve, natural size. After Meek.
FIG. 16. Exterior view of left valve of the variety *C. perundata* Meek.
FIG. 17. Similar view of another left valve of the same variety.
(Both natural size, and both after Meek.)
FIG. 15. Right side view of the variety *C. tropidophora* Meek, natural size.
FIG. 14. Right side view of the variety *C. crassatelliformis* Meek, natural size.
FIG. 11. Left side view of an example from Crow Creek, Colorado; natural size.
FIG. 12. Dorsal view of the same.
FIG. 13. Left side view of another example from the same locality.



LARAMIE.

PLATE 20. LARAMIE.

CORBICULA (LEPTESTHES) FRACTA Meek. (Page 439.)

FIG. 1. Copy of Mr. Meek's original figure.
FIG. 2. Left side view of a robust example.
FIG. 3. Dorsal view of the same.
FIG. 4. Left side view of a young example.
FIG. 5. Dorsal view of the same.
FIG. 6. Left side view of a more elongate, partially crushed example.
(All natural size.)

CORBICULA CLEBURNI White. (Page 437.)

FIG. 7 Left side view of an adult example.
FIG. 8. Right side view of a smaller example.
FIG. 9. Interior view of the same.
(All natural size.)

CORBICULA SUBELLIPTICA Meek & Hayden. (Page 437.)

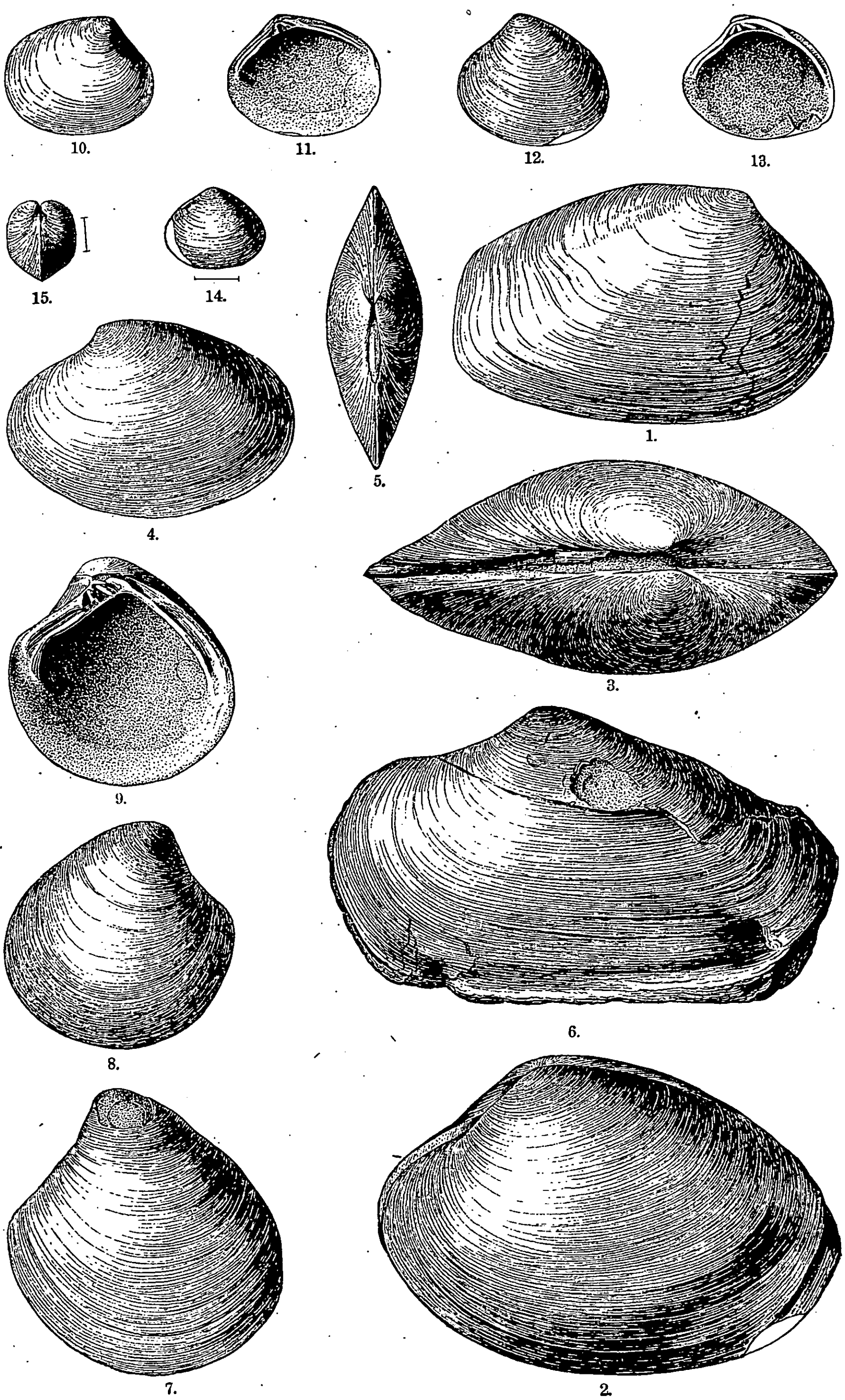
FIG. 10. Exterior view of a right valve; natural size.
FIG. 11. Interior view of the same.

CORBICULA NEBRASCENSIS M. & H. (Page 437.)

FIG. 12. Exterior of a left valve; natural size.
FIG. 13. Interior view of the same.

PISIDIUM SAGINATUM W. (Page 440.)

FIG. 14. Lateral view, enlarged.
FIG. 15. Front view of the same.



LARAMIE.

PLATE 21. LARAMIE.

CORBICULA BERTHOUDI White. (Page 438.)

FIG. 1. Left valve of a large example, exterior view.
FIG. 2. Dorsal view of another example.
FIG. 3. Interior view of a left valve.
(All natural size.)

CORBICULA AUGHEYI W. (Page 438.)

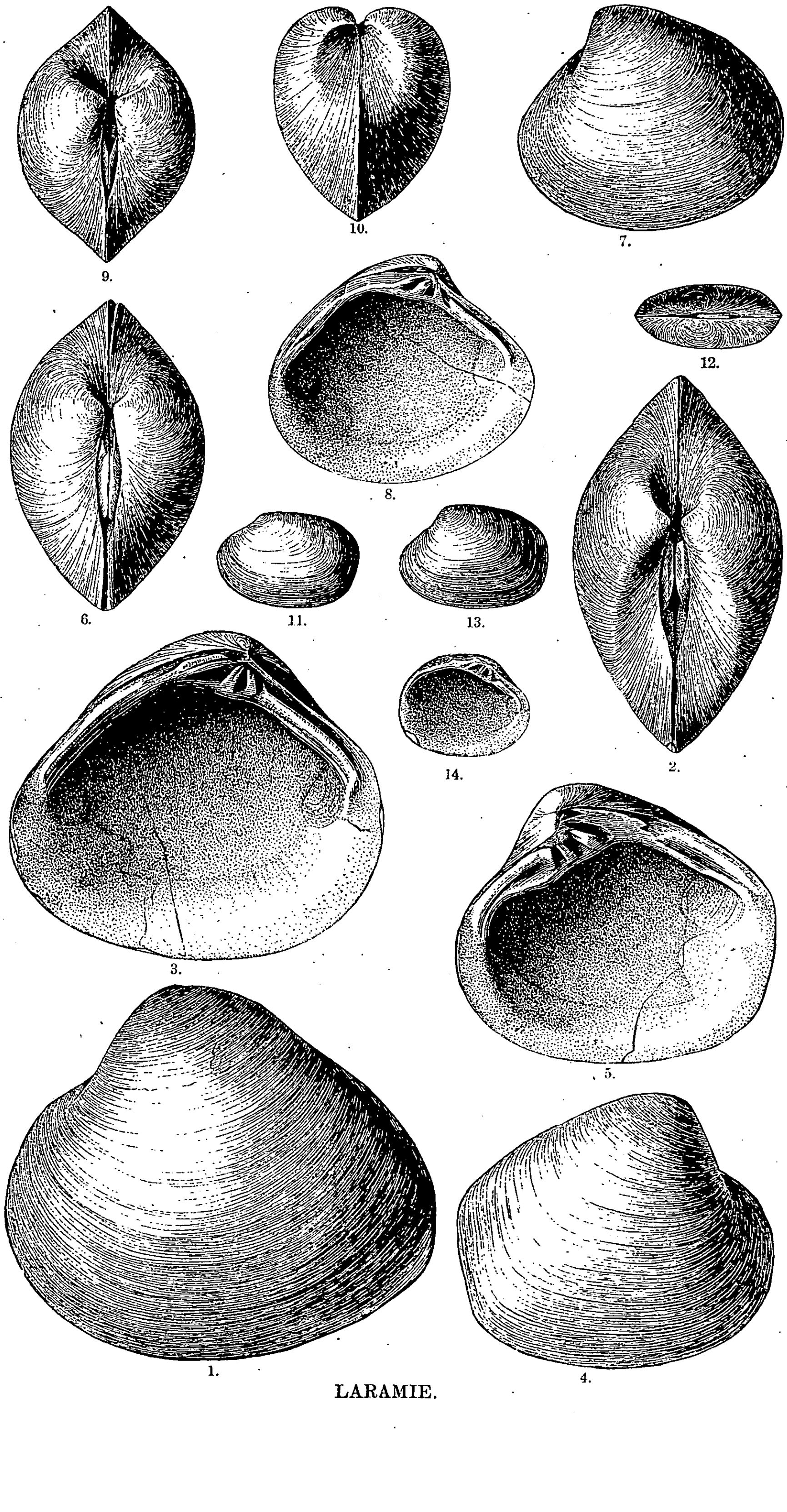
FIG. 4. Exterior view of a right valve.
FIG. 5. Interior view of the same.
FIG. 6. Dorsal view of another example.
(All natural size.)

CORBICULA UMBONELLA Meek. (Page 438.)

FIG. 7. Exterior view of a left valve.
FIG. 8. Interior view of the same.
FIG. 9. Dorsal view of another example.
FIG. 10. Front view of the same.

CORBICULA (LEPTESTHES) MACROPISTHA W. (Page 437.)

FIG. 11. Left side view of an adult example.
FIG. 12. Dorsal view of the same.
FIG. 13. Left side view of another example.
FIG. 14. Interior view of a left valve



LARAMIE.

PLATE 22. LARAMIE.

CORBICULA CYTHERIFORMIS Meek & Hayden. (Page 437.)

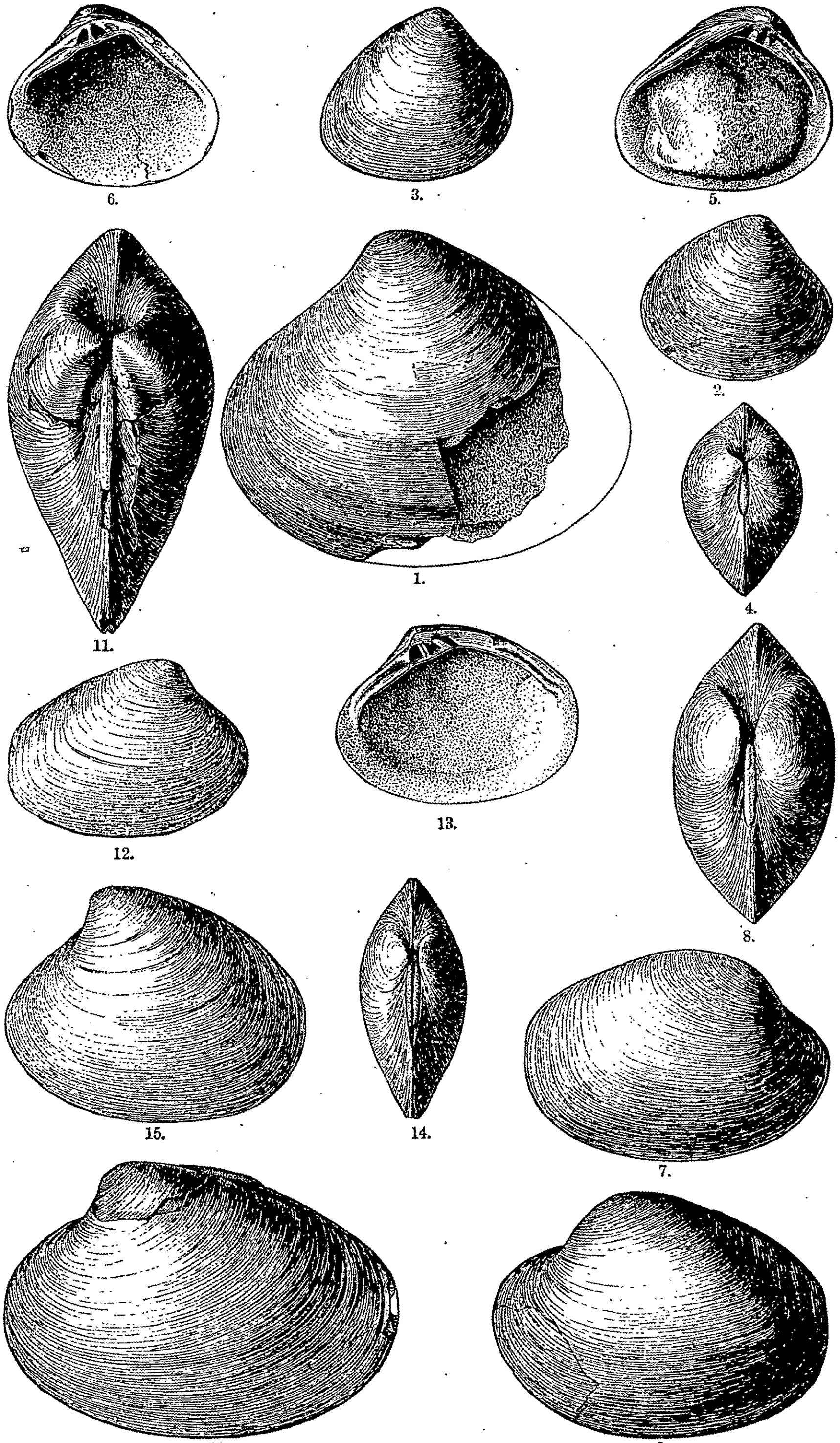
FIG. 1. Left side view of a large example.
FIG. 2. Right side view of a small example.
(Both after Meek.)
FIG. 3. Right side view of an example from Southern Wyoming.
FIG. 4. Dorsal view of the same.
FIG. 5. Hinge view of left valve; from same locality.
FIG. 6. Similar view of right valve; from same locality.
(All natural size.)

CORBICULA (LEPTESTHES) PLANUMBONA Meek. (Page 437.)

FIG. 7. Right side view of an adult example.
FIG. 8. Dorsal view of the same.
FIG. 9. Left side view of a large example.
(All natural size.)

CORBICULA (LEPTESTHES) CARDINIÆFORMIS White. (Page 437.)

FIG. 10. Left side view of a large example.
FIG. 11. Dorsal view of the same.
FIG. 12. Exterior view of a right valve of a smaller example.
FIG. 13. Interior view of the same.
FIG. 14. Dorsal view of another example.
FIG. 15. Exterior view of a left valve, less transversely elongate than usual.
(All natural size.)



LARAMIE.

PLATE 23. LARAMIE

CORBICULA OCCIDENTALIS Meek & Hayden. (Page 437.)

FIG. 1. Exterior view of the right valve of an example from Yampa River. Northwestern Colorado.
FIG. 2. Interior view of the same.
FIG. 3. Dorsal view of the same; the left valve restored in symmetry with the right
FIG. 4. Left side view of an example from the same locality of less proportionate height than usual.
FIG. 5. Dorsal view of the same.
FIG. 6. Copy of one of Mr. Meek's original figures.
(All natural size.)

CORBICULA OBESA White. (Page 437.)

FIG. 7. Exterior view, right side.
FIG. 8. Dorsal view of the same.
FIG. 9. Front view of the same.
FIG. 10. Dorsal view of another example.
FIG. 11. Interior view of a left valve.
(All natural size.)

NERITINA VOLVILINEATA W. (Page 458.)

FIG. 12. Lateral view, enlarged.
FIG. 13. Opposite view of the same.

NERITINA BRUNERI W. (Page 459.)

FIG. 14. Lateral view, natural size; showing color-markings.
FIG. 15. Opposite view of the same.

NERITINA (VELATELLA) BAPTISTA W. (Page 458.)

FIG. 16. Dorsal view of the type specimen from Wyoming, showing the color-markings; enlarged.
FIG. 17. Lateral view of the same.
FIG. 18. Dorsal view of an example from Northeastern Colorado, showing the color-markings; enlarged.
FIG. 19. Lateral view of the same.
FIG. 20. Inferior view of the same.

MELANOPSIS AMERICANA W. (Page 461.)

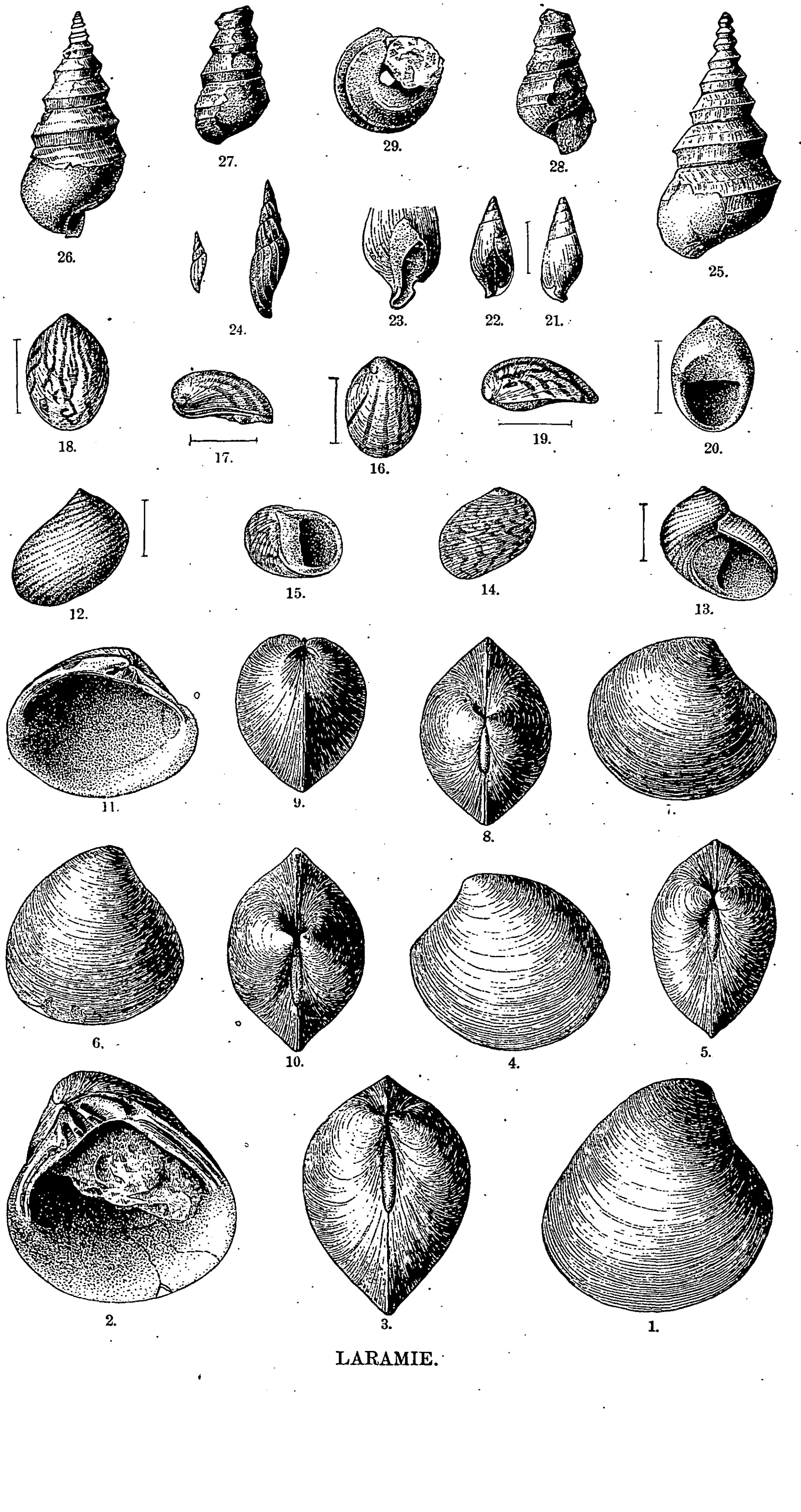
FIG. 21. Lateral view, enlarged.
FIG. 22. Opposite view of the same, showing aperture and broken outer lip.
FIG. 23. Similar view of the proximal portion of the same more enlarged, showing callus of inner lip and canal.

LIMNÆA (PLEUROLIMNÆA) TENUICOSTATA M. & H. (Page 445.)

FIG. 24. Lateral view, natural size and enlarged. After Meek.

CASSIOPELLA TURRICULA W. (Page 464.)

FIG. 25. Lateral view of the type specimen; the proximal volutions a little broadened by compression.
FIG. 26. Similar view of another example.
FIG. 27. Similar view of a smaller example.
FIG. 28. Lateral view of another example showing the umbilicus, and approximately the outline of the aperture.
FIG. 29. Inferior view of a basal fragment of another example showing the umbilicus.



LARAMIE.

PLATE 24. LARAMIE.

VIVIPARUS RETUSUS Meek & Hayden. Page 467.)

FIG. 1. Lateral view of an adult example.
FIG. 2. Similar view of another example.
FIG. 3. Lateral view of another example, showing aperture.
(All natural size.)

VIVIPARUS CONRADI M. & H. (Page 467.)

FIG. 4. Lateral view of an adult example.
FIG. 5. Opposite view of the same.
FIG. 6. Another example, more than usually elongate.

VIVIPARUS LEIDYI M. & H. (Page 467.)

FIG. 7. Lateral view of the type specimen. After Meek.

VIVIPARUS LEIDYI var. FORMOSUS M. & H. (Page 467.)

FIG. 8. Lateral view of the type specimen.
FIG. 9. Opposite view of the same. After Meek.

VIVIPARUS TROCHIFORMIS M. & H. (Page 467.)

FIGS. 10, 11, 12, 13, 14, 15, and 16. Lateral views of different examples; all natural size.

TULOTOMA THOMPSONI White. (Page 467.)

FIGS. 17, 18, 19, 20, and 21. Lateral views of different examples, showing the ornamentation of the first to be nearly like that of *V. trochiformis*, and the increasing size of the nodes towards the higher numbers; all of natural size, and all from Northern Colorado, east of the Rocky Mountains.
FIG. 22. Lateral view of an example from Southern Wyoming, west of the Rocky Mountains.

VIVIPARUS PECULIARIS M. & H. (Page 467.)

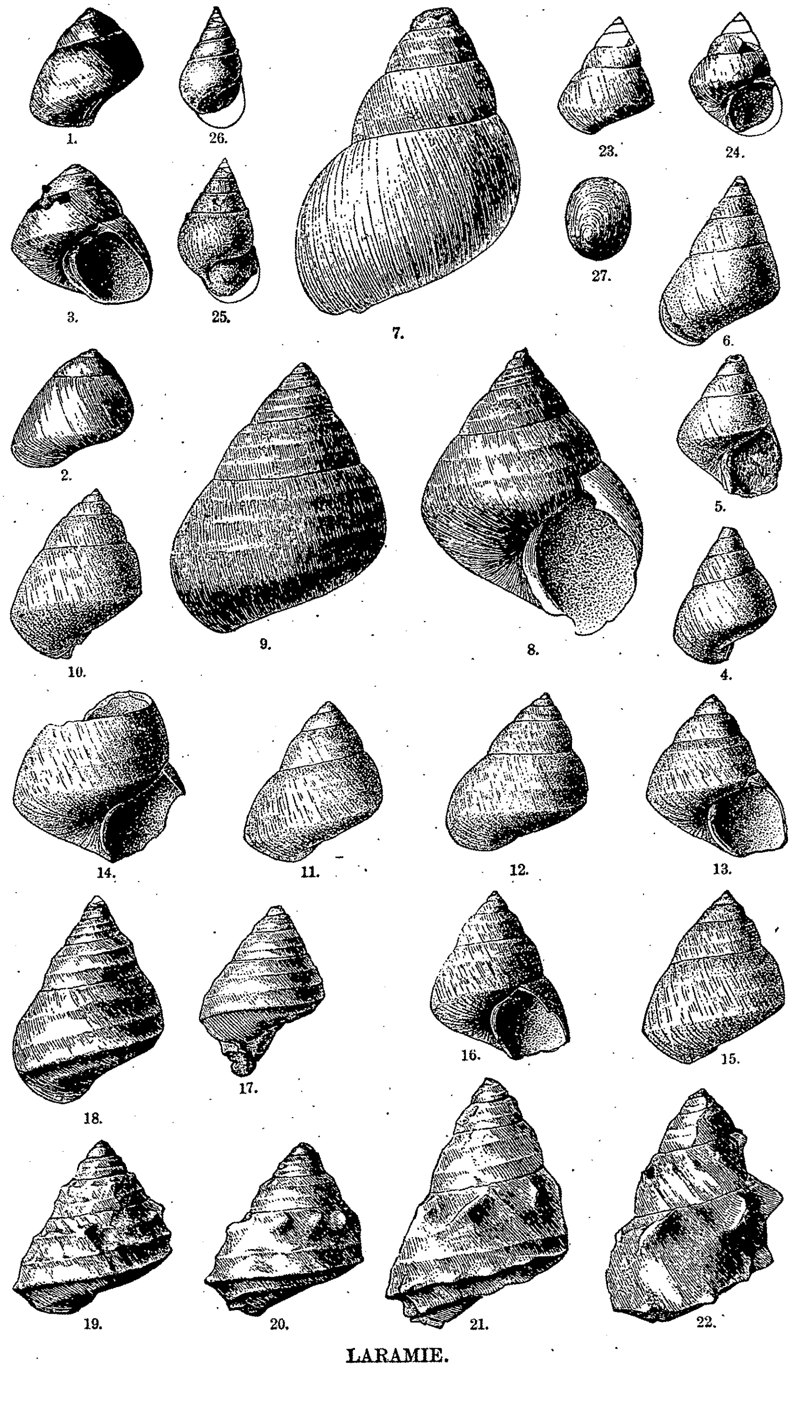
FIG. 23. Lateral view of the type specimen of Meek & Hayden.
FIG. 24. Opposite view of the same, natural size.

VIVIPARUS PLICAPRESSUS W. (Page 467.)

FIG. 25. Lateral view, natural size.
FIG. 26. Similar view of another example.

ACROLOXUS MINUTUS M. & H.

FIG. 27. Apical view, magnified to four diameters.



LARAMIE.

PLATE 25. LARAMIE.

PHYSA COPEI White. (Page 450.)

FIG. 1. Lateral view, natural size.
FIG. 2. Opposite view of the same.

PHYSA FELIX W. (Page 450.)

FIG. 3. Lateral view of an imperfect example, natural size.

BULINUS DISJUNCTUS W. (Page 451.)

FIG. 4. Lateral view, natural size.
FIG. 5. Opposite view of the same.

BULINUS ATAVUS W. (Page 450.)

FIG. 6. Lateral view, natural size.
FIG. 7. Opposite view of the same.

BULINUS LONGINSCULUS Meek & Hayden. (Page 451.)

FIG. 8. Two lateral views of the same example, natural size. After Meek.

BULINUS RHOMBOIDEUS M. & H. (Page 451.)

FIG. 9. Lateral view, natural size. After Meek.

BULINUS SUBELONGATUS M. & H. (Page 450.)

FIG. 10. Lateral view, natural size.
FIG. 11. Opposite view of the same. After Meek.

HELIX KANABENSIS W. (Page 454.)

FIG 12. Lateral view of an internal cast of the last volutions, showing the grooves left by the internal ridges near the aperture; natural size.
FIG. 13. Upper view of the same.
FIG. 14. Under view of the same.

COLUMNA TERES M. & H. (Page 454.)

FIG. 15. Lateral view, natural size, and enlarged. After Meek.

COLUMNA VERMICULA M. & H. (Page 454.)

FIG. 16. Lateral view, natural size, and enlarged. After Meek.

VIVIPARUS PRUDENTIUS W. (Page 467.)

FIG. 17. Lateral view, natural size.
FIG. 18. Opposite view of the same.

VIVIPARUS PANGUITCHENSIS W. (Page 467.)

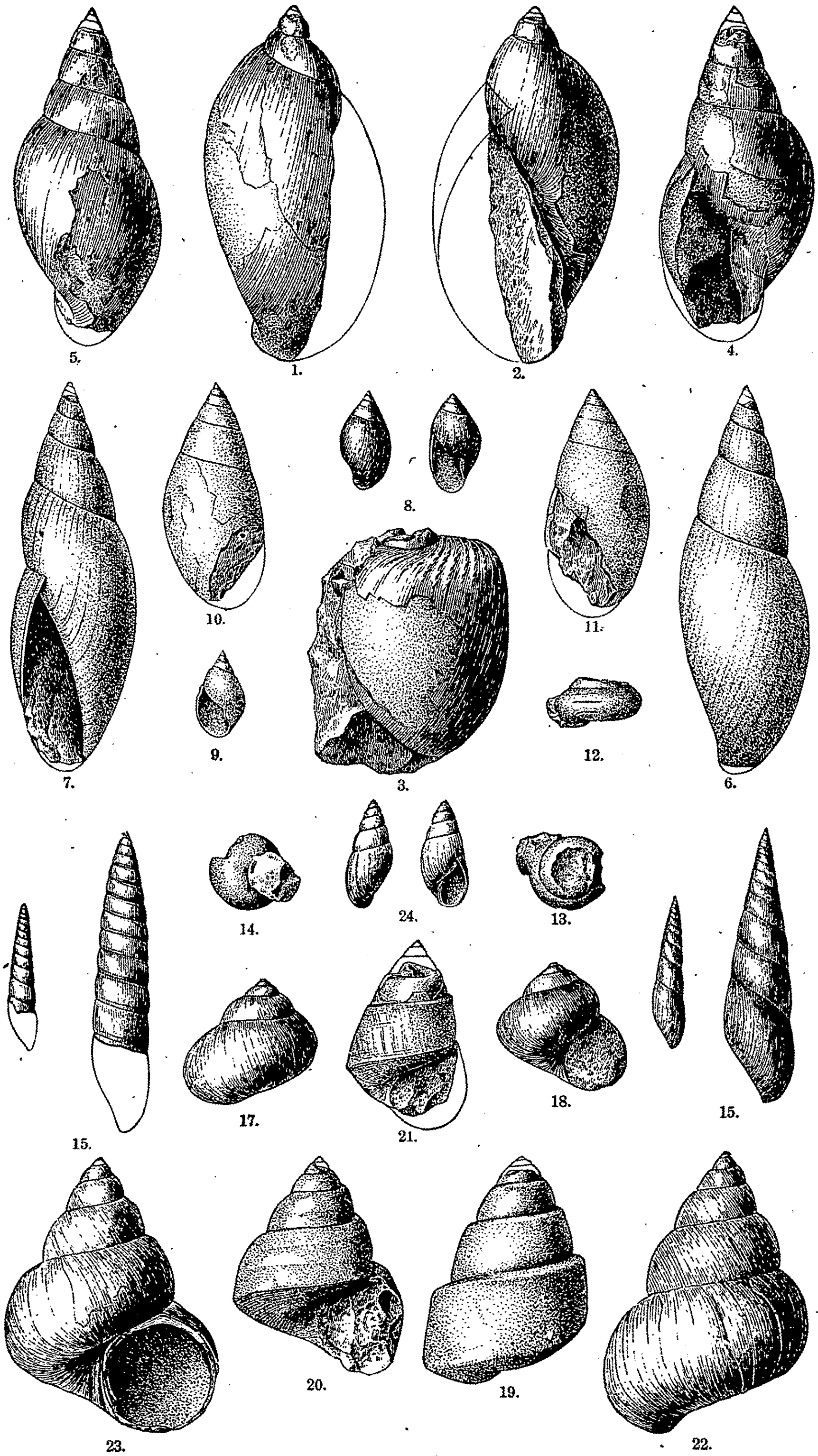
FIG. 19. Lateral view of an internal cast.
FIG. 20. Opposite view of another example, showing a part of the surface markings.
FIG. 21. Lateral view of another example, showing a portion of the natural surface of the shell.
(All natural size.)

VIVIPARUS REYNOLDSIANUS M. & H. (Page 467.)

FIG. 22. Lateral view, natural size.
FIG. 23. Opposite view of the same example.

THAUMASTUS LIMNÆIFORMIS M. & H. (Page 454.)

FIG. 24. Apertural and opposite views of an example not quite adult; natural size.



LARAMIE.

PLATE 26. LARAMIE.

MELANIA WYOMINGENSIS Meek. (Page 460.)

FIG. 1. Lateral view, showing the outline of the outer lip.
FIG. 2. Similar view of another example.
FIG. 3. Similar view of the distal volutions, showing those of the apical portion to be destitute of spines.

MELANIA INSCULPTA M. (Page 460.)

FIG. 4. Fragment of an adult example.
FIG. 5. Fragment of a smaller example.
(Both natural size, and both from Northeastern Colorado.)

GONIOBASIS CONVEXA Meek & Hayden. (Page 463.)

FIG. 6. Lateral view, natural size.
FIG. 7. Opposite view of the same example.

GONIOBASIS CONVEXA var. IMPRESSA M. & H. (Page 463.)

FIG. 8. Lateral view, natural size.
FIG. 9. Opposite view of the same example.

GONIOBASIS ? OMITTA M. & H. (Page 463.)

FIG. 10. Apertural and opposite views; natural size. After Meek.

GONIOBASIS TENUICARINATA M. & H. (Page 463.)

FIG. 11. Apertural and opposite views; natural size.

GONIOBASIS GRACILENTA M. (Page 463.)

FIG. 12. Apertual and opposite views of Mr. Meek's type specimen.
FIG. 13. Lateral view of an example from Crow Creek, Colorado.
(Both natural size.)

LIMNÆA ? COMPACTILIS M. (Page 445.)

FIG. 14. Apertural and opposite views of Mr. Meek's type specimen, natural size.

GONIOBASIS NEBRASCENSIS M. & H. (Page 463.)

FIG. 15. Lateral view, natural size.
FIG. 16. Opposite view of the same example.

GONIOBASIS INVENUSTA M. & H. (Page 463.)

FIG. 17. Lateral view of the type specimen of Meek & Hayden, natural size.

GONIOBASIS SUBLÆVIS M. & H.. (Page 463.)

FIG. 18. Lateral view of the type specimen of Meek & Hayden, natural size.

CERITHIDEA ? NEBRASCENSIS M. & H. (Page 463.)

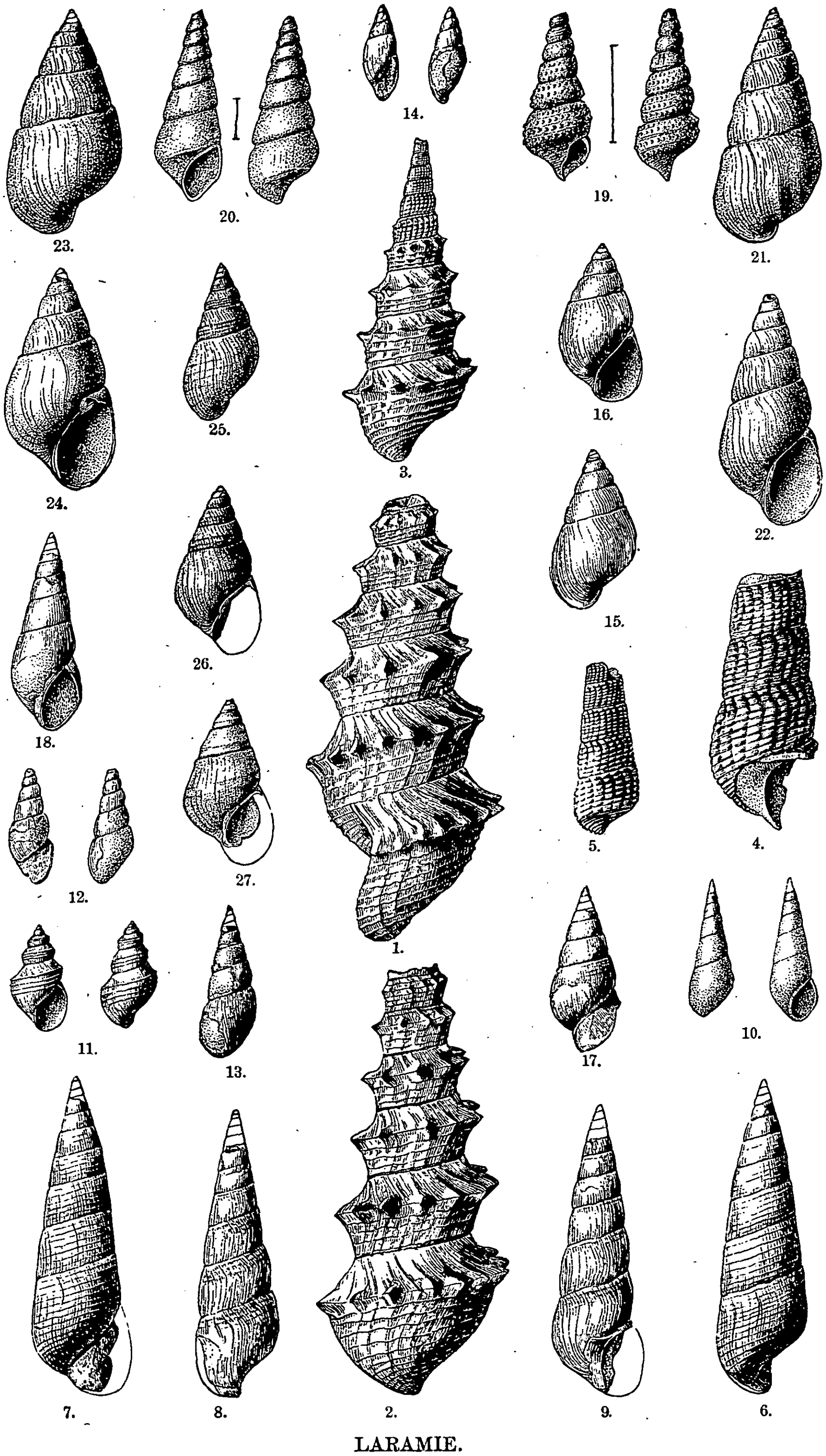
FIG. 19. Apertural and opposite views of the type specimen of Meek & Hayden, enlarged. After Meek.

MICROPYRGUS MINUTULUS M. & H. (Page 465.)

FIG. 20. Apertural and opposite views of the type specimen of Meek & Hayden, enlarged.

CAMPELOMA PRODUCTA White. (Page 469.)

FIG. 21. Lateral view of an elongate example, regarded as the type.
FIG. 22. Opposite view of the same.
FIG. 23. Lateral view of a more robust example.
FIG. 24. Opposite view of the same.
FIG. 25. Lateral view of a subcarinate variety.
FIG. 26. Similar view of another example of the same variety.
FIG. 27. Similar view of another example of the same variety.
(All natural size.)



LARAMIE.

PLATE 27. LARAMIE.

CAMPELOMA MULTILINEATA Meek & Hayden. (Page 469.)

FIG. 1. Copy of Meek's original figure.
FIG. 2. Lateral view of a larger example, showing a slight angularity at the distal side of the larger volutions.
FIG. 3. Opposite view of the same.
FIG. 4. Lateral view of another example, having the angularity a little more distinct.
FIG. 5. Lateral view of another example, having the angularity distinct and prominent.
FIG. 6. Fragment showing the aperture, and prominent angularity.
FIG. 7. Lateral view of an example from Crow Creek, Colorado.
Figs. 2–6 are from the valley of the Yellowstone, Montana. (All natural size.)

CAMPELOMA VETULA M. & H. (Page 469.)

FIG. 8. Lateral view of the type specimen of Meek & Hayden.
FIG. 9. Opposite view of the same, natural size.

VIVIPARUS LEAI M. & H. (Page 467.)

FIG. 10. Lateral view of a large example.
FIG. 11. Opposite view of the same.
FIG. 12. Lateral view of another example.
FIG. 13. Opposite view of the same.
FIG. 14. Lateral view of another example, a little more elongated than usual.
(All natural size.)

CAMPELOMA MULTISTRIATA M. & H. (Page 469.)

FIG. 15. Copy of Meek's original figure.

PLANORBIS CONVOLUTUS M. & H. (Page 447.)

FIG. 16. Upper, under, and peripheral views of the type specimen of Meek & Hayden. After Meek.

PLANORBIS (BATHYOMPHALUS) PLANOCONVEXUS M. & H. (Page 447.)

FIG. 17. Upper view of the type specimen of Meek & Hayden, natural size.
FIG. 18. Peripheral view of the same. After Meek.

PLANORBIS (BATHYOMPHALUS) AMPLEXUS M. & H. (Page 447.)

FIG. 19. Upper view of the type specimen of Meek & Hayden, natural size.
FIG. 20. Under view of the same, enlarged. After Meek.

PLANORBIS (BATHYOMPHALUS) KANABENSIS White. (Page 447.)

FIG. 21. Upper view, natural size.
FIG. 22. Under view of the same example.
FIG. 23. Peripheral view of the same example.

VALVATA? MONTANAENSIS Meek. (Page 470.)

FIG. 24. Outline views, enlarged. After Meek.

VALVATA SUBUMBILICATA M. & H. (Page 470.)

FIG. 25. Upper and under views of the type-specimen of Meek & Hayden, natural size. After Meek.

HYALINA? EVANSI Meek & Hayden. (Page 452.)

FIG. 26. Outline views, enlarged. After Meek.

HYALINA? OCCIDENTALIS M. & H. (Page 452.)

FIG. 27. Upper, under, and peripheral views of the type-specimen of Meek & Hayden. After Meek.

HELIX? VETUSTA M. & H. (Page 454.)

FIG. 28. Apertural and opposite views of the type-specimen of Meek & Hayden; natural size. After Meek.

HELIX EVANSTONENSIS White. (Page 454.)

FIG. 29. Lateral view, enlarged.
FIG. 30. Opposite view of the same example.
FIG. 31. Under view of the same example.

VITRINA OBLIQUA M. & H. (Page 452.)

FIG. 32. Lateral view of type specimen of Meek & Hayden, natural size.
FIG. 33. Apical view of the same. After Meek.

GONIOBASIS? SUBTORTUOSA M. & H. (Page 463.)

FIG. 34. Apertural and opposite views of the type specimen of Meek & Hayden, natural size. After Meek.

HYDROBIA UTAHENSIS W. (Page 466.)

FIG. 35. Lateral view, enlarged.

HYDROBIA SUBCONICA Meek. (Page 465.)

FIG. 36. Outline lateral view, enlarged; copy of Meek's original figure.

HYDROBIA? EULIMOIDES M. (Page 465.)

FIG. 37. Outline lateral view, enlarged; copy of Meek's original figure.

HYDROBIA RECTA W. (Page 466.)

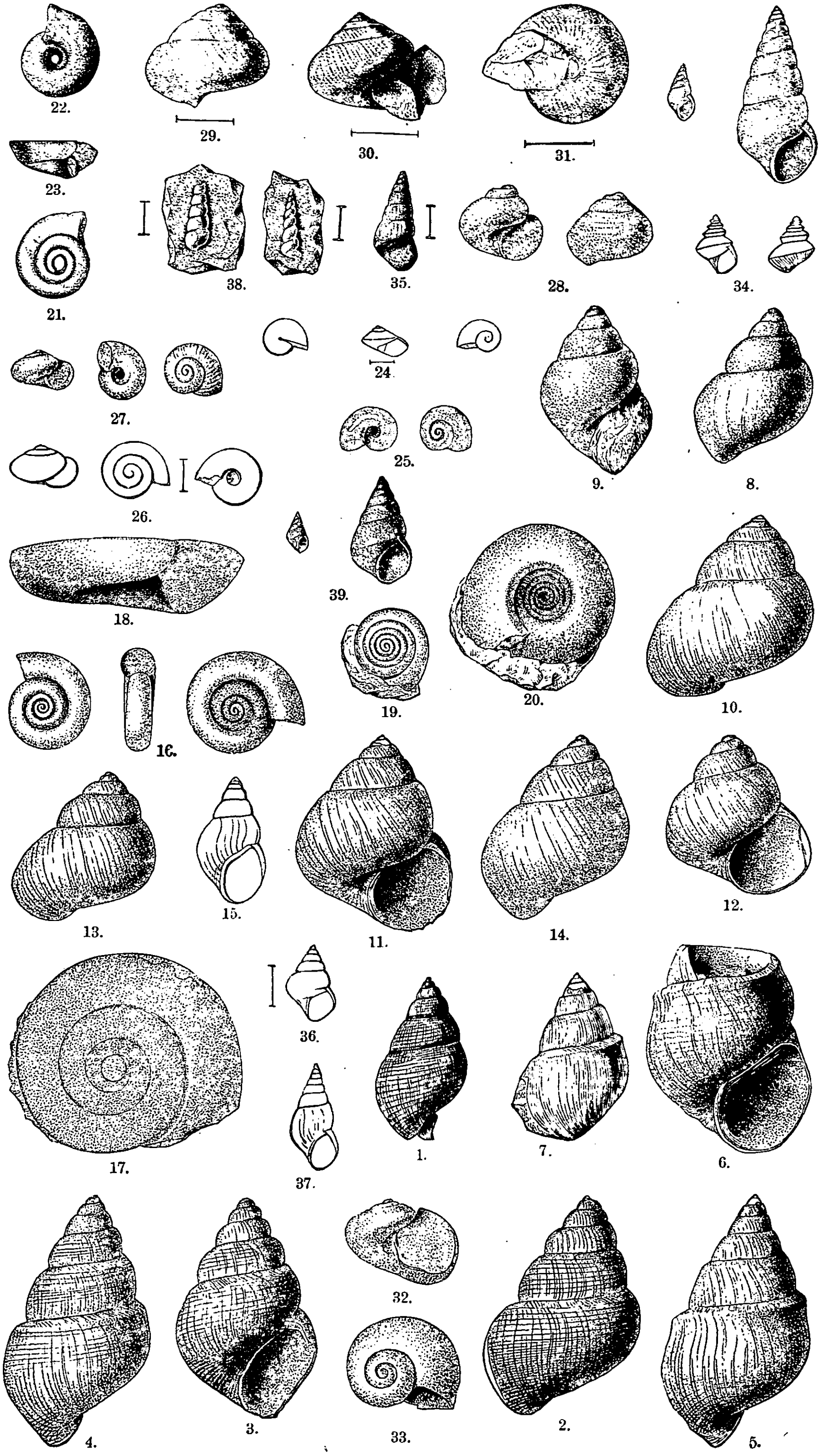
FIG. 38. Lateral views of two fragments, enlarged.

HYDROBIA ANTHONYI M. & H. (Page 465.)

FIG. 39. Lateral view, natural size and enlarged. After Meek.

HYDROBIA WARRENANA M. & H. (Page 465.)

FIG. 40. Lateral view, natural size and enlarged. After Meek.



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LARAMIE.

PLATE 28. EOCENE.

UNIO CLINOPISTHUS White. (Page 434.)

FIG. 1. Left side view, natural size.
FIG. 2. Dorsal view of the same.

UNIO SHOSHONENSIS W. (Page 435.)

FIG. 3. Left side view, natural size.

UNIO HAYDENI Meek. (Page 435.)

FIG. 4. Right side view, natural size.
FIG. 5. Left side view of a smaller example.

UNIO WASHAKIENSIS M. (Page 435.)

FIG. 6. Left side view, natural size.
FIG. 7. Right side view of a sandstone cast.
FIG. 8. Interior view of a fragment of a right valve.

UNIO TELLINOIDES Hall. (Page 435.)

FIG. 9. Copy of Hall's original figure.

PLANORBIS (GYRAULUS) MILITARIS W. (Page 447.)

FIG. 10. Upper view, enlarged.
FIG. 11. Under view of the same example.

BYTHINELLA GREGARIA M. (Page 466.)

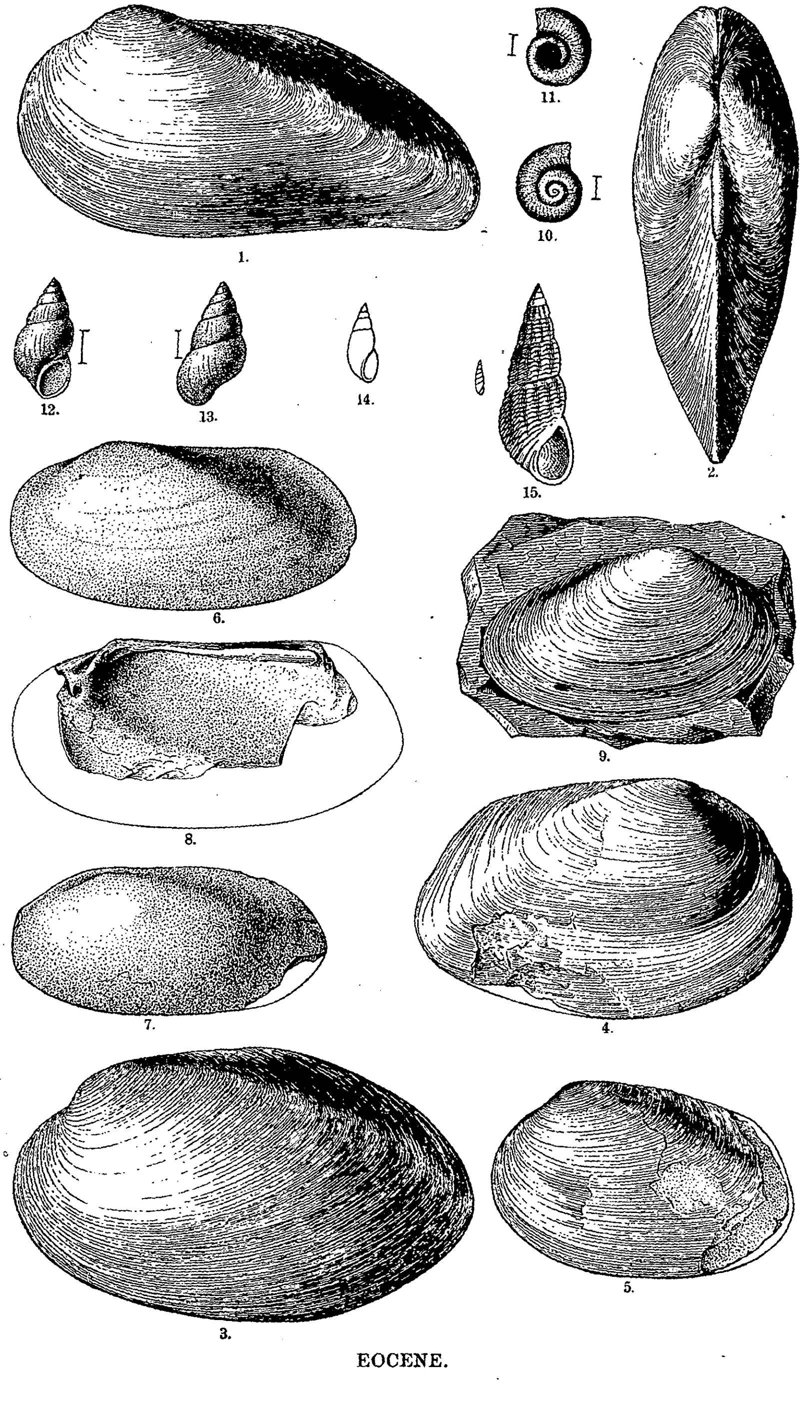
FIG. 12. Lateral view, enlarged.
FIG. 13. Opposite view of the same.

BULIMUS FLORIDANUS Conrad. (Page 454.)

FIG. 14. Copy of Conrad's original figure.

MELANIA CLAIBORNENSIS Heilprin. (Page 460.)

FIG. 15. Lateral view, much enlarged, together with an outline of natural size. After Heilprin.



EOCENE.

PLATE 29. EOCENE.

PLANORBIS UTAHENSIS Meek. (Page 447.)

FIG. 1. Upper view, natural size.
FIG. 2. Under view of the same example.
FIG. 3. Peripheral view of the same. After Meek.

PLANORBIS UTAHENSIS var. SPECTABILIS M. (Page 447.)

FIG. 4. Upper view, natural size.
FIG. 5. Under view of the same example.
FIG. 6. Peripheral outline of the same. After Meek.

PLANORBIS CIRRATUS White. (Page 448.)

FIG. 7. Upper, under, and peripheral views, enlarged.

PLANORBIS ÆQUALIS W. (Page 448.)

FIGS. 8 and 9. Under and peripheral views, enlarged.
FIG. 10. Upper view of a smaller example, enlarged.
(All are imperfect, and perfect adult examples are doubtless larger.)

HELIX PERIPHERIA W. (Page 455.)

FIG. 11. Lateral view, natural size.
FIG. 12. Opposite view of the same.

HELIX RIPARIA W. (Page 455.)

FIG. 13. Lateral view, natural size.
FIG. 14. Opposite view of the same example.

PUPA INCOLATA W. (Page 456.)

FIG. 15. Lateral view, enlarged.
FIG. 16. Opposite view of the same example, showing the aperture.
FIG. 17. View of the same, showing the edge of the outer lip.

PUPA ATAVUNCULA W. (Page 456.)

FIG. 18. Lateral view, enlarged.

PUPA ARENULA W. (Page 50 456.)

FIG. 19. Two lateral views of the type specimen. The rim of the aperture has been broken off.

LIMNÆA SIMILIS M. (Page 445.)

FIG. 20. Lateral view, enlarged.
FIG. 21. Opposite view of the same. After Meek.

LIMNÆA VETUSTA M. (Page 445.)

FIG. 22. Lateral view, natural size.
FIG. 23. Opposite view of another example, a little enlarged. After Meek.

LIMNÆA MINUSCULA W. (Page 446.)

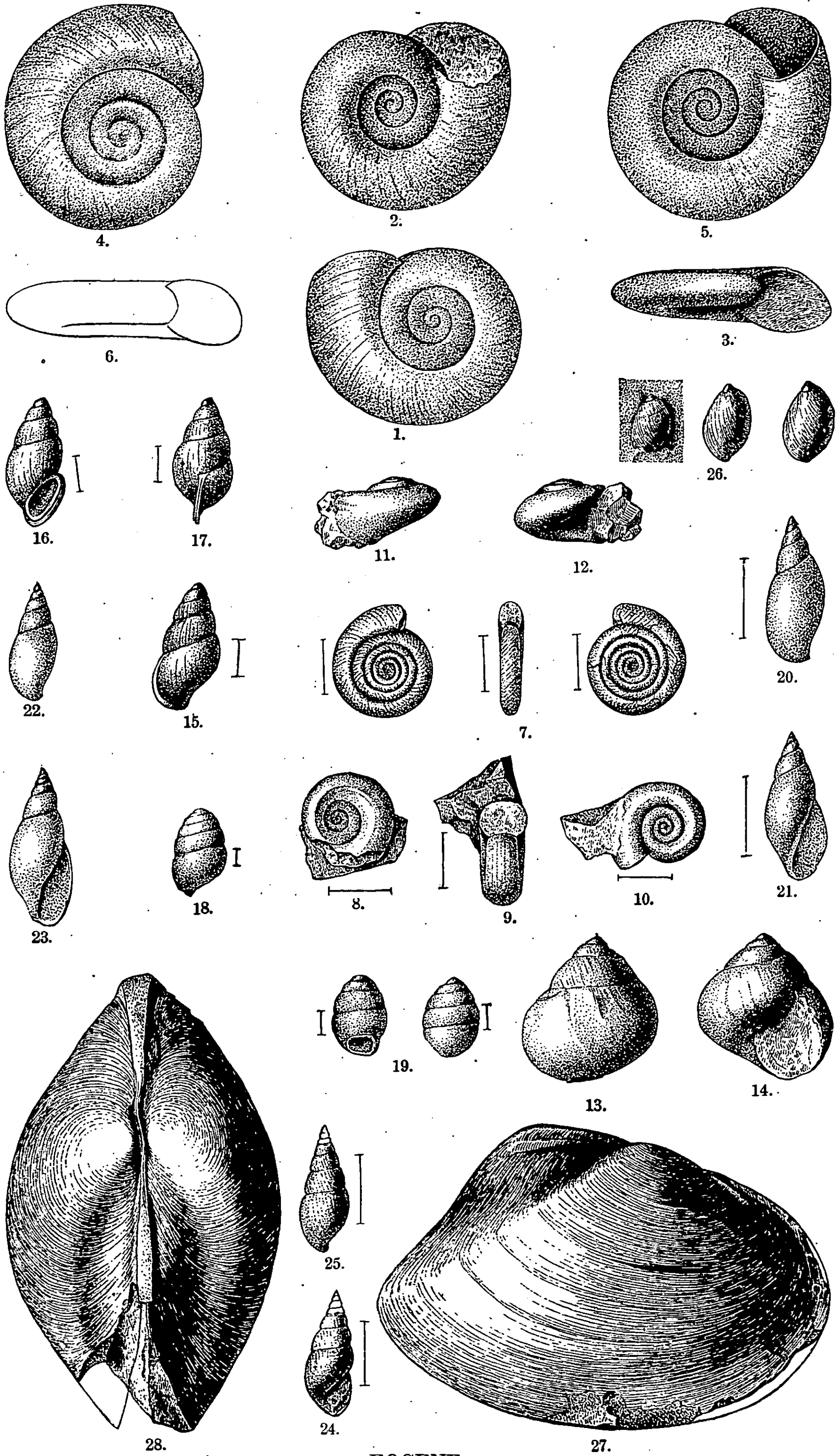
FIG. 24. Lateral view, enlarged.
FIG. 25. Opposite view of the same example.

SUCCINEA (BRACHYSPIRA) PAPILLISPIRA W. (Page 457.)

FIG. 26. Three views of separate examples, natural size, from gutta-percha casts in natural molds.

ANODONTA DECURTATA Conrad. (Page 479.)

FIG. 27. Lateral view, natural size, from an example believed to have been Conrad's type specimen.
FIG. 28. Dorsal view of the same. The true geological age of this species is not certainly known, but it is believed to be Eocene.



EOCENE.

PLATE 30. EOCENE.

MACROCYCLIS SPATIOSA Meek & Hayden. (Page 452.)

FIG. 1. Upper view, natural size.
FIG. 2. Lateral view of the same example.
FIG. 3. Under view of the same, all natural size. After Meek.

HELIX ? VETERNA M. & H. (Page 454.)

FIGS. 4 and 5. Copies of Meek's outline figures.

PHYSA PLEROMATIS White. (Page 450.)

FIG. 6. Lateral view of type specimen.
FIG. 7. Opposite view of a larger example, a little distorted, probably belonging to this species.
FIG. 8. Fragment of a very large example, believed to belong to this species. (All natural size.)

PHYSA BRIDGERENSIS Meek. (Page 450.)

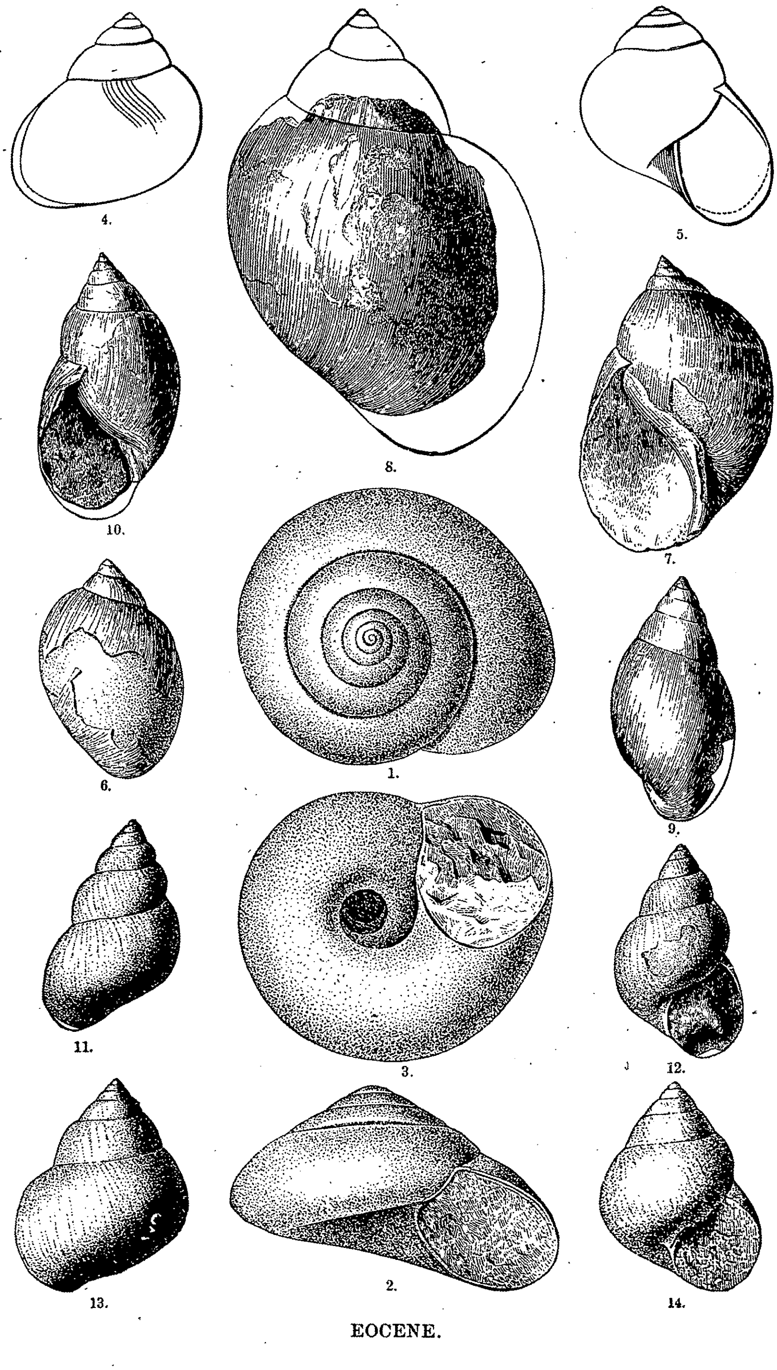
FIG. 9. Lateral view, natural size.
FIG. 10. Opposite view of a more robust example.

VIVIPARUS PALUDINÆFORMIS Hall. (Page 468.)

FIG. 11. Lateral view, natural size.
FIG. 12. Opposite view of the same.

VIVIPARUS WYOMINGENSIS M. (Page 468.)

FIG. 13. Lateral view, natural size.
FIG. 14. Opposite view of the same.

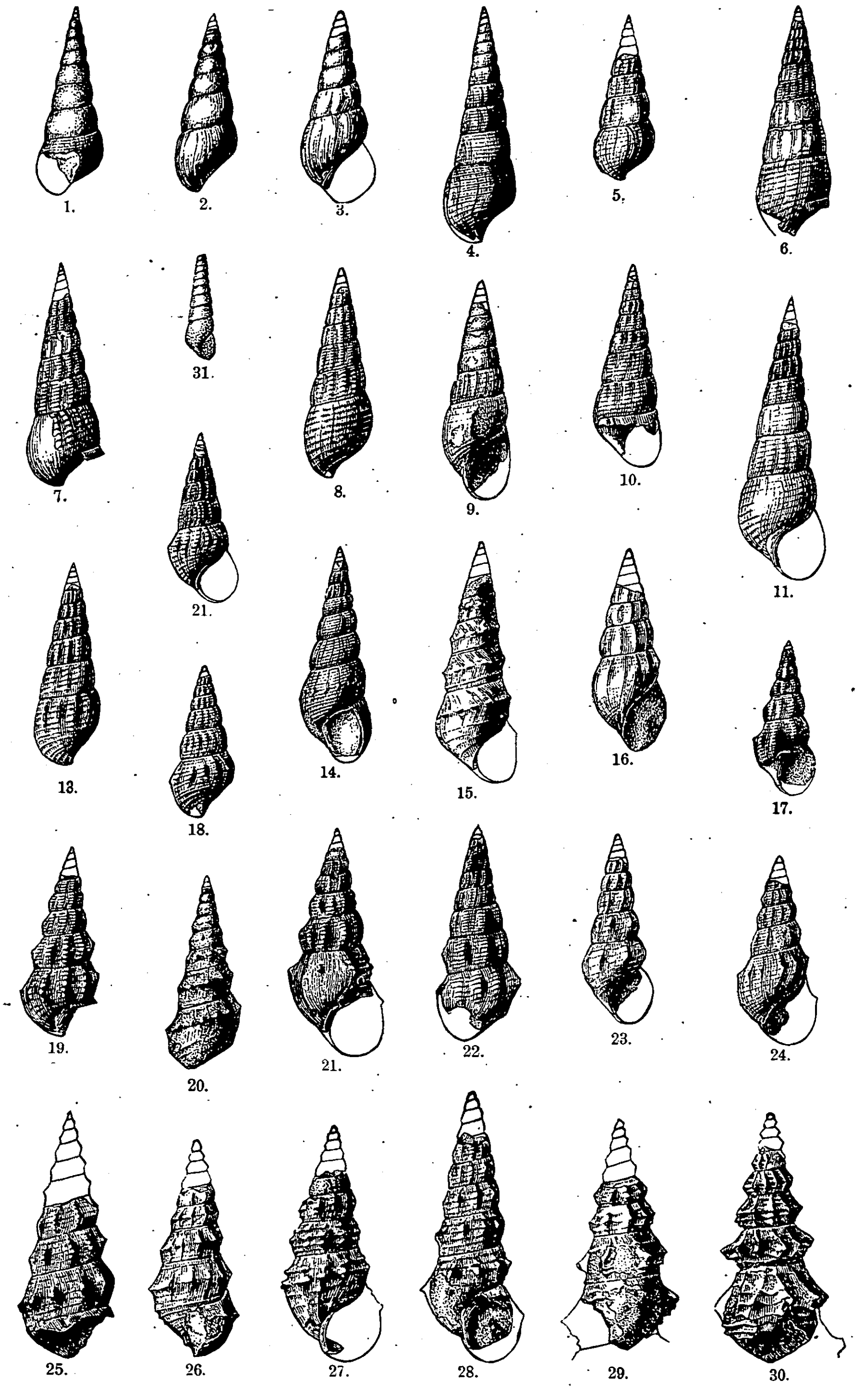


EOCENE.

PLATE 31.

All the forms represented on this plate occur in the fresh-water Eocene deposits of Wyoming, Colorado, and Utah; and all are believed to be genetically related. They have been described by different authors under six respective names, according to the variation of ornamentation and form. (See remarks on page 464.)

Figs. 1, 2, and 3 may be regarded as representing the *Goniobasis simpsoni* of Meek; Figs. 5, 10, 12, and others, *G. tenera* Hall; Figs. 14, 15, 20, and others, *G. nodulifera* Meek; Figs. 19, 25, 28, and others, *G. carteri* Conrad; and Figs. 29 and 30, *G. columinis* White. Fig. 31 is a copy of Meek's figure of *G. arcta*, which he finally regarded as only a variety of his *G. simpsoni*. It, is however, very like a form which occurs in the Laramie beds of Bear River Valley in Southwestern Wyoming.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EOCENE.

PLATE 32. MIOCENE AND PLIOCENE?

MELANIA SCULPTILIS Meek. (Page 461.)

FIG. 1. Lateral view, natural size. After Meek.

MELANIA SUBSCULPTILIS M. (Page 461.)

FIG. 2. Lateral view, natural size. After Meek.

MELANIA TAYLORI Gabb. (Page 461.)

FIG. 3. Lateral view, natural size. After Gabb.

LITHASIA ANTIQUA G. (Page 465.)

FIG. 4. Lateral view, showing the aperture, natural size. After Gabb.

CARINIFEX (VORTICIFEX) BINNEYI M. (Page 448.)

FIG. 5. Lateral view, natural size, showing the aperture.
FIG. 6. Upper view of the same example. After Meek.

CARINIFEX (VORTICIFEX) TRYONI M. (Page 448.)

FIG. 7. Lateral view, natural size, showing the aperture.
FIG. 8. Upper view of the same example.
FIG. 9. Under view of the same. After Meek.

ANCYLUS UNDULATUS M. (Page 451.)

FIG. 10. Upper view and lateral outline, natural size. After Meek.

SPHÆRIUM RUGOSUM M. (Page 440.)

FIG. 11. An example of not quite adult size, enlarged two diameters.
FIG. 12. A larger example, enlarged two diameters.
FIG. 13. Outline showing the convexity of the valves. After Meek.

SPHÆRIUM IDAHOENSE M. (Page 440.)

FIG. 14. An imperfect example, natural size.
FIG. 15. Outline showing the convexity of the valves. After Meek.

PLANORBIS VETUSTUS Meek & Hayden. (Page 448.)

FIG. 16. Under view, natural size.
FIG. 17. Upper view of the same example, enlarged.
FIG. 18. Peripheral view of the same, more enlarged. After Meek.

PLANORBIS LEIDYI M. & H. (Page 448.)

FIG. 19. Upper view, natural size.
FIG. 20. Peripheral view of the same, enlarged, showing the aperture.
FIG. 21. Under view of the same, less enlarged. After Meek.

PLANORBIS NEBRASCENSIS Evans & Shumard. (Page 448.)

FIG. 22. Upper view, natural size.
FIG. 23. Peripheral view of the same, enlarged. After Meek.

PLANORBIS LUNATA Conrad. (Page 448.)

FIGS. 24 and 25. Copies of Conrad's original figures.

LIMNÆA MEEKII Evans & Shumard. (Page 446.)

FIG. 26. Lateral view of a large example, natural size.
FIG. 27. Opposite view of a smaller example. After Meek.

LIMNÆA SHUMARDI Meek & Hayden. (Page 446.)

FIG. 28. Lateral view, natural size.
FIG. 29. Opposite view of the same. After Meek.

LIMNÆA (POLYRHYTIS) KINGII Meek. (Page 446.)

FIGS. 30 and 31. Copies of Meek's original figures, natural size.

HELIX LEIDYI Hall & Meek. (Page 455.)

FIG. 32. Lateral view, natural size.
FIG. 33. Apical view of the same example. After Meek.

HELIX (ZONITES) MARGINICOLA C. (Page 453.)

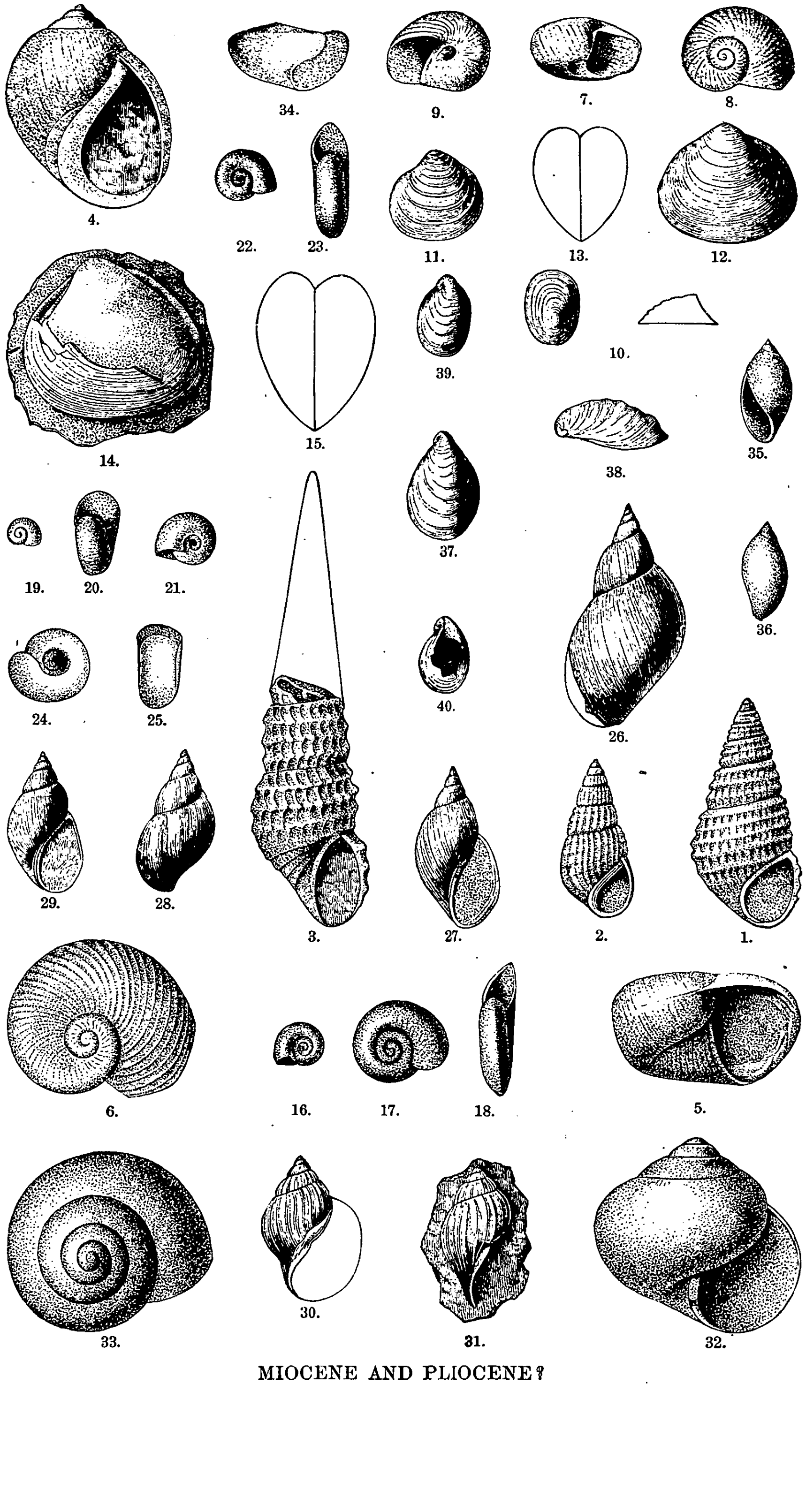
FIG. 34. Copy of Conrad's original figure.

PHYSA SECALINA E. & S. (Page 450.)

FIG. 35. Lateral view, natural size.
FIG. 36. Opposite view of the same. After Meek.

LATIA DALLII White. (Page 451.)

FIG. 37. Dorsal view, natural size.
FIG. 38. Lateral view of the same example.
FIG. 39. Dorsal view of another example.
FIG. 40. Similar view of another example, showing a portion of the shell broken away, revealing the large lunate shelf extending forward from the beak.



MIOCENE AND PLIOCENE?

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